An Optimization-Based Qualitative/Algorithmic Approach to Transit Service Planning: Addressing the MBTA Green Line Extension

by
John Takuma Moody
B.S., The Ohio State University (2018)

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Author . . . .
Department of Civil and Environmental Engineering
August 13, 2021

Certified by . . . .
Jinhua Zhao
Associate Professor
Thesis Supervisor

Certified by . . . .
Haris N. Koutsopoulos
Professor, Northeastern University
Thesis Supervisor

Certified by . . . .
John P. Attanucci
Research Associate
Manager, MIT Transit Research Program
Thesis Supervisor

Accepted by . . . .
Colette L. Heald
Professor of Civil and Environmental Engineering
Chair, Graduate Program Committee

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Abstract

When changes to transit operations are necessary to accommodate changes in the network, demand levels, or agency resources, there is a risk that more obvious solutions (e.g., adjusting headways without changing service patterns) may be unnecessarily detrimental to the quality of the service provided. Complex trunk-with-branches transit networks present both opportunities and challenges for service planning in this context. There may be a large number of potentially feasible operating schemes that could address the problem, with some presenting worthwhile trade-offs that result in much better outcomes for passengers. However, identifying the most promising alternatives from such a large set is a difficult task. While human judgment is a critical part of the process, particularly in the analysis of the most promising solutions, subjectivity from human judgment introduced too early on in the alternative identification process can lead to a suboptimal selection of alternatives.

This research proposes and demonstrates the benefits of a combined qualitative/algorithmic approach to service planning. The proposed approach combines scenario planning, optimization, and qualitative analysis to generate solutions that are robust against uncertainty while providing consistently high passenger level-of-service. An integer optimization program is used to model complex trunk-with-branches transit networks, which outputs a set of service patterns that satisfy various constraints (e.g., passenger capacity, agency resources, fleet composition, infrastructure limitations) while minimizing detriments to passenger level-of-service, namely wait time and transfers. The value of the subsequent qualitative assessment is increased by the use of optimization, as comparisons are being made between high-performance operating schemes.

This approach is applied to the MBTA Green Line to propose service plans after the construction of the Green Line Extension (GLX), which adds an additional two branches to the current four. This extension is occurring during the COVID-19 pandemic, which has resulted in a significant reduction in demand and tightening of agency resources. Both events warrant and facilitate a shift in service patterns. Four phases of post-GLX evolution of demand and resources were considered to illustrate short- and long-term operating conditions. In most cases, plans generated by the qualitative/algorithmic approach included single-car train operations during the peak period to reduce expected wait time relative to the current plans. The alternatives identified may allow post-GLX operations to achieve a pre-pandemic level of service even before agency resources have fully recovered. The research suggests that the qualitative/algorithmic approach can allow service planners to maximize the potential benefits of paradigm shifts such as the GLX.

Thesis Supervisor: Jinhua Zhao
Title: Associate Professor

Thesis Supervisor: Haris N. Koutsopoulos
Title: Professor, Northeastern University

Thesis Supervisor: John P. Attanucci
Title: Research Associate
Manager, MIT Transit Research Program

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Chapter 1

Introduction

Complex transit networks present both opportunities and challenges in service planning. The complexity of a network may provide a wide range of possibilities to address changing conditions, and even adverse changes may potentially be addressed with little-to-no degradation of passenger level-of-service by taking advantage of these options. However, the evaluation of these options is cumbersome and ill-suited for traditional service planning methods, most of which are designed for evaluation of simple lines.

The Massachusetts Bay Transportation Authority (MBTA) Green Line is a trunk-with-branches transit system serving greater Boston, MA. Two important developments, the completion of the Green Line Extension (GLX) — adding two new branches to the line — and rising demand and agency resources in the wake of reduced COVID-19-affected service levels make new service plans necessary. This thesis presents a service planning method to identify highly promising solutions for complex networks like the Green Line, and proposes alternative service plans for post-GLX operations that improve level-of-service relatively to current plans in the short- and long-term future.

1.1 Motivation and Problem Definition

Service planning can be complicated for networks of a trunk-with-branches design. Figure 1-1 is a simple example of this type of network. Trunk-with-branches networks have advantages over simple end-to-end lines in that the area served by the branches can be much greater than that of a simple line while preserving direct paths towards the trunk. Moreover, by combining services within the trunk, the costs of building parallel infrastructure along the trunk corridor are avoided. Trunks are commonly found through the central business districts of cities, with branches extending into outer neighborhoods and suburbs.

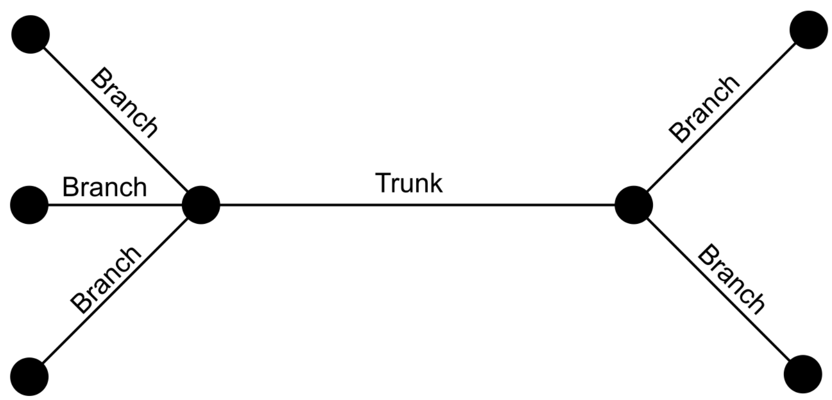

Figure 1-1: Simple Example of a Trunk-With-Branches Network

From the perspective of possible service patterns, there may be numerous options for through-running between the branches and the trunk, turnaround locations, or the assignment of consist lengths or rolling stock varieties to different branches. It is difficult to compare every feasible combination of service patterns using traditional methods of service planning owing to the sheer volume of possible service patterns. Certain options may not even be identified as potential solutions if the identification is driven primarily by human evaluation. Therefore, service planners may resort to solutions that are sub-par from a passenger LOS perspective but are more easily identifiable, such as raising headways on existing routes.

Operating conditions such as demand or agency resources may change over time, which only exacerbates this problem by introducing additional scenarios that must be planned for. Even if the service patterns currently in place are a good fit for the current situation, this may not be true once conditions change. Once again, in a complex network, the totality of options may not be considered and the eventual proposed remedy to the changing conditions may be sub-par.

The MBTA Green Line is currently facing this issue. The branches added by the GLX necessitate new service plans, and existing operating paradigms may need to be reevaluated in light of the large changes to the network. Furthermore, it is likely that the beginning years of GLX operations will see changes in demand and agency resources as Greater Boston recovers from the COVID-19 pandemic. It is therefore important to implement service plans that are specifically designed to deliver a high LOS in the new configuration and are easily adaptable to changing conditions. The service planning method proposed in this thesis addresses both the challenges inherent to trunk-with-branches networks and the uncertainty of future operating conditions.

1.2 Background

The MBTA Green Line is presented as the case study in this thesis. Figure 1-2 shows the basic layout of the Green Line. The following terminology is used to refer to various sections of the network:

- **The western branches:** from north to south, the western branches consist of the **B, C, D,** and **E** branches. These are all at surface level, except for the easternmost two stations on the E branch.

- **The Central Subway:** the Central Subway, ranging from Kenmore to North Station, is nearly coterminous with the trunk of the system, although the trunk also includes a section between North Station and Lechmere that is on a viaduct. In this thesis, "Central Subway" is used interchangeably with "trunk."

- **The Green Line Extension (GLX):** The GLX is the newest section of the line, planned to open in sections between Winter 2021 and Spring 2022. The GLX consists of the **Union Square branch** serving Union Square in Somerville, and the **Medford branch** serving parts of Somerville and Medford, including Tufts University.

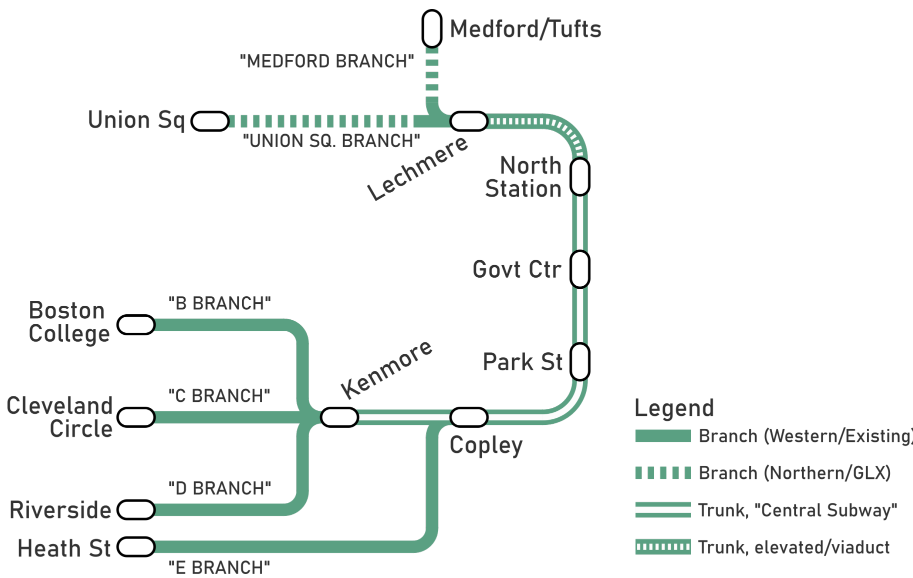

Figure 1-2: The Green Line Network, Including New GLX Segments

The various sections of the Green Line network vary greatly in character, with the Central Subway being a high-capacity, high-frequency corridor through downtown Boston, and the branches ranging from shared right-of-way street-running to 40 mph grade-separated rail lines. A brief history of the Green Line, as well as overviews of the two major changes occurring to the Green Line — the Green Line Extension and the COVID-19 pandemic — are provided below.

1.2.1 Relevant History of the Green Line

The Green Line is the oldest subway line in North America when considering the original section of tunnel built in 1897 between Boylston and Park Street [13]. However, today's Green Line is the product of many additions to the network over time. The unusually wide variety of infrastructure present on the Green Line today, which results in many important service planning considerations on the Green Line, is due in part to this history.

The modern-day B, C, and E branches were all originally electrified by the West End Street Railway to resolve issues inherent to horse-drawn operations. However, the efficiency of electrification also led to unmanageable congestion downtown, where the streetcar lines met. The solution was the Central Subway, which was gradually extended over the course of several decades to push streetcar-related congestion further away from downtown [13]. However, while tunnel construction ended at the current branch point of Kenmore, the B, C, and E branches have continued to serve Commonwealth Avenue, Beacon Street, and north Huntington Avenue, respectively, on the surface level. All three roads are wide and feature enough room for dedicated median tracks on most of the route, alleviating the need for a subway. The result, however, is that the Green Line to this day features hybrid subway/streetcar operations. The subway sections of the line feature built-up infrastructure (fare gates, signals, layup tracks, etc.) whereas the streetcar sections are still sparsely designed (on-board payment, traffic intersections, trolley loops, etc.).

The modern-day D branch was added in 1957 when the MTA (predecessor to the MBTA) purchased the Highland Branch of the Boston & Albany Railroad [13]. This was originally built to steam railroad standards, and features a right-of-way entirely separate from road traffic, including grade separation at crossings. Despite operating in a similar area as the other branches, the D branch features characteristics closer to that of a heavy rail line than the other branches, with signals, maximum speeds of 40 mph, and park-and-ride facilities.

By the 1960s, however, the rest of the Green Line was considered in some ways to be obsolete. In 1962, when considering how to address heavy travel demand from north of downtown, the North Terminal Area Policy Committee comprised of state transportation officials and local politicians declared that the Green Line had a "blighting effect" around North Station and Cambridge, and cited low ridership from Lechmere as a reason to truncate service to the north [3]. However, these plans were never executed, perhaps because the report tied the abandonment of the northern

Green Line to controversial plans for highway expansion. Other branches, such as the former A branch to Watertown and the original E branch beyond today's terminus at Heath Street, were abandoned.

1.2.2 The Green Line Extension

Public perception of the Green Line has shifted since then, and eventually the Green Line's northern extent was viewed as a valuable springboard for further transit service. The Big Dig project, a large tunneling endeavor under downtown Boston to dismantle its elevated highways, came with agreements from the state to increase transit service in order to offset automobile emissions [12]. The municipalities of Somerville and Medford, both bordering I-93 and thus affected by the higher volumes of traffic, agreed to a northern extension of the Green Line as a mitigation measure.

The Green Line Extension was designed to follow existing commuter rail rights-of-way to minimize the costs of new right-of-way acquisition and grading. A positive consequence of this decision is that the GLX is similar to the D branch in infrastructure quality, with features including grade separation, a flying junction, and signals. As a condition of its acceptance, the city of Somerville required a stop in centrally-located Union Square [10]. Because the commuter rail line passing through Union Square occupies a separate right-of-way from the commuter rail line passing through Medford, the GLX was split into two branches.

The Green Line extension is scheduled to open in sections: the Union Square branch in winter of 2021, including the reconstructed Lechmere station, and the Medford branch in Spring of 2022.

1.2.3 The COVID-19 Pandemic

On March 10th, 2019, Massachusetts Governor Charlie Baker declared a state of emergency due to the COVID-19 pandemic. In the following weeks, fare collection data reveals that transit ridership dropped by more than 90% at downtown stations as people limited their travel. More than a year later, transit demand has not recovered past 35% of pre-pandemic levels at these downtown stations. It is likely that the opening of the GLX sections in this upcoming year will occur before ridership has fully recovered.

Negative consequences of the pandemic have included a loss of agency revenue, less operators, and the postponement of several capital programs [20]. For example, a replacement of the on-board fare collection system that was due to begin upon the opening of the GLX is now postponed. However, the drop in ridership due to the pandemic has enabled the MBTA to more aggressively address maintenance and construction priorities, and run times have improved not only as a result of the lower ridership but also due to better infrastructure quality and consolidated stations.

As mentioned before, the near-simultaneous occurrences of GLX construction and the COVID-19 pandemic have created the need for a comprehensive evaluation of service possibilities. The complex network and infrastructure characteristics of the Green Line itself as highlighted in this section further requires an approach that can take into consideration the nuances of every service planning outcome.

1.3 Objectives

The primary objective of the research is to propose one or more peak-hour service plans for the post-GLX Green Line that provides a high passenger level-of-service while also being operationally desirable. The service plan should be adaptable to both various levels of peak demand and levels of agency resources to ensure a high-quality service is delivered in all reasonable scenarios.

The service plans must be easily implementable, such that modified operations may begin once the GLX opens (as early as Winter 2021). The plans should carefully balance any new operational strategies or patterns introduced with existing practices to ensure that the benefits are significant enough to warrant change, both for the sake of the MBTA and for its passengers.

Finally, the service plans should be designed to provide high-quality service for at least the next decade. While there are eventual plans to replace the Green Line fleet, at which point another reorganization of service may be warranted, this may not occur until the 2030s. Thus, even if a large emphasis is placed on adaptability to short-term change, the ability for the service plans to adequately serve long-term demand is equally important.

1.4 Research Approach

The research approach centers around a combined integer optimization and qualitative method to achieve the service planning goals. The combined qualitative/algorithmic approach allows for a full exploration of the solution space and a subsequent evaluation based on value judgments. The basic steps are scenario planning, optimization, qualitative analysis, and solution identification.

First, a scenario planning exercise is conducted to determine reasonably likely states of operation as they relate to demand levels, the fleet, and total operator hours. At the same time, a review of current operating practices is performed to enumerate every feasible service pattern, which is defined as a terminus, a turnaround location, a headway, and a consist length. Inputs specific to each service pattern, such as a cycle time, a fleet requirement, number of transfers etc. are calculated, in some cases relying on estimation or simulation when the data do not yet exist.

Next, an integer program identifies combinations of service patterns that minimize wait time and transfers while providing adequate capacity and using only the allowable resource levels. The program can take into account operational considerations relevant to the Green Line, such as ADA accessibility requirements and preferences for certain headways.

Then, a qualitative analysis framework is used to identify the most promising operational strategies. Apart from the degree of optimality as defined by the integer program, strategies are evaluated on the basis of robustness to change, operational flexibility, and the inertia of the status quo, among other qualities.

Finally, a set of solutions may be identified from the most promising operational strategies that constitute a logical progression of service plans across the various scenarios. These service plans are identified by their consistency (both for the agency and for riders), high level-of-service, and implementation simplicity.

1.5 Literature Review

Two theses related to the MBTA Green Line in the past 10 years of the Transit Lab at the Massachusetts Institute of Technology provided helpful context for Green Line service planning. Malikova [11] studied capacity improvements on the Green Line related to 3-car trains, and specifically found that the mixing of two- and three-car trains led to a decrease in actual throughput despite the theoretical increase in scheduled throughput. The first recommendation highlighted was to separate the different consist lengths by branch (e.g. scheduling all 3-car trains onto the D branch), as doing so would minimize the impact of bunching on these lines and simplify passenger communication. This was useful in deciding how single-car trains should be incorporated into the service patterns proposed in this thesis.

In the course of evaluating the benefits of a Green Line fleet replacement, Sindel [22] also evaluated the use of newly-installed data collection equipment on the Green Line that was unavailable at the time of the analysis in Malikova [11]. The work in this thesis helped to establish the available data sources for the preparation of inputs to this study, and also explained the current system of dispatching and station inspecting, which informed the selection of service patterns used.

Fabian [4] developed a Green Line simulation model, including a detailed analysis of the proportions of riders using different types of fare media on the Green Line and the amount of time it took for riders to board based on the Green Line (this is pertinent for the branch sections of the Green Line, which have on-board fare collection). The results from this study were used to inform estimates of run times on the GLX.

Lin and Wilson [8] developed models of dwell times on the Green Line in 1993, during a time when rolling stock unreliability resulted in the unscheduled use of single-car trains across the Green Line network. It was found that single-car trains were more susceptible to high variability in dwell times than two-car trains when loads were near policy capacity levels. Because these single-car trains were scheduled to be two-car trains, headways were not designed around the capacity of a single-car train. Similarly to Malikova [11], the findings of Lin and Wilson [8] helped to properly structure the use of single-car trains.

Finally, Guo [6] studied the passenger level-of-service penalty associated with transfers within the MBTA. One of the models developed in this study was used to establish the penalty of 5 minutes of wait time per transfer used for the results herein.

1.6 Organization of Thesis

Chapter 2 is a detailed discussion of recent and current Green Line operations. Chapter 3 explains the methodology highlighted in the Research Approach and provides the mathematical framework for the integer optimization formulation. Chapter 4 details the preparation of inputs for the GLX case study. Chapter 5 presents the results from the case study and compares the performance of the results with current plans for the post-GLX Green Line. Finally, Chapter 6 highlights recommendations for short- and long-term service planning and suggests future research avenues.

Chapter 2

Green Line Operating Characteristics

The purpose of this chapter is to analyze recent operational and passenger-facing aspects of the Green Line to determine both their nature and their effects. It is far from certain which pre-pandemic conditions will remain relevant after the construction of the GLX, after the pandemic, and after several impending capital programs are implemented (e.g., AFC 2.0, Green Line Transformation); but outlining past and current practices helps make more informed assumptions for future-state conditions, as well as to evaluate the feasibility of proposed solutions. Some aspects of the situation described below represent relatively rigid constraints that must be respected, such as vehicle compatibility or serious infrastructure limitations. Other aspects may represent opportunities for change, either in the short-term with the implementation of new service patterns, or for future consideration.

2.1 Scheduling

In the ratings immediately preceding the pandemic, scheduling practices were updated to re-evaluate schedules on a more frequent rating-by-rating basis to reflect changing conditions, such as run times. Recent changes in run times could be attributed to two reasons: firstly, a rapidly changing set of speed restrictions due to deferred maintenance; and secondly, more consistent enforcement of speed limits beginning in October of 2019 [21]. A new rating's schedules are based on the 90th percentile run times from the previous rating.

Trains are dispatched according to the schedule from Boston College, Cleveland Circle, Riverside, Lechmere (prior to its reconstruction), and Heath Street. Inspectors posted at Park Street, Kenmore, and Brigham Circle have access to the schedules but are primarily concerned with headway maintenance, and may adjust the order of trains to achieve this outcome [22].

Finally, both vehicles and operators are scheduled on a car-by-car basis, rather than by consist, despite the fact that most trips are served by 2-car trains. This situation arises by way of issues with the rolling stock: Type 7s and Type 8s, which must be paired for accessibility reasons, do not have compatible electronics to remotely control the doors of the second car from the cab in the leading car [14] [2]. Therefore, an operator must be present in each car to control that car's doors at stations. Although the Type 9s — which can only paired with other Type 9s — may have remedied this issue, the one-operator-per-car policy is still upheld for the Type 9 consists. An important consequence of this situation is that a single-car train requires only half the operator hours of a two-car train over the same route.

Green Line departures are scheduled on the minute, meaning that scheduled headways between successive trains are always whole minutes. However, average headways are more relevant for the purposes of this analysis. Based on schedules in recent ratings, sequences of headways are usually patterns that repeat after five trains or less: for example, four trains may depart with a headway of six minutes, then the fifth train departs with a headway of seven minutes, then followed by another four trains with a headway of six minutes, then the tenth train departs with a headway of seven minutes, etc. This can be expressed as an average headway of 6.2 minutes. For the purposes of scheduling, the range of headway options to consider is not continuous, but a discrete set (e.g., 6, 6.2, 6.25, 6.33, etc.).

The headways used for Spring 2020 schedules, the final set of schedules developed prior to the pandemic, are shown in Table 2.1. In the Final Environmental Impact Statement, the formal document which was the basis of the federal approval of the GLX, it was stated that the post-GLX Green Line would preserve the same headways

Table 2.1: Spring 2020 Headways

Service	AM Headway (minutes)	PM Headway (minutes)
B	5.40	5.80
C	6.75	7.25
D	6.00	6.00
E	6.00	6.50

as that of the pre-GLX Green Line [12]. While headways were increased during the pandemic, these Spring 2020 headways remain an important benchmark from a service perspective. Service provided in the peak period is the focus of the analyses throughout this thesis, as this is when demand (and, therefore, use of resources) is highest.

Given the layout of the Green Line network — a trunk line with branches — most feasible service patterns run from one of the branches direct onto the trunk (Central Subway). The trunk section is shared with the other branches. Therefore, passengers making trips within the Central Subway will typically experience shorter wait times than those making trips that begin or end on one of the branches. Similarly, changes to individual branch headways will have a lesser effect on the shared sections of the Central Subway, compared to the impact on wait times along the branch where service is effectively limited to a single service pattern.

2.2 Fleet Composition

The Green Line uses three distinct varieties of rolling stock, referred to as the Type 7s, Type 8s, and Type 9s. All three rolling stock types are capable of operating on all sections of the Green Line. Under pre-pandemic operating conditions, fleet-related limitations were the main operational constraint on the Green Line. Please see Table 2.2 for an overview of the fleet.

Table 2.2: Green Line Fleet Composition

Rolling Stock Series	Number of Available Vehicles	ADA Compliant?	Compatible Series
Type 7	103	No	Type 7, Type 8
Type 8	85	Yes	Type 7, Type 8
Type 9	9 (current), 24 (ordered)	Yes	Type 9

The Type 7s are the oldest active cars in the Green Line fleet. Having been refurbished recently between 2012 and 2016 — which included a full replacement of the propulsion system, among other critical components — the Type 7s are considered highly reliable vehicles by the MBTA. In addition, with 103 available vehicles, the Type 7s represent the majority of the currently available 197 vehicles in the Green Line fleet [2].

Type 7s, however, suffer from two major shortcomings: a) they were not built to be wheelchair-accessible, so to comply with ADA requirements, they must always be paired with an accessible vehicle; and b), despite both Type 8s and Type 9s fulfilling accessibility requirements, only the Type 8s have propulsion systems compatible with Type 7s. If a Type 7 is coupled to a Type 9, only one train's motor can be used, which is inadequate to meet operational demands. The technological incompatibility between the Type 7s and Type 9s would require significant and potentially costly reprogramming of on-board systems to be resolved [2].

The Type 8s were acquired in 1999, but despite their relative youth, have long suffered from reliability issues — MBTA maintenance staff estimate they break down 50% more often than Type 7s. With only 85 Type 8 cars in active service and a relatively strict spare ratio due to the aforementioned reliability concerns, the limitations of the Type 8s are functionally also limitations on the Type 7s as they are almost always run in pairs. An ongoing truck replacement program is expected to alleviate some of the most frequently appearing issues, namely derailments, and put one currently damaged car back into service, raising the total to 86 [2].

Finally, the Type 9s are the latest addition to the fleet, and were ordered in anticipation of the Green Line Extension. A total of 24 cars were ordered, though delivery and testing is ongoing. As mentioned before, these cars may only be paired with one another, making them particularly well-suited for operation in one-car trains if needed. Prior to the pandemic, the 9 cars that were delivered were largely used as spare vehicles in case too many of the Type 7-Type 8 pairs were out of service [2].

2.3 Maintenance

Green Line maintenance is currently carried out in two facilities: Riverside (Type 7 base, temporary Type 9 base, and heavy overhaul work for all types) and Reservoir (Type 8 base and regular inspections for all types). Due to the large amount of vehicle-specific parts and tools required to perform maintenance, it is preferable for each facility to specialize in performing maintenance on one of the three types. It is anticipated that the new East Somerville Maintenance Facility will be the base for the Type 9s. Currently, because of the low number of Type 9s, space at Riverside has been temporarily allocated to them while construction of the new facility is ongoing. It is likely that the East Somerville facility will have to be at least partially opened in order for the full fleet of twenty-four Type 9s to be adequately maintained, as space at Riverside is very limited [2].

Vehicles undergo routine maintenance on a 90-day interval, but this will be changed to a mileage-based interval (every 10,000 miles) that is not expected to significantly affect the size of the available fleet. To accommodate scheduled maintenance as well as replacing broken down cars, a 12% spare ratio is considered adequate for the Type 8s [2]. It is assumed that a 12% spare ratio is also adequate for the more reliable Type 7s and Type 9s.

2.4 Fare Collection

At present, fare collection is a mixture of fare gates, on-board cash, and on-board CharlieCard payments. All Central Subway stations (including Science Park, Prudential, and Symphony, but not the reconstructed Lechmere) as well as Riverside (D) use fare gates. The remaining pre-GLX stops, all surface stations, require on-board payment. Some surface stops, particularly along the D branch, have fare top-up machines for CharlieCard users.

Prior to the pandemic, all ungated stations were scheduled to be transitioned over to AFC 2.0, a new fare system, by late Spring of 2023. AFC 2.0 will see boarding passengers tapping at readers installed at all doors (rather than just the front doors) with more universal fare media (e.g., smartphones, credit cards), which is expected to reduce dwell times [17].

Stations in the GLX project — including the rebuilt Lechmere — are not being built with fare gates. The pre-pandemic plan was to place MBTA staff on platforms with handheld fare media scanners, a scheme referred to informally as "AFC 1.5." This has been planned due to the island platforms constructed along the GLX, which do not allow operators to board passengers from the front doors where the farebox is located [17].

2.5 Crowding

The available data suggest that, pre-pandemic, passenger demand on the Green Line seldom exceeded 60% of provided capacity, even during peak periods, assuming regular headways on the Central Subway. This is consistent with demand data from other subway lines. However, there is a common perception that the Green Line experiences crowding during peak periods, and there are several possible explanations for this discrepancy between perception and data. Firstly, these calculations assume even headways, which is seldom achieved on the Green Line. Secondly, all Green Line rolling stock feature stairs within the vehicles, slowing boarding and alighting as well as hampering the movement of passengers further into the vehicle. Thirdly, Green Line trains are never longer than two cars, resulting in crowded platforms despite frequent service. Finally, there are assumptions present in the available data, such as the proportion of transfers at certain stations, that may be outdated [14]. Therefore, assumptions made in the following chapters regarding capacity and crowding are conservative.

2.6 Termini and Turnaround Locations

The locations of potential termini play an integral role in the development of service plans for the Green Line. There are many options, each with operational considerations including (but not limited to) the turnaround time, track capacity, interference with non-turning operations, and labor. Understanding the nature of the various termini and turnaround options is critical for both the identification of feasible service patterns as well as comparing the merits of full operating schemes. The primary purpose of this section is to justify the inclusion or exclusion of certain termini from this analysis. Table 2.3 contains an overview of the viable terminus and turnaround locations as well as their associated turnaround times, and Figure 2-1 shows where on the network these termini and turnaround locations exist.

Table 2.3: Viable Termini/Turnaround Locations and Times

Location	Turnaround Time (min)	Interference with Other Trains	Source of Turnaround Time
Boston College	5	Low	Supplied by MBTA
Cleveland Circle	3	Low	Supplied by MBTA
Riverside	5	Low	Supplied by MBTA
Heath Street	2	Low	Supplied by MBTA
Packards Corner	3	High	Estimated
Washington St	3	High	Estimated
Summit Avenue	3	High	Estimated
Reservoir	3	Low	Estimated
Brigham Circle	3	High	Supplied by MBTA
Northeastern U.	3	High	Estimated
Kenmore (WB)	7	Medium	Estimated
Kenmore (EB)	3	Medium	Estimated
Park Street	2	Low	Supplied by MBTA
Govt. Center	3	High	Supplied by MBTA
North Station	7	Medium	Supplied by MBTA
Union Square	4	Low	Estimated
Medford/Tufts	4	Low	Estimated

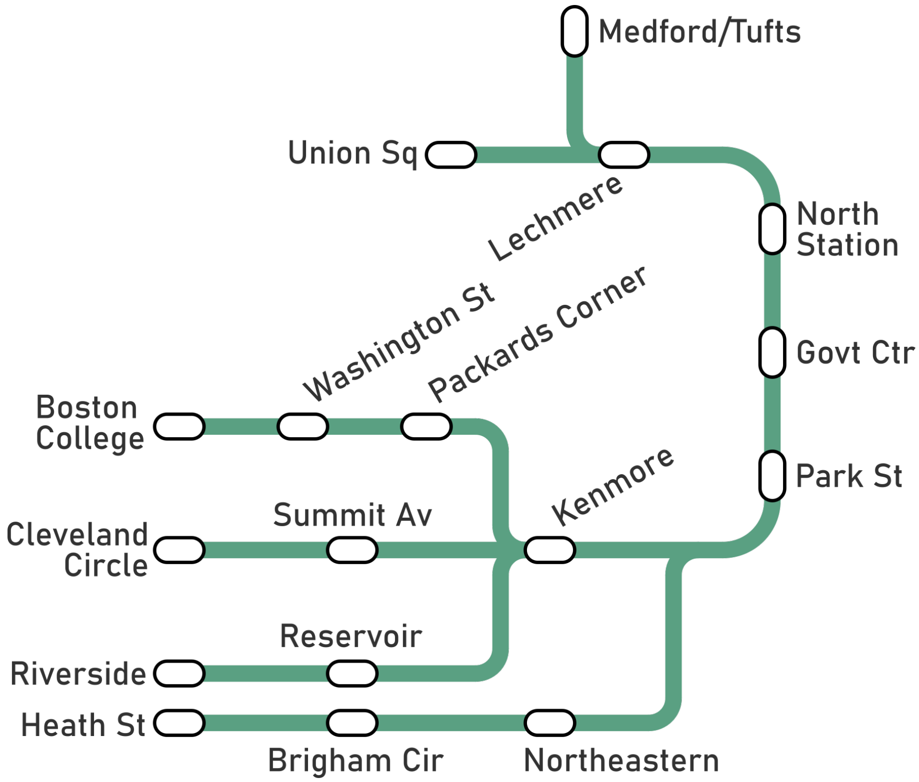

Figure 2-1: Green Line Termini and Turnaround Locations

It should be noted that within this thesis, the terms *terminus* and *turnaround* refer to distinct types of locations. Typically, a non-loop transit service is described as having two termini, commonly at either end of the line. However, the Green Line is comprised of service patterns which, for the most part, have one terminus at the end of a branch (e.g., Boston College), and one terminus somewhere in the Central Subway (e.g., Park Street). Typically, it is much easier to hold and store trains at the branch terminus than at the Central Subway terminus, as most branch terminus locations have an attached or nearby yard [9]. Conversely, a Central Subway terminus may have platforms shared with both turning and non-turning services (e.g., Government Center, North Station), may not allow turning trains to leave in a different order than they arrived (e.g., Park Street, Government Center), or may see more than one service sharing the same termini (e.g., North Station). Most importantly, however, under any reasonable operating scheme, a branch terminus will be associated with exactly one service; whereas a Central Subway terminus could see anywhere between zero and four services turning. These differences mean that, throughout the thesis, the *terminus* — defined as the terminus of a service pattern most able to hold and dispatch trains, most often at the end of a branch; and the *turnaround* — the other end of the service pattern, most often within the Central Subway, are treated as distinct types. There is sometimes overlap between these types; e.g., the terminus of a Riverside to Union Square service is Riverside, but the terminus of a Government Center to Union Square service would be Union Square, because even though it is more complicated to dispatch and hold trains from Union Square than from Riverside, it is easier than dispatching and holding at Government Center.

2.6.1 End-of-Branch Termini

Boston College, Cleveland Circle, Riverside, and Heath Street are the termini of the B, C, D, and E branches, respectively. Of these, the former three have an attached yard or shop complex, making dispatching and storage convenient [14]. However, Boston College (and the former Lechmere yard) is considered to have variable storage space depending on the time of day: when the Green Line is out of service overnight, the yard has a capacity of 24 cars. However, some of the storage tracks also function as the turning tracks, so the effective daytime capacity is only 12 cars [18]. Heath Street does not possess a nearby yard; however, it contains two parallel looping tracks that provide some space for temporary train layups and holding, and like the three other branch termini, a dispatcher is stationed at Heath Street [22]. All four are turnaround locations for trains to serve the entirety of the branches. Table 2.4 summarizes the above information for each of the existing yards.

Table 2.4: Green Line Yard Capacity

Yard	Overnight Capacity	Daytime Capacity
Boston College	24 cars	12 cars
Reservoir	83 cars	83 cars
Riverside	111 cars	111 cars
Lechmere (demolished 2020)	20 cars	8 cars
Heath Street (turnaround)	4 cars	2 cars

The new branch termini introduced by the GLX, Union Square and Medford/Tufts, consist of two tracks with a crossover. Of the two, Union Square is slightly more favorable for dispatching, as there are yard leads to the new East Somerville Maintenance Facility shortly down the line [23]. Both stations are suitable for basic layovers, as they will function similarly to Heath Street. At this time, it has not been determined what the functional capacity of the new yard complex will be [18].

2.6.2 Branch Short-Turning Locations

There are several locations on the branches that allow short-turns. Packards Corner (B), Washington Street (B), Summit Avenue (C), Reservoir (D), Northeastern University (E), and Brigham Circle (E) all have infrastructure to support turning trains [9]. Of these, Reservoir (D) is the most promising, as it has two separate platforms for terminating trains, an adjacent yard complex, and switches that can be controlled from within the cab [19]. Northeastern also provides a track for layups. The rest of these stations would require proper scheduling to ensure turning trains do not block non-turning trains. All of the locations except for Reservoir would also need MBTA staff present at the station to control switches [19]. Therefore, there are significant operational challenges to performing many of these short-turns, despite the variety of options.

Currently, trains are short-turned at Brigham Circle on an ad-hoc basis to preserve headway regularity [21] rather than continuing on to the end of the line at Heath Street. The segment from Brigham Circle to Heath Street runs in mixed traffic, and interactions with street traffic can cause delays and variability. Figure 2-2 shows the proportion of trips that are short-turned for real-time control purposes by hour of day, demonstrating that these short-turns peak during the peak hours as well as just before end-of-service (presumably to help shifts end on time). It is generally assumed in this thesis that the E branch will continue to run in mixed traffic for the foreseeable future, and therefore in practice some trains may still be short-turned despite being scheduled to run to Heath Street.

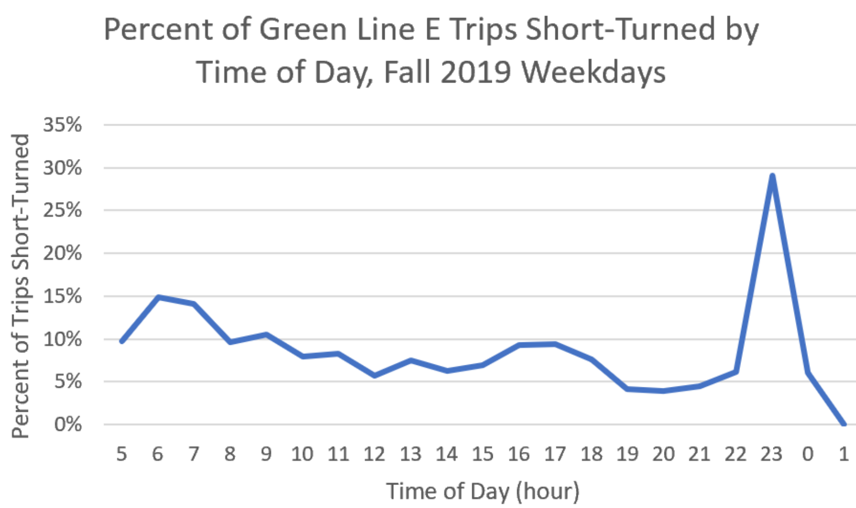

Figure 2-2: Percentage of Green Line E Trips Short-Turned by Time of Day, Fall 2019 Weekdays

2.6.3 Central Subway Turnaround Locations

The primary locations within the Central Subway at which trains may turn are Kenmore, Park Street, Government Center, and North Station. Government Center and Kenmore can turn trains in both directions; however, turning trains must share tracks with non-turning trains [9]. The westbound turn at Kenmore utilizes a layup track at the Blandford Street stop on the B branch and requires on-site staff to operate the switches [19]. Government Center contains flat junctions between the opposing loops, introducing the possibility of track congestion if two or more services are regularly turned in opposing directions. Park Street has separate tracks for continuing trains and turning trains, allowing for a greater degree of potential headway management and/or schedule recovery. North Station similarly possesses two layup tracks outside of the station and out of the way of through trains [9].

2.7 Track Congestion

It is not current practice to coordinate the schedules of branches to reduce interference at convergence points within the Central Subway. Not only would this reduce the flexibility of being able to schedule each line at its own headway, it would also be an extremely difficult schedule to maintain, as trains are dispatched from the western branches and must traverse through many signalized intersections and, in the case of the E branch, mixed traffic sections before reaching the Central Subway. In addition, because of its age and piecemeal construction, the Central Subway features flat junctions at several locations — namely Copley and Government Center — that introduce practical limits on track capacity. Finally, while operators are allowed to pull up to the next train at Park Street to unload and load two trains simultaneously on the same track, this practice is not allowed at the other stations in the Central Subway, further limiting throughput.

Track circuits likely do not provide the spatial resolution necessary to diagnose the interaction effects of the above situations in detail. However, the macroscopic effect of track congestion can be analyzed by applying basic queueing theory to the Green Line. The service rate of the Central Subway can be defined as the rate of trains exiting the subway from any one of Blandford Street (B), St Mary's Street (C), Fenway (D), Prudential (E), or Science Park (E) within a ten-minute period. Each ten-minute period is also associated with a number of trains within the Central Subway, measured at the midpoint of the ten-minute period. Figure 2-3 illustrates the average service rate experienced under a certain number of trains in the Central

Subway. The maximum service rate (8 trains per 10 minutes) is reached when 27 trains enter the Central Subway. After 30 trains the service rate decreases as conditions become congested and trains slow down moving through the central subway area.

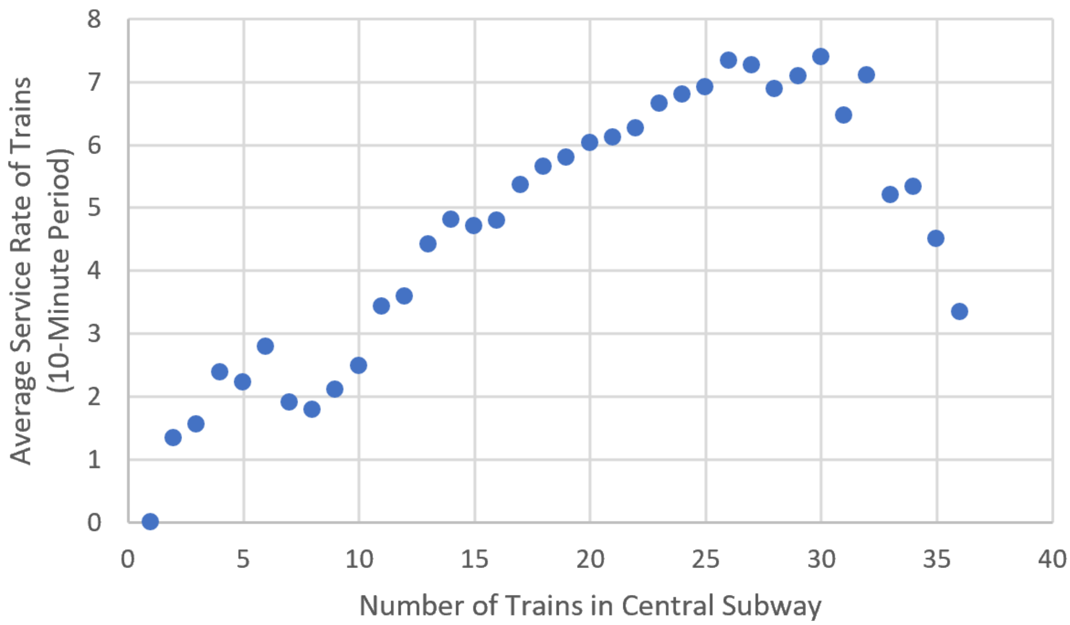

Figure 2-3: Central Subway Service Rate Versus Number of Trains

This is important from a service planning perspective as it means that the Green Line may become overwhelmed by headways that are too low. Solutions or remedies such as one-car trains, allowing multiple trains to simultaneously load and unload at stations besides Park Street, coordination between inspectors at Kenmore and Park Street, holding at stations immediately outside the Central Subway, as well as signal upgrades (included within upcoming Green Line Transformation projects) may lessen the chance that congestion-related service rate drops occur, even with trains scheduled at higher frequencies.

Chapter 3

Methodology

3.1 Introduction

Uncertainty is an unavoidable aspect of planning. It is conceivable that a range of distinct scenarios will be encountered over the duration of any service plan, and the ability for a service plan to provide reliably good service over many reasonable scenarios is valuable. This aspect as well as the desire to identify flexibility within certain service plans motivates an approach to service planning that emphasizes broad applicability and compromise.

The proposed approach below consists of a combination of integer linear optimization alongside subjective evaluation techniques to achieve these ends. The efficient nature of linear optimization can be harnessed to quickly identify potentially promising trends and solutions; and by evaluating across a wide range of objective scenarios and subjective criteria, well-balanced and resilient solutions can be determined. The process has four key steps, as seen in Figure 3-1. The bullet points below each step summarize the actions comprising the step, which are discussed in greater detail below.

The four steps in Figure 3-1 are mostly a sequential process. However, iteration may be beneficial particularly between the optimization and qualitative analysis steps. As will be explained below, it is easy to investigate trends or generate solutions with specific characteristics by optimizing with additional constraints in place, and the necessary investigations may not be identified until the qualitative analysis stage. Moreover, while value judgments play a critical role in evaluating trade-offs in generated solutions, the same value judgments can also be used to shape the solution generation process itself through the selection of inputs or the implementation of constraints.

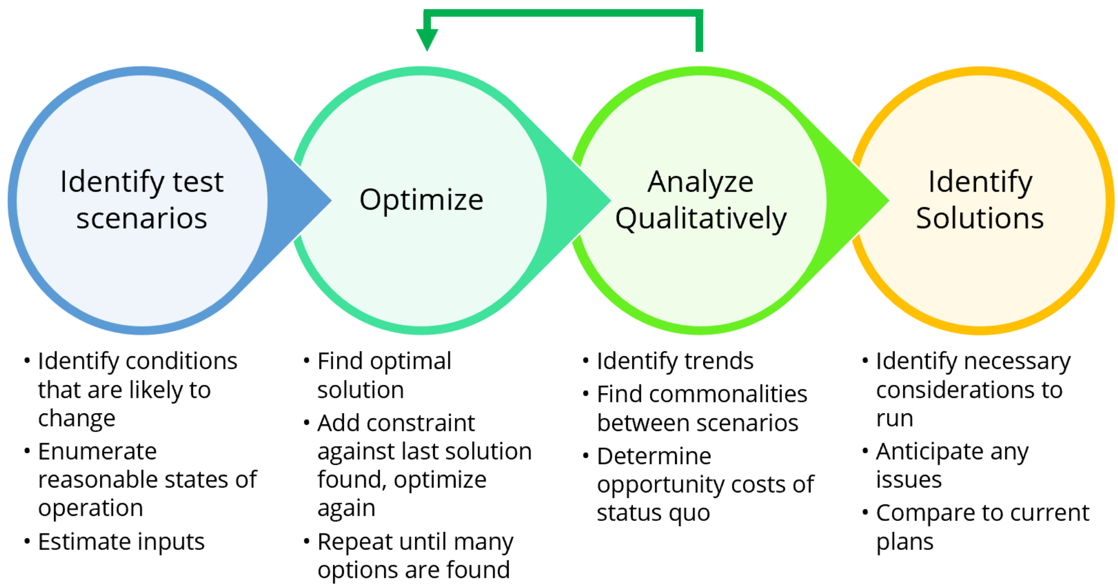

Figure 3-1: Flowchart of Service Planning Method

This chapter explains in greater detail each step, providing the general framework within which the case study in this thesis, operations on the post-GLX Green Line, is analyzed.

3.1.1 Scope and Assumptions

In this thesis, networks of a trunk-with-branches configuration are considered. Figure 3-2 shows a simplified example of this type of network. The trunk section often features higher demand than the branches, and the capability usually exists for vehicles serving the branches to through-run onto the trunk portion of the line. The MBTA Green Line is an example of this kind of network.

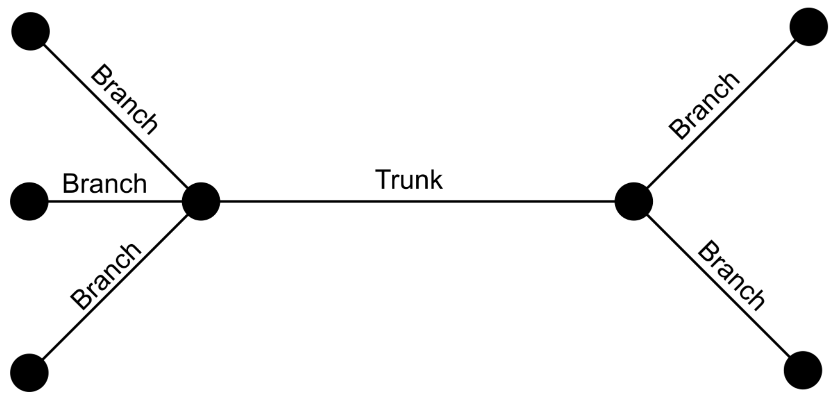

Figure 3-2: Simple Example of a Trunk-With-Branches Network

Service planning challenges in these kinds of networks include balancing capacity between the trunk and the branches, managing transfers within the system, and managing wait time and crowding on branches. The method below is specifically designed to address these challenges.

An important assumption in this method is that demand is independent of the level of service provided. At the extreme, this is not likely to be true: a service on a 2-minute headway will be more attractive to riders than a service on a 20-minute headway. However, it is assumed that the range of reasonable headways in a given scenario is small enough that the demand inputs do not need to be adjusted for the particular headways within a solution.

3.2 Identify Test Scenarios

The purpose of identifying a range of test scenarios is both to evaluate how individual solutions perform under certain conditions as well as to identify the broader trends that might arise over changing conditions. Therefore, it is useful to think of scenario creation as a way to capture changes that may arise over time, ensuring that the solutions that are identified for further analysis are likely to perform well regardless of future conditions. For example, changes in passenger demand, agency resources, operating characteristics, physical infrastructure, electronic infrastructure, and vehicle types are some of the many inputs that could potentially change over time. Once the important changes have been identified, individual scenarios may be constructed that are combinations of these inputs that are reasonably likely to occur together.

It is important to evaluate which inputs in each scenario should be independently assigned and which depend on the state of other inputs, because this may result in more realistic scenarios and simpler scenario construction. For example, in the following chapter, it will be shown that run times on the Green Line are highly correlated with demand (in the form of gate taps). Therefore, the demand dimension of the scenarios evaluated for the case study controls not only the actual demand inputs but also the set of run times. Some inputs are also likely to be static: for example, there are no further extensions to the Green Line immediately planned after the GLX. Therefore, it can be assumed that all scenarios will use the same network inputs.

Lastly, the scenario planning/input preparation stage is also an appropriate time to identify how certain undesirable outcomes may be avoided through curation of inputs. For example, because the optimization is evaluating from a system optimum perspective, individual branches could be assigned drastically high headways if it were to result in a significant enough benefit to the passengers as a whole. This type of solution, while mathematically sensible, is undesirable from a politically pragmatic standpoint. These solutions could be limited by simply restricting the headway inputs to those under a certain duration (i.e., a maximum policy headway), guaranteeing that level of service on any particular branch will not be worse than what the inputs allow.

3.3 Optimization

Integer linear optimization is a valuable tool to identify solutions with desirable properties. However, it is limited in two significant ways. Firstly, as the name implies, the objective function and constraints to the problem must be linear with respect to the decision variables included. This necessarily results in the exclusion of certain non-linear relationships among variables from the formulation, all of which will be explained in this chapter. Secondly, given a set of inputs, the optimization will produce exactly one optimal solution. A single solution is not useful for trend identification and subjective evaluation, so it will be shown later in this section how to produce many close-to-optimal results for a more thorough investigation of the solution space.

Fundamentally, an optimization formulation consists of an *objective function*, which is the quantity to be maximized or minimized, and the *constraints*, which are mathematically-defined conditions that must be met by a solution. Solutions are reached by adjusting the values of the *decision variables*, which are the variables that, taken together, define a unique solution. In this formulation, the objective function is a combination of expected wait time (EWT) and a transfer penalty. The constraints represent lower and upper bounds of the service provided, such as agency resources (an upper bound) and required passenger capacity (a lower bound). The decision variables are the service patterns that are selected to run the service as well as variables that represent the fleet composition chosen for the service. The service patterns are defined by a unique combination of terminus, turnaround location, headway, and consist length.

The following notation will be used throughout this chapter:

- N: stations/nodes
- T: termini $= T \subseteq N$
- S: turnaround locations $= S \subseteq N$
- k: number of cars $= k \in \{1, 2\}$
- h: headway,
- (m, n): segments of the network $= (m \in N, n \in N)$
- Y: type of rolling stock, important for the Green Line given accessibility concerns
- (i, j): route of a service pattern $= i \in T, j \in S$

- (mn, pq): generic OD pair from segment $(m \in N, n \in N)$ to segment $(p \in N, q \in N)$

- W: set of all (mn, pq) OD pairs to be evaluated within the objective function

Most trunk-with-branches transit networks, including the Green Line, have a much heavier demand on the trunk than on any individual branch; therefore, it can be assumed that all reasonable solutions assign only one service to each branch, as there is never a purpose for additional branch capacity without additional trunk capacity. This means one may assume that any service pattern selected provides *exclusive* service to any riders along its branch. The resulting implication is that passenger flows within a particular branch and passenger flows between a particular branch and the trunk have wait times dependent on only a single service pattern choice. Limiting the objective function to evaluating passenger impacts only within these flows keeps it linear. These are the set of OD pairs described by the variable W above.

This means that wait time and transfer impacts are *not* evaluated for passengers whose trips are entirely contained within the trunk. This omission is not critical — wait time is not as large of a concern on the trunk line, where trains are at their most frequent, as it is on the branches, where wait times will necessarily be several times longer than on the trunk. Furthermore, passengers on the branches generally have longer journeys and may have smaller stations with less passenger amenities, which makes reducing wait time a greater priority for these passengers. Transfers are also less of a concern on the trunk line, given that they will have multiple services serving each station, in almost all cases eliminating the need for a transfer.

It should be noted that on the Green Line, any terminus-turnaround pair results in a single unambiguous routing. More complex networks involving the possibility of multiple viable paths between route endpoints may require additional routing variables beyond i and j. Additionally, segments are used rather than individual stations for variables such as OD flows to simplify the inputs, where segments are sections of the line in which service is constant at each station within the segment (i.e., there can be no trains terminating or exiting partway through the segment). For some networks it may be appropriate to use disaggregate OD flows instead.

3.3.1 Core inputs

The following is a list of inputs for the formulation. Additional variables that are non-essential to define the problem will be described in their respective sections.

Decision Variables:

x_{ijkh}: binary decision variable

$$x_{ijkh} = \begin{cases} 1, & \text{if service pattern } ijkh \text{ is included in the solution} \\ 0, & \text{otherwise} \end{cases}$$

y^{Y}_{ijkh}: integer decision variable equal to the number of cars of type Y assigned to service pattern $ijkh$

Input Variables (known):

σ_{ijmn}: binary variable

$$\sigma_{ijmn} = \begin{cases} 1, & \text{if an } ij \text{ service pattern serves the segment } (m, n) \\ 0, & \text{otherwise} \end{cases}$$

α_{ijmnpq}: binary variable

$$\alpha_{ijmnpq} = \begin{cases} 1, & \begin{array}{l}\text{if passengers in OD pair mnpq are on a branch and rely exclusively} \\ \text{on an } ij \text{ service}\end{array} \\ 0, & \text{otherwise} \end{cases}$$

r_{ijmnpq}: binary variable

$$r_{ijmnpq} = \begin{cases} 1, & \text{if passengers in } \alpha_{ijmnpq} \text{ require a transfer to complete their trip} \\ 0, & \text{otherwise} \end{cases}$$

R_{mnpq}: number of riders during the PM peak hour in OD pair (mn, pq)

P_T: factor that converts an instance of a transfer into equivalent minutes of wait time

D_{mnpq}: highest PM peak hourly flow on segment (mn, pq) in either direction

F_Y: total number of cars in the fleet of type Y

Q_Y: minimum spare ratio for type Y vehicles

f_{ijkh}: fleet requirement for service pattern $ijkh$

H: total available operator hours

η_{ijkh}: operator hours required for service pattern $ijkh$

ϕ_{ijkh}: hourly passenger flow capacity provided by service pattern $ijkh$

γ: maximum allowed flow-to-capacity ratio (similar to a safety factor), $(0 < \gamma < 1)$

τ_j: maximum number of services that can be turned at location j

3.3.2 Objective Function

The objective function aims to minimize the sum of the expected wait time (EWT) and a wait time-equivalent penalty for transfers across all selected service patterns. To adhere to requirements of linearity, not all passengers are represented in the objective function; however, the most important OD flows from a wait time perspective are included. The representation of these two components is described below.

Wait Time

Assuming perfectly spaced headways (i.e., zero variability), the expected wait time of a passenger using a service pattern x_{ijkh} is $\frac{h}{2}$. Although the assumption of perfectly spaced headways is not always realistic, the assumption is also made that the various choices of x_{ijkh} will all have similar levels of variability.

As explained earlier, the wait time impacts are evaluated for passengers who exclusively rely on a given branch service along some part of a trip (captured by the network input variable α). Combining this with the EWT definition in the previous paragraph and the passenger OD flow R, the total wait time impacts across all service patterns are given by:

$$\sum_{ijkh} \sum_{(mnpq)\in W} x_{ijkh}(\frac{h_{ijkh}}{2})\alpha_{ijmnpq}R_{mnpq} \tag{3.1}$$

Transfers

Transfers significantly detract from passengers' perception of level of service, so the objective function takes into consideration the transfers created by a combination of service patterns and penalizes them in units of wait time. For simple routes, this may not be a factor, but for complex routes (such as the Green Line) involving many possible locations for services to branch out or turn around, the pairings of branch services on opposite ends, as well as the chosen turnaround locations can have a major impact on the number of passengers requiring a transfer.

The number of transfers required for each particular service pattern, r_{ijmnpq}, is calculated during the input preparation stage, and requires passenger origin-destination (OD) flow data. Any passenger boarding or alighting on a particular branch whose origin or destination does not exist along the service pattern's route is assumed to make at least one transfer. However, the formulation will only assign a single transfer penalty to each case. There is a possibility that certain combinations of service patterns may require more than one transfer for some passengers; however, in most systems similar to the case studied in this research, these are likely to be fringe cases.

Therefore, given P_T, the conversion factor between a single transfer and equivalent minutes of wait time, the transfer impact is expressed as:

$$P_T \sum_{ijkh} \sum_{(mnpq) \in W} x_{ijkh} \alpha_{ijmnpq} r_{ijmnpq} R_{mnpq} \tag{3.2}$$

For the case study presented here, a value of 5 is chosen for P_T (i.e., on average, a transfer is equivalent to five minutes of wait time). A 1993 survey found that MBTA riders value a transfer to be roughly equivalent to 10.6 minutes of in-vehicle travel time [6]. It is a common assumption in transportation studies that a minute of out-of-vehicle waiting time is equivalent to 2 minutes of in-vehicle travel time; thus, 5 minutes is chosen as an approximate conversion factor. It should be noted that this is likely a conservative (i.e., inflated) assessment of the transfer penalty: the transfers evaluated in the Boston study were between *different* lines of the MBTA system, which require the use of stairs and walking through station complexes; whereas the case study here focuses on intra-Green Line transfers, which are nearly all cross-platform transfers and thus less of an inconvenience.

3.3.3 Core Constraints

The following constraints are universal in nature and are applied in every scenario. Note that some inputs, such as the fleet requirement and the required operator hours, are not necessarily readily available and may require estimation or modeling. For examples of these methods to produce the inputs, please see the discussion of the particular input preparation methodology used in the GLX case study in the following chapter.

Fleet Requirement

All types of rolling stock, Y, must retain sufficient spare ratios Q from its portion of the fleet F:

$$\sum_{ijkh} y^Y_{ijkh} \leq Q_Y F_Y \ \forall Y \tag{3.3}$$

The Green Line has three types of rolling stock (Type 7s, 8s, and 9s). The sum of all the Type 7s, 8s, and 9s assigned to a service pattern must be equal to the fleet requirement f_{ijkh} of that service pattern (calculated by dividing the cycle time of the service pattern by the headway, rounding up to the nearest integral number of trains, and multiplying by the consist length):

$$y^7_{ijkh} + y^8_{ijkh} + y^9_{ijkh} = f_{ijkh} x_{ijkh} \ \forall (i, j, k, h) \tag{3.4}$$

The Green Line case study requires further fleet requirement constraints to ensure ADA accessibility is maintained, as the Type 7 rolling stock is not ADA accessible. Every Type 7 must be paired with an ADA-accessible Type 8 (at this time, Type 7 trains are incompatible with the Type 9s, although Type 9s are also ADA accessible). To ensure ADA requirements are met by solutions, no Type 7 cars may operate as single-car trains:

$$y^7_{ij1h} = 0 \ \forall (i, j, h) \tag{3.5}$$

Secondly, because the Type 7s must operate in pairs with Type 8s, the number of Type 7s used in a two-car train service pattern will always be equal to or less than the number of Type 8s used in the same service pattern:

$$y^7_{ij2h} \leq y^8_{ij2h} \ \forall (i, j, h) \tag{3.6}$$

Operator Hours

Each service pattern x_{ijkh} is associated with a required number of operator hours η_{ijkh} to run. The following constraint ensures that the total operator hours of the selected service patterns fall below the total available operator hours H.

$$\sum_{ijkh} x_{ijkh}\eta_{ijkh} \leq H \tag{3.7}$$

Capacity

Each service pattern x_{ijkh} adds a certain amount of passenger capacity ϕ_{ijkh} to all segments that it serves (the segments are accounted for by the binary indicator σ_{ijmn}). A fraction of this capacity γ, less than one, should be capable of serving the average peak hour demand D_{mn} of each (m, n) segment.

$$\gamma \sum_{ijkh} x_{ijkh}\sigma_{ijmn}\phi_{ijkh} \leq D_{mn}\ \forall (m, n) \tag{3.8}$$

Smaller values of γ result in more conservative allocation of capacity on the most crowded sections. ϕ_{ijkh} is calculated by multiplying the policy capacity of a train by the hourly frequency of the service $\frac{60}{h}$. In the case of the Green Line, all cars are assumed to have the same policy capacity, so the policy capacity of a train is equivalent to the consist length k multiplied by the policy capacity of a single car.

Turnarounds

Many transit lines include intermediate points along the route at which trains may turn around; however, not all turnaround locations share the same capacity to serve turning trains. On one hand, stations such as the Green Line's Park Street represent a high standard for turning operations, including dedicated tracks for turning trains, the ability to load/unload trains simultaneously, and a lack of track/block interference between through trains and turning trains. On the other hand, a station like the Green Line's Brigham Circle may consist of only a single crossover and shared tracks/platforms. Trains are turned at both locations; however, there is far more capacity for turning at Park Street than at Brigham Circle. To reflect this, a constraint is introduced that limits the number of service patterns x_{ijkh} to be less than or equal to the maximum number of turning trains τ_j at all turnaround locations j:

$$\sum_{i}\sum_{k}\sum_{h} x_{ijkh} \leq \tau_j \; \forall j \tag{3.9}$$

3.3.4 Other Constraints

The following constraints are nonessential to operations and may be thought of as ways to further modify the solution space. However, while these constraints may not be critical to describe the transit system, they are valuable tools for analysis, and are often helpful to achieve a wide range of qualitatively desirable solutions.

Generation of Many Close-To-Optimal Solutions

"Optimal" in the mathematical sense is a single solution, and a solver will arrive at the same optimal solution each time the same inputs are passed in. However, given a complex system with many possible options, described by imperfect estimates of scenarios and conditions, solutions that are subjectively "close-to-optimal" are, for most intents and purposes, just as valuable and informative as solutions that are theoretically strictly "optimal."

To allow the optimization to arrive at many close-to-optimal solutions, the optimization can be solved many times over with the same inputs, alongside a new binary variable ξ^A_{ijkh}. ξ^A_{ijkh} is modified for each instance of the optimization: ξ^A_{ijkh} is equal to x^*_{ijkh} (the optimal value of x_{ijkh}) for each prior optimization A. Another equivalent definition of ξ^A_{ijkh} is:

$$\xi^A_{ijkh} = \begin{cases} 1, & \text{if service pattern } ijkh \text{ is part of the optimal solution in a previous optimization } A \\ 0, & \text{otherwise} \end{cases}$$

By comparing the sums of the product of x and ξ in each subsequent optimization, solutions in which a subset of the service patterns identified in x have already been identified as an entire solution in ξ will be invalid.

$$\sum_{ijkh} x_{ijkh}\xi^A_{ijkh} \leq \sum_{ijkh} \xi^A_{ijkh} - 1 \; \forall A \tag{3.10}$$

Equation 3.10 guarantees that identical solutions will not be generated in subsequent solver runs.

Routing

There are cases in which it is advantageous to constrain solutions to always include a certain routing, defined here as a unique combination of terminus i and turnaround location j. Because the chosen routings have a large impact on transfers, changes in routing have the potential to impact the quality of the journey, and the opportunity cost of adopting new routings can thus be high. In other cases, certain routings may be ideal for various reasons, such as to fulfill a previous commitment to the community.

To ensure a particular routing is chosen, one may change the inputs, but a simple constraint is oftentimes easier to implement. For example, in the case where services from terminus $i = 1$ should always turn at turnaround $j = 3$, the constraint is simply:

$$\sum_{k} \sum_{h} x_{13kh} = 1 \tag{3.11}$$

Branch Headways

Precedent, track/station layouts, equity considerations, or other hard-to-quantify situations may justify deviating from the system optimum to constrain branch headways relative to one another. This may be accomplished by use of a simple branch headway constraint. For example, one could ensure that the headway of trains from terminal $i = 2$ is always lower than the headway of trains from terminal $i = 1$ by the following constraint:

$$\sum_{j} \sum_{k} \sum_{h} x_{1jkh} h_{1jkh} \geq \sum_{j} \sum_{k} \sum_{h} x_{2jkh} h_{2jkh} \tag{3.12}$$

Level of Service

As noted before, the inputs may be limited in such a way that the level of service (LOS), in the form of wait time, is effectively constrained by the options that the optimization may pick from. However, this may also be added as a constraint. A benefit to adding the LOS restriction as a constraint is that the limitation may be applied generally to all branch segments of the line rather than to specific service patterns. This may help to address potential equity concerns that result when changes in wait time are highly uneven for riders of different branches.

For each segment mn, one may define the headway h^0_{mn} as the reference or benchmark headway. Then, two factors are defined: β_I is the individual branch LOS factor, the factor that represents the maximum increase in EWT for any particular branch relative to the reference case (e.g., a maximum allowable headway increase of 30% over the reference headway would be represented by 1.3). Similarly, β_O is the overall LOS factor that determines the maximum increase in EWT for branch passengers overall. Finally, B is the set of mn segments comprising only the branches of the system. The following two constraints allow control of LOS increases at both the branch and system level:

$$\sum_{ijkh} x_{ijkh}(\frac{h_{ijkh}}{2})\sigma_{ijmn}D_{mn} \leq \beta_I(\frac{h^0_{mn}}{2})D_{mn}\ \forall(mn) \in B \tag{3.13}$$

$$\sum_{ijkh,(m,n)\in B} x_{ijkh}(\frac{h_{ijkh}}{2})\sigma_{ijmn}D_{mn} \leq \sum_{ijkh,(m,n)\in B} \beta_O(\frac{h^0_{mn}}{2})D_{mn} \tag{3.14}$$

3.4 Qualitative Analysis

At this stage in the process, there are likely many optimization outputs ("solutions") for each scenario. The solutions generated by the formulation are very specific, down to the precise peak headway. However, it is best to take a step back and analyze the results at the trend level first. By identifying which *groups* of solutions tend to perform better or worse against different criteria, the overarching choices and trade-offs become clear. Moreover, the level-of-service differences between the top-performing specific solutions are likely small enough that subjective criteria, rather than the theoretical estimates of LOS metrics, will be the deciding factors. The main criteria considered are robustness, the inertia of existing practices, and miscellaneous operational considerations. However, this analysis should be tailored to the particular system, so the criteria described below are not exhaustive.

3.4.1 Robustness

Robustness of a solution against uncertainty and changing conditions is an important attribute. Robustness should be considered in two distinct and equally important ways. Firstly, the similarity of one close-to-optimal solution to other close-to-optimal solutions within a given scenario implies that flexibility is present. For example, if 80 of the top 100 solutions in a particular scenario always have two service patterns with a particular routing, it can be inferred that this routing is likely robust against unforeseen conditions within the scenario, as minor details can be adjusted (such as headways) while retaining the core aspects of operation that are harder to change (such as the through-running of trains from one branch to another). It is important, therefore, to weigh the relative difficulty of changing various aspects of the service plan. As an example, if there are many similar options to the service plan in question that involve small adjustments of headways, these are changes that are easier to act on and communicate to the public than many similar options that also require changing the turnaround location of a service.

The second variety of "robustness" is the performance of a group of solutions across many different scenarios. If, for example, a general type of service plan performs well in every single scenario, then it is likely a stronger candidate for adoption than a type of service plan that is clearly the best choice in 60% of scenarios, but has a considerably worse LOS than the optimal solution in the remaining 40%. In some cases, certain routings may even be impossible to accomplish under some levels of agency resources; adoption of these service plans carry the inherent risk that the agency may be forced to substantially cut or modify service as a result of changing conditions.

3.4.2 Inertia

If this method is being used to generate service plans in systems which are wholly or mostly already in existence, then it should be recognized that there is a certain degree of inertia present in the status quo. Riders may have decided their location of residence based on existing service patterns, or they may have developed other habits that are enabled by the existing configuration. To some degree, this is captured in existing origin-destination flow data, as riders' aversion to transfers will likely impact the OD flow. Therefore, the solutions presented by the optimization do (to a degree) already favor existing travel patterns rather than theoretical new ones. Nonetheless, one should be familiar enough with the existing situation to be able to identify when certain service proposals represent a cutback to someone's existing service. For example, turning a train around at a station upstream of where it normally turns is usually less desirable than turning a train downstream of where it normally turns, because those whose travel patterns are already established will have to modify their travel patterns to accommodate the former case (but not the latter case). With that said, such a solution may still be desirable if, for example, it contributes to substantially lower headways or some other significant benefit.

3.4.3 Other Costs

There are possibly other miscellaneous costs to various service patterns that the formulation does not take into consideration. For example, as mentioned earlier, some turnaround locations are less desirable than others. The use of some tracks or platforms may require manual activation of switches. In some cases, reactivation or refurbishment of inactive tracks and platforms may even be necessary for certain service patterns even if the infrastructure exists. It is up to the discretion of the analyst to include service patterns with these types of conditions among the choices available to the solver; while inclusion may reveal opportunities to improve level of service, it may also result in solutions where additional work would have to be undertaken for a marginal benefit.

There are also qualitative judgments to be made on certain combinations of service patterns. Beyond the capacity at turnaround stations, track capacity is not included in the formulation; very low headways may congest tracks, especially in the trunk section, and lead to increases in run times. Certain infrastructure features, such as flat junctions, may be particularly susceptible to the effects of track congestion. Mixing of consist lengths on the same segments may come with drawbacks associated with crowding, dwell times, and communication/signage. Again, the inclusion of service patterns that create the potential for operationally undesirable situations is at the discretion of the user; however, the possibility stands that significant benefits materialize from the inclusion of novel options. In other words, the solver's indifference to qualitative concerns must be balanced with human judgment, but this indifference also adds a potentially valuable perspective to the decision.

3.5 Solution Identification

At this point, the best groups of solutions have likely been identified, where each group of solutions is characterized by similar service patterns and operating strategies. From these groups of solutions, specific individual solutions may be highlighted that are representative of the service proposal under a given scenario. It is valuable to have a sense of how the scenarios might develop over time, as this can inform the selection of individual solutions.

For example, three scenarios have been developed, and they are labeled in the same order in which they are likely to occur over time (e.g., based on future demand levels): A, then B, then C. A group of solutions has been identified in the previous steps that is likely to perform well in scenarios A, B, and C. The time dimension of the planning leads to some additional considerations: for example, If Scenarios A and B are shorter-term than Scenario C, then weight should be given to eventually settling on a service pattern that works well under Scenario C even if there is a slight additional LOS cost in A or B. Additionally, raising headways or truncating a route increases public dissatisfaction with the service. Therefore, an effort should be made to evaluate if there is a low-cost way to progress from A to B and B to C without this occurring between scenarios. Neither of these considerations should override all other considerations about the level of service; however, there are often cases where differences between similar solutions are on the margin and these considerations become important factors.

At the end of this process, it is important to keep in mind that the solutions generated by the proposed approach are often based on estimates of the various inputs. Details, such as the individual headways, may need to change based on the real-world conditions of operation. Once a final set of service plans is developed, it is also prudent to validate assumptions on run times, vehicle hours, fleet requirements, and other aspects by testing individual service plans with more detailed models (e.g., simulation).

Chapter 4

Application: GLX Case Study Inputs

As described in the last chapter, the inputs to the optimization method include information about service patterns, run times, demand, fleet requirement, operator hours, and provided passenger capacity. While these data are commonly used in the context of service planning, special considerations must be made for the Green Line Extension as a case study: planning post-extension service requires combining available data about the existing portions of the Green Line with estimates of the Green Line Extension. This chapter discuses the data sources available for the construction of inputs and explains the methods used to generate them.

4.1 Service Patterns

A service pattern is defined as having a unique combination of the following four characteristics:

1. Terminus (most often where the train is dispatched)

2. Turnaround location

3. Consist length (Number of cars per train)

4. Headway

For this case study, mid-branch short-turning locations were excluded for several reasons, including the challenge of automating schedule generation and the low level-of-service provided to riders beyond the short-turning location. Therefore, combinations of the following locations were included (direction of trains that may turn denoted):

1. Boston College
2. Cleveland Circle
3. Government Center
4. Heath Street
5. Kenmore (both EB/WB)
6. Park Street (EB only)
7. Government Center (both EB/WB)
8. North Station (EB only)
9. Union Square
10. Medford/Tufts

For example, service pattern options that originate from Boston College, head eastbound, and turn at Kenmore, Park Street, Government Center, North Station, Union Square, and Medford/Tufts, respectively, are considered. From the east (geographically north), service patterns are included that would originate from Medford/Tufts and turn at Kenmore and Government Center, but not Boston College, as a Boston College-to-College-Avenue service has already been accounted for (and Boston College is a more favorable dispatching location due to its direct connection to a yard). In this way, all feasible combinations of the above stations are accounted for (including short services, such as Kenmore to Park Street).

Trains can be 1- or 2-cars long. 3-car trains are excluded as the operator costs are high (there must be one operator per car) and the longer trains necessitate longer headways for both operator hour and fleet requirement reasons — a direct contradiction to the goals of this analysis.

Finally, given that the period of interest is the afternoon peak, headway options are included in the range from 4 minutes to 7.8 minutes, with decimal minutes approximating the MBTA's integral minute headways as described in Chapter 3 (e.g., a headway of 5.5 minutes is an approximation of a 5 minute headway followed by a 6 minute headway, followed by a 5 minute headway, followed by a 6 minute headway, and so on). However, not every possible headway value between 4 and 7.8 is included as an option — only the lowest headway that results in a distinct fleet requirement. For example, if a service pattern has a cycle time of 120 minutes, a 6-minute headway with 1-car trains results in a fleet requirement of 20 cars: $\frac{120}{6} = 20$. However, raising this headway to 6.2 minutes would not save any cars despite the lower frequency: the integrality of the fleet requirement means that 20 cars are still necessary to service a route with a theoretical fractional fleet requirement of $\frac{120}{6.2} = 19.35$. Therefore, it is unnecessary to include a 6.2-minute headway in this case.

These service patterns — again, the unique combinations of terminus, turnaround location, consist length, and headway — form the basis for the rest of the inputs. Each service pattern has a run time, fleet requirement, etc. The specific service patterns included in the evaluation can be found in Appendix A.

4.2 Run Times

Each service pattern must be associated with a run time in order to calculate quantities such as the fleet requirement and the required operator hours. It is fairly easy to estimate existing run times on the Green Line, as Automatic Vehicle Location (AVL) data indicates to a sufficient degree of precision when a train departs from its terminal and then returns at the end of its cycle.

However, there are two instances in which the necessary data does not exist.

First, as the GLX has not yet been constructed, run times between GLX stations do not exist, and need to be estimated. Second, the current operation does not cover all possible routes in the service patterns identified, outside of some special moves during the off-peak (which are not representative of peak service conditions). For example, with the exception of a few limited trips per day and occasional unplanned diversions, all B Branch trains (those serving Boston College) turn at Park Street, so there is no data on travel times of trips that depart from Boston College and turn at Government Center (one stop beyond Park Street).

The former problem (GLX-specific run times) is addressed by using kinematic properties of the Green Line cars along with geometric characteristics of the proposed infrastructure to estimate run times over the GLX. A distribution of possible run times is generated by introducing variability to the results using data from similar segments on existing branches. The latter problem is addressed by simulation. A trip is simulated by drawing individual run times (real or estimated) from segments of the line that together make up the components of the entire trip pattern. For each service pattern, 10,000 run times were simulated to create a distribution of run times for scheduling purposes (i.e., to determine the 90th percentile run time).

This section explains how AVL data for existing Green Line trips are generated as well as the method of estimating run times on the GLX. Then, the run time simulation is described, which draws from both sources to create a set of cycle times.

4.2.1 Green Line AVL Data

AVL data from the Central Subway (including the subsurface portion of the E branch as far as Symphony), the Riverside/D branch, and the Lechmere viaduct are generated from records made when track circuits along the route are triggered. These are the same track circuits used to control the block signal system, so the sections of track with circuit-based AVL correspond to the sections of track that are signal-protected as well as the sections along which remote control of switches is possible [19]. Track circuits report both the time of activation as well as information about the passing vehicle(s) via overhead electronic readers, including the vehicle ID, trip

ID, and headsign indicator. The passing of trains over track circuits immediately preceding and following a station results in an estimate of the arrival and departure times of trains to or from that station.

However, a significant portion of the Green Line — specifically, the entirety of the surface B, C, and E branches — is dark territory, without signals nor the track circuitry required to operate them (while Green Line-specific traffic signals do exist on these branches, they are tied to the municipal street grid rather than to the MBTA system) [19]. However, because these sections of the line are above-ground, GPS-based AVL is available and installed on every Green Line vehicle. While a 60-second heartbeat AVL is reported by vehicles and available on these surface sections, geofence-based AVL is used in the thesis. All surface stations are surrounded by a static geofence, and a record is made (also including vehicle ID, trip ID, and headsign indicator) when a vehicle's GPS transponder is determined to have entered the geofence. A second record is made when a vehicle's GPS transponder leaves the geofence. In this way, an arrival and departure from each station can be estimated [14].

Vehicle ID information is static with respect to each particular vehicle and is thus reliable; however, trip IDs and headsign indicators are set by the operator, and human error as well as on-the-spot diversions inevitably lead to inconsistent records (e.g., a train incorrectly signed for Park Street recorded as continuing past Park Street rather than turning). Therefore, these analyses use station records and vehicle IDs rather than trip IDs or headsign indicators to determine trip origins and destinations. For example, if a Green Line consist is recorded as having departed from Boston College, turned at Park Street, then returned to Boston College in a reasonable timeframe, it is considered a Green Line B service — even if the headsign was for a C service or if the trip ID was one normally assigned to a yard move. One important caveat is that this lack of trip ID validation may result in unscheduled trips being counted the same as a scheduled trip. However, if one assumes that these unscheduled trips are a normal and expected feature of operations that will not change with the opening of the GLX, the estimates resulting from the inclusion of these trips are likely to be representative of real-world conditions.

4.2.2 Estimation of GLX Run Times

The GLX is currently only half-constructed, and tests under operational conditions have not yet begun. Therefore, run times for the GLX must be estimated from existing sources, such as construction plans, rolling stock, and run time data from other parts of the network.

A model based primarily on the physical characteristics of the route (such as the location of switches, grades, and curvature) and the technical specifications of the rolling stock is used, and is referred to as the "kinematic model." These two sources are used to estimate the stop-to-stop travel times. Existing dwell times and a dwell time model developed for use in a simulation tool [4] are used to estimate dwell times, along with estimated turnaround times supplied by the agency. Finally, because a distribution of run times will produce more conservative estimates for scheduling than a single expected run time, run time variability observed in the similarly-constructed D branch is applied to the GLX.

GLX Run Times

Basic kinematic relations between position, velocity, acceleration, and time were used to estimate the station-to-station run times on the GLX. With known quantities for the positions (locations of and distances between features, such as stations and switches), velocities (the cruising and "impacted" speed of a train), and accelerations (service acceleration and braking rates), the travel time may be found for all sections.

To find distances between features, satellite imagery from Google Earth was used to estimate the locations of the features based on visual identification or reference to nearby landmarks. For example, the cross streets at the ends of stations are listed on track schematics [23], and the GLX right-of-way is already in existence as the current commuter rail right-of-way, so the locations of the proposed ends of platforms are simple to identify. In cases where only one end of platform is near a cross-street, it is known that the standard platform length for the GLX is 225 feet long [12]. Crossovers and switches are assumed to be located immediately adjacent to stations based on the track schematic [23]. The distances between the features were found by tracing along the right-of-way with the built-in measurement tool.

For velocity, a simple model is assumed in which operators on the GLX travel at one of two primary speeds. One is a “cruising” speed in areas without significant infrastructure constraints. The other is an “impacted” speed over areas with serious grades, horizontal curves, or certain interlockings – namely the Red Bridge interlocking north of Lechmere station, where the two branches diverge; and the crossovers located just before each new terminus, which trains will have to use in order to turn around [23]. It is assumed that turnouts for yard leads are designed such that the yard lead is the diverging track; therefore, trains passing straight through will not have to reduce their speed from the cruising speed. The “impacted” speed is chosen to be 10 mph. It is assumed the train must decelerate to the impacted speed *before* entering the segment with the slowing feature, and accelerate back to cruising speed *after* exiting the segment.

To ascertain the likely cruising speed, the distribution of average speeds of AM peak-direction trains on the longest stop-to-stop pairs on the D branch – Reservoir to Chestnut Hill and Chestnut Hill to Newton Centre, each slightly longer than a mile – was computed. The D branch was chosen for comparison with the GLX as it shares many physical characteristics with the new branches – among them grade separation from street traffic, on-board fare payment, and relatively straight sections. This average speed was computed by dividing the distance between each stop pair by the run time between each stop pair (the distribution of speeds for the Chestnut Hill to Newton Centre segment is shown in Figure 4-1). Although the GLX is being built to a 40-mph operating speed, a more conservative estimate of a 30 mph cruising speed was used. It should be noted that this distribution includes time spent accelerating and decelerating from stops, so actual cruising speeds are expected to be slightly greater than those shown in Figure 4-1. No maintenance-related speed restrictions were present on either of the segments at the time that the trips used to estimate this distribution were operated.

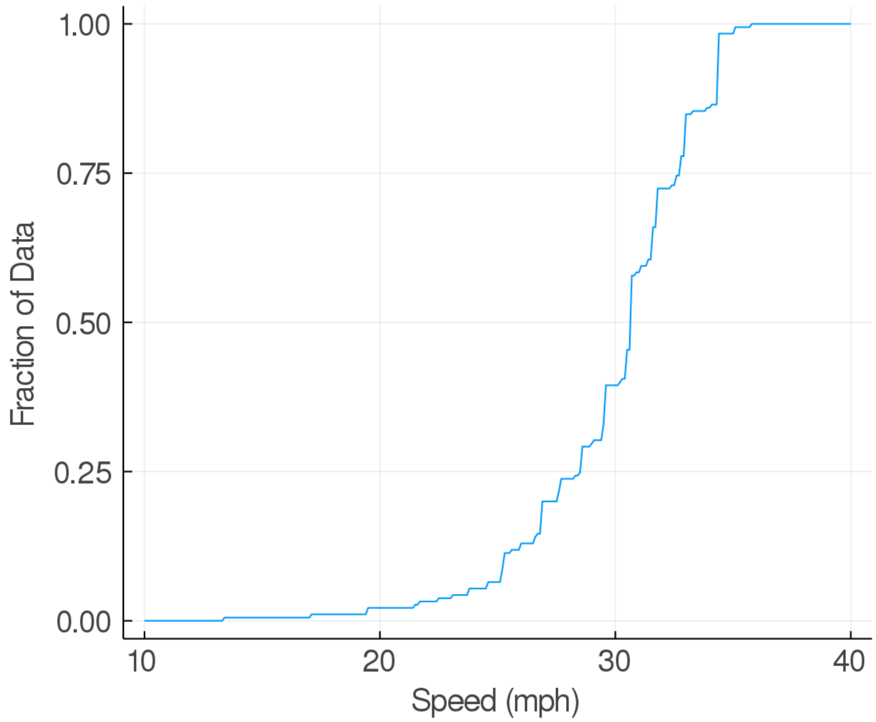

Figure 4-1: Cumulative Distribution of AM Peak Inbound Average Stop-to-Stop Speeds on the D Branch Between Chestnut Hill and Newton Centre

Finally, Green Line AVL data is not resolute enough to construct an accurate model of acceleration characteristics, so a factsheet of the Type 7 rolling stock created by Kinki Sharyo (the manufacturer) was used to inform the analysis. This factsheet lists the acceleration as 1.25 mph-per-second and deceleration at 1.56 mph-per-second.

Finally, the stop-to-stop travel times are found by the following steps, which apply basic kinematic principles to the travel time problem:

1. Assuming constant acceleration/deceleration a, the distance d it takes to accelerate/decelerate from one velocity v_1 to another velocity v_2 is given by:

$$d = \frac{v_2^2 - v_1^2}{2a} \tag{4.1}$$

2. Therefore, subtraction of the "acceleration distance" and the "deceleration dis-

tance" (both found by Equation 4.1) from the length of a larger travel segment gives the distance over which the train will be proceeding at a constant speed.

3. The travel time t for a train traversing a given distance d at a constant speed v is given by:

$$t = \frac{d}{v} \tag{4.2}$$

4. The travel time t for a train accelerating/decelerating from one velocity v_1 to another velocity v_2 is given by:

$$t = \frac{v_2 - v_1}{a} \tag{4.3}$$

5. Addition of the travel times over every acceleration segment (Equation 4.3), constant velocity segment (Equation 4.2), and deceleration segment (Equation 4.3) within the overall length of the segment between the two stops gives the total stop-to-stop travel time.

More generally, the travel time may be expressed as the integral of the *velocity profile* over the stop-to-stop segment. The velocity profile shows the expected speed of the train as a function of the distance of a train from an origin point (usually set at one end of the segment). An example profile for Lechmere to Union Square may be seen in Figure 4-2, which also labels the infrastructure features encountered that affect the maximum speed.

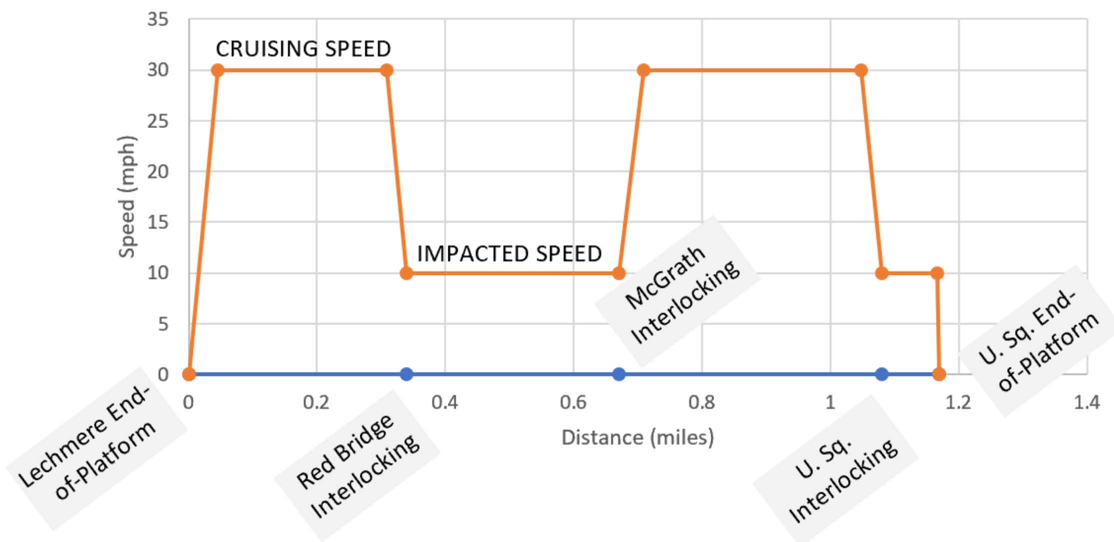

Figure 4-2: Estimated Speed Profile Between Lechmere and Union Square

It should be noted that the rates of acceleration and deceleration used in the kinematic model may not hold true across the different types of rolling stock, or across individual operators. However, a sensitivity analysis performed on the acceleration values found little change in the estimated total run time. The velocity profile in Figure 4-2 also shows that the distance spent accelerating and decelerating is relatively minor compared to the total distance traveled. The acceleration rates would have a greater impact if the stop spacing were shorter.

GLX Dwell Times

Over time, dwell times on the GLX are likely to vary for two reasons: rising demand (particularly in the short-term), and the implementation of Automated Fare Collection (AFC) 1.5 and eventually AFC 2.0. As discussed in Chapter 2, AFC 1.5 will place MBTA staff on GLX platforms to scan fare media prior to train boarding. Eventually, AFC 2.0 will automate this system and allow riders to validate their fare media at train doors and on personal devices. The expectation is that, even if the number of boarding passengers rise, the improvements to the boarding process offered by the new AFC roll-out will keep dwell times stable [17].

For this reason, a single dwell time value was estimated for the GLX stations, both for the recovering-demand, traditional-boarding scenarios and the high-demand, AFC 1.5/2.0-boarding scenarios. Two reference points were used: existing dwell times on the branches, and a dwell time model developed for a simulation of the Green Line [4].

Figure 4-3 shows the dwell times at stations on the eastbound D branch in the PM Peak based on AVL data. These dwell times are representative of ones recorded on the other three surface branches (on all four branches, payment is made on-board). An estimate based on these data is that dwell times would be one minute at each station.

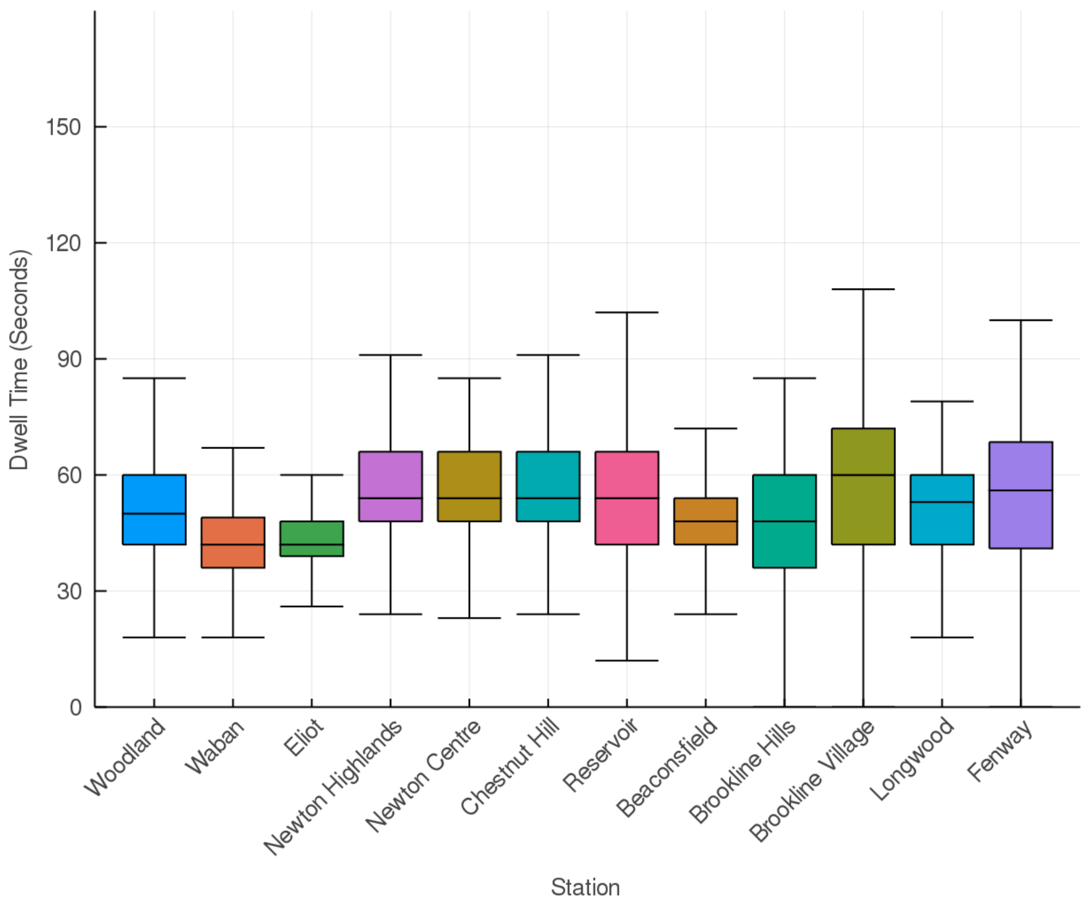

Figure 4-3: Eastbound PM Peak Dwell Times on the D Branch

The dwell time model developed by [4] predicts similar dwell times. This model splits boarding passengers into different types of fare media payment (card, ticket, cash, and card with a cash top-up) and incorporates a distinct per-person boarding time for each group (based on actual observation). The effect of crowding on the train is also taken into consideration. Assuming consistent headways, a deterministic arrival of passengers distributed evenly throughout the GLX stations, and one-way flow towards downtown, the average dwell time at a GLX station in the inbound direction would be 65 seconds, according to the model, which is similar to the estimate from existing AVL.

However, these two conservative estimates do not take into account the changes in demand or fare collection expected to affect the GLX. The magnitude of the reduction in dwell times is hard to predict; however, the impact of the AFC programs is likely to be large, as the goal is to transition away from cash payments and on-board top-ups, the most time-consuming methods of fare payment. Therefore, it is estimated that dwell times at stations and in all scenarios will be 30 seconds on the GLX, either by reason of low demand or the beginning of AFC 1.5.

Table 4.1 shows the run time and dwell time components that make up the total run time estimates for GLX trips. A four-minute turnaround time is estimated at both Union Square and Medford/Tufts [16]. Dwell times at Lechmere (the boundary station between the GLX and the existing network) are not included; these will be added during the simulation.

Table 4.1: GLX Run Time Estimates

Branch	Portion of Trip	Time (min)
Union Square	Lechmere to Union Square stop-to-stop run time	4.2
	Turnaround time at Union Square	4
	Union Square to Lechmere stop-to-stop run time	4
	Union Square Branch Total Run Time:	**12.2**
Medford	Lechmere to Medford/Tufts total stop-to-stop run times	6.2
	Intermediate stop dwell times	4
	Turnaround time at Medford/Tufts	4
	Medford/Tufts to Lechmere total stop-to-stop run times	6.2
	Medford Branch Total Run Time:	**20.4**

GLX Run Time Variability

The stop-to-stop travel times and the dwell times calculated above are enough to establish a single estimate of the total run time. However, for scheduling and simulation purposes, it is useful to have a distribution of run times available so that more conservative benchmarks can be established.

A regression model was constructed to estimate the variance of the GLX run time. Using run times from the Green Line's D Branch, a relationship was found between the average run time and the logarithm of the variance of the run time, with an $R^2 = 0.42$. Although this is not a perfect correlation, the variability is nonetheless helpful for establishing a distribution, and the conservative assumptions made in the kinematic model means that the resulting distribution of run times is likely sufficient for the purposes of this analysis. The relationship between an estimated average stop-to-stop run time r and the variance v is modeled as:

$$\log(v) = 0.950r - 2.438 \tag{4.4}$$

Table 4.2 shows the resulting standard deviation of the total GLX run times from the application of Equation 4.4 to each stop-to-stop run time. The resulting average and standard deviation of GLX run times are used in the simulations described in the following subsection. In this analysis, variance is only applied to the run times. A more robust study of the projected GLX run times could also apply variance to the dwell times.

Table 4.2: GLX Stop-to-Stop Run Times

	Estimated Average Run Time (min)	Variance	Std Dev (min)
Lechmere to Union Sq	4.20	4.72	
Union Sq to Lechmere	4.00	3.90	
TOTAL (Union Sq Branch)	**8.2**	**8.63**	**2.94**
Lechmere to East Somerville	1.61	0.40	
East Somerville to Gilman Sq	1.29	0.30	
Gilman Sq to Magoun Sq	1.13	0.26	
Magoun Sq to Ball Sq	1.01	0.23	
Ball Sq to Medford/Tufts	1.14	0.26	
Medford/Tufts to Ball Sq	1.14	0.26	
Ball Sq to Magoun Sq	1.01	0.23	
Magoun Sq to Gilman Sq	1.13	0.26	
Gilman Sq to East Somerville	1.29	0.30	
East Somerville to Lechmere	1.61	0.40	
TOTAL (Medford Branch)	**12.36**	**2.89**	**1.70**

4.2.3 Run Time Simulation

As mentioned earlier, simulation allows for the run time of trips not previously captured by regular trips on AVL to be constructed from portions of existing trips. For example, nearly all D branch (Riverside) trains turn at Government Center, but the simulation approach can be used to find the run time of a theoretical trip of a D branch train beyond Government Center, past Lechmere, and onto the GLX's Union Square branch before turning around and returning to Riverside:

1. A draw from the distribution of run times from Riverside to Government Center

(from existing D service AVL data)

2. A 1-minute dwell time at Government Center
3. A draw from the distribution of run times from Government Center to Lechmere (from existing E service AVL data)
4. A 1-minute dwell time at Lechmere
5. A draw from the distribution of run times from Lechmere to Union Square (estimated)
6. A 4-minute turnaround time at Union Square (estimated by MBTA schedulers [16])
7. A draw from the distribution of run times from Union Square to Lechmere (estimated)
8. A 1-minute dwell time at Lechmere
9. A draw from the distribution of run times from Lechmere to Government Center (from existing E service AVL data)
10. A 1-minute dwell time at Government Center
11. A draw from the distribution of run times from Government Center to Riverside (from existing D service AVL data)
12. A 5-minute turnaround time at Riverside (supplied by MBTA schedulers)

By summing these quantities, it is assumed that the distributions of run times between these segments are independent, and that run times on the individual portions of these lines will not fluctuate due to the addition or subtraction of service relative to current conditions. Although these are not well-substantiated assumptions, the eventual end products — cycle times based on the 90th percentile (or higher) run times — should still be able to serve as sufficient guide to service planning.

The simulation process is also a useful tool to address two anticipated changes in run times. Firstly, many of the speed restrictions in place in Fall of 2019 and Winter of 2020 — the two primary run time analysis periods — have been resolved due to an accelerated maintenance schedule in 2020. In particular, entire sections of all four branches have seen replacements of ties, track, catenary, and other infrastructure. Fortunately, despite the difficulty of assessing run time impacts during the pandemic, a record of all of the speed restrictions as well as their estimated impacts on run times has been kept and the assumption has been made that run times will decrease by the amount logged on this record [15].

Secondly, four stops are being consolidated into two on the B branch: Boston University West and Saint Paul Street are being consolidated into one station, named Amory Street; and Pleasant Street and Babcock Street are being consolidated into a new Babcock Street station. Assuming that total passenger boardings and alightings will not be significantly affected by these consolidations, the dwell time along this segment should not substantially change (in the short term) due to the fact that most of the dwell time results from the on-board fare payment. However, less time will be spent accelerating and decelerating on this segment, and some time savings would be realized due to the longer cruising times.

Conveniently, the dwell time as it is measured by AVL data includes not only the time spent boarding and alighting passengers at stations, but also a significant portion of the time spent accelerating and decelerating. This is due to the geofencing mentioned earlier in the chapter, which includes a generous portion of track to accommodate GPS imprecision and variable operator stopping locations. Therefore, it is assumed that roughly 50% of the AVL dwell time captures acceleration and deceleration (as well as other fixed time penalties, such as opening/closing doors), whereas the other 50% is the alighting and boarding of passengers.

It is assumed that 50% of the total dwell time is representative of acceleration and deceleration. Therefore, with two of the four acceleration/decelerations eliminated with the stop consolidation, 75% of the dwell time before consolidation will reflect the dwell time after consolidation. Table 4.3 shows the median AVL dwell times in

Fall 2019 (October 28th — November 22nd) for weekday trips arriving at any of the four stations between 17:00 and 17:59. Overall, the median trip saves 53 seconds, and the 90th percentile trip saves 66 seconds.

Table 4.3: Fall 2019 PM Dwell Times at Stations Due for Consolidation

Stop Name	Direction	Median Dwell Time
BU West	EB	48
	WB	54
Saint Paul Street	EB	48
	WB	54
Pleasant Street	EB	54
	WB	54
Babcock Street	EB	60
	WB	54

4.2.4 Run Time Scenarios

During the COVID-19 pandemic, run times have decreased significantly due to lower passenger volumes. As mentioned previously, demand is not expected to return in full prior to the opening of the GLX, so some test scenarios are designed to model "COVID-19 adjusted" levels of demand, whereas others anticipate long-term conditions in which demand returns to what was originally forecast for the GLX. Existing run times are likely a good estimate of the latter condition, but shorter run times must be found to represent the former condition.

The effect of the pandemic on run times can be seen by comparing dwell times on surface branches — where fares are collected at the front door — prior to and following the pandemic. Figure 4-4 shows that both median and 90th percentile dwell times on the D branch have declined substantially between Fall 2019 and Fall 2020, indicating that lessened demand is responsible in part for the lower run times. The overall effect on run times can be seen in Figure 4-5, which shows that 90th percentile run times on the B Branch (the branch with the least shutdowns or service changes over the analysis period) have remained at a level substantially lower than pre-pandemic levels well into the pandemic.

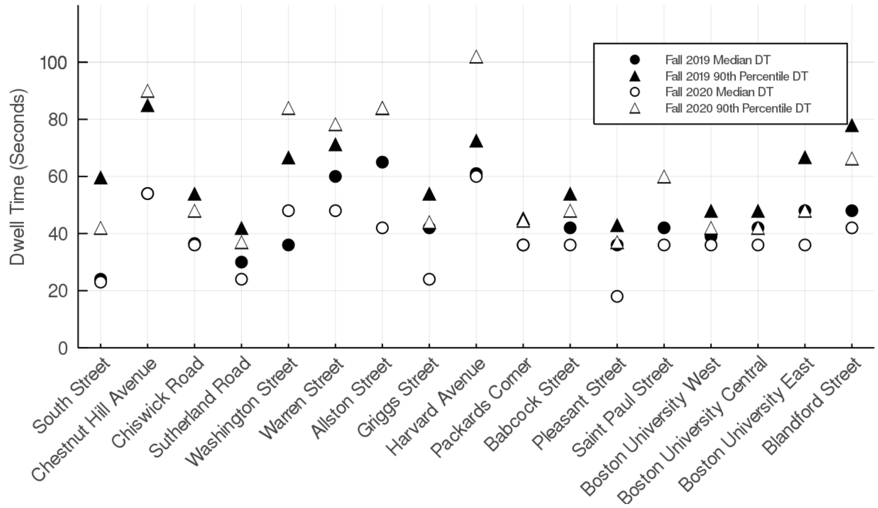

Figure 4-4: Dwell Time Comparison on Eastbound D Branch for Station Departures Between 7:00 AM and 7:59 AM

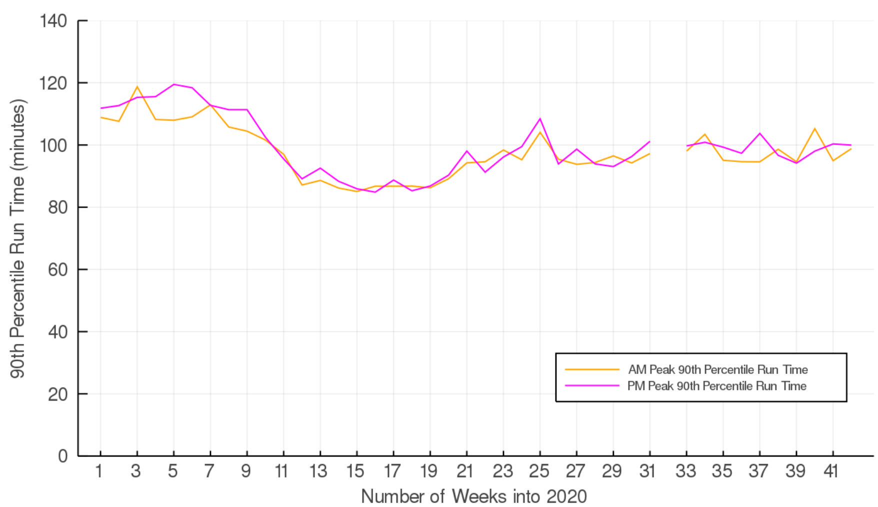

Figure 4-5: Green Line B Peak-Period Run Times Over Time

Figure 4-6 demonstrates that a relationship between gate taps and 90th percentile run times appears to exist. Each point represents one weekday's PM peak period, comparing the 90th percentile B branch cycle time observed during the day's peak period with the number of gate taps in the Central Subway during that same day's peak period. The red and blue clusters are days during the COVID-19 shutdown and gradual reopening, respectively; whereas the green and brown clusters are days taken from Fall 2019 and Winter 2020, respectively. It is assumed that demand will have returned to some point roughly halfway in-between the clusters on the right and the left by the time of GLX opening. Although there are not many points in that area, for the B branch, it can be assumed that 90th percentile run times with this demand level could fall anywhere between 95 and 115 minutes.

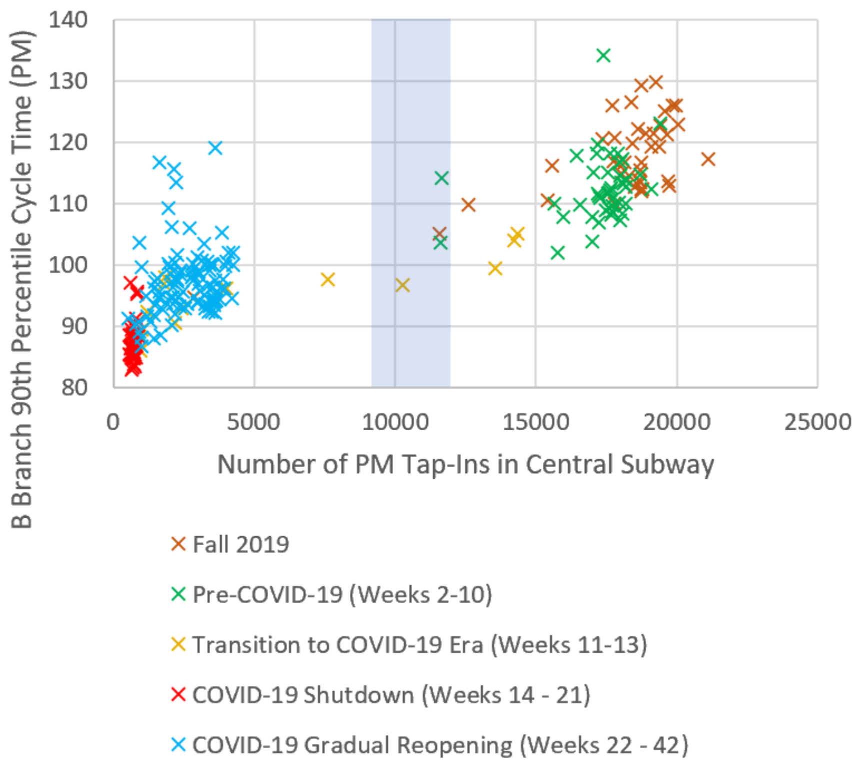

Figure 4-6: Run Time vs. Gate Taps (Estimated GLX Opening Demand Range Shaded)

However, due to the low number of points in that range of the plot, a run time simulation based on those points would draw from very few records. It was found experimentally that using Winter 2020 run times as simulation inputs, then taking the 75th percentile (rather than the 90th percentile) of simulated run time outputs results in run times that are similar in comparison to those seen in Figure 4-6 in the shaded area (e.g., the 75th percentile simulated B branch run time using Winter 2020 data is 103 minutes), as well as for similar plots of the C and D branches. These

Winter 2020 inputs are therefore used to generate the COVID-19 adjusted demand run time estimates. Full-demand scenarios are expected to cause a return to Fall 2019 run times (scheduled for the 90th percentile).

4.2.5 Cycle Times

Table 4.4 shows the cycle times generated for the COVID-19-affected demand scenarios. Table 4.5 shows the cycle times generated for the originally forecast (i.e., high demand) scenarios. The results in both tables were obtained by the simulation method detailed above.

Table 4.4: Cycle Times for COVID-19 Adjusted Demand Scenarios

Pattern Name	Full Cycle Time (min)
Boston College to Park Street	103.1
Boston College to Government Center	111.6
Boston College to North Station	123.7
Boston College to Union Square	145.2
Boston College to Medford/Tufts	153.2
Cleveland Circle to Kenmore	52.7
Cleveland Circle to Park Street	81.0
Cleveland Circle to Government Center	89.6
Cleveland Circle to North Station	102.1
Cleveland Circle to Union Square	123.4
Cleveland Circle to Medford/Tufts	131.4
Riverside to Kenmore	78.6
Riverside to Park Street	106.6
Riverside to Government Center	115.2
Riverside to North Station	127.8
Riverside to Union Square	149.1
Riverside to Medford/Tufts	157.1
Heath Street to Park Street	67.1
Heath Street to Government Center	74.9
Heath Street to North Station	86.6
Heath Street to Union Square	107.5
Heath Street to Medford/Tufts	115.2
Kenmore to Park Street	36.8
Kenmore to Government Center	45.5
Kenmore to North Station	58.0
Union Square to Kenmore	79.6
Medford/Tufts to Kenmore	87.1
Union Square to Government Center	39.2
Medford/Tufts to Government Center	46.6

Table 4.5: Cycle Times for Original Forecast Demand Scenarios

Pattern Name	Full Cycle Time (min)
Boston College to Park Street	109.2
Boston College to Government Center	117.6
Boston College to North Station	132.1
Boston College to Union Square	153.7
Boston College to Medford/Tufts	161.8
Cleveland Circle to Kenmore	54.2
Cleveland Circle to Park Street	84.7
Cleveland Circle to Government Center	92.8
Cleveland Circle to North Station	107.8
Cleveland Circle to Union Square	129.5
Cleveland Circle to Medford/Tufts	137.1
Riverside to Kenmore	82.9
Riverside to Park Street	112.9
Riverside to Government Center	121.1
Riverside to North Station	135.5
Riverside to Union Square	157.3
Riverside to Medford/Tufts	164.7
Heath Street to Park Street	74.4
Heath Street to Government Center	82.2
Heath Street to North Station	95.4
Heath Street to Union Square	118.0
Heath Street to Medford/Tufts	125.4
Kenmore to Park Street	40.5
Kenmore to Government Center	49.4
Kenmore to North Station	64.8
Union Square to Kenmore	86.2
Medford/Tufts to Kenmore	93.7
Union Square to Government Center	43.8
Medford/Tufts to Government Center	51.1

4.3 Fleet Requirement

Every service pattern includes a fleet requirement, which is the (integral) number of cars required to run the service pattern. For a service pattern with terminus i, turnaround location j, number of cars k, headway h, and cycle time C_{ijh}, the fleet requirement f_{ijkh} is given by:

$$f_{ijkh} = k \left\lceil \frac{C_{ijh}}{h} \right\rceil \tag{4.5}$$

Where the $\lceil \cdot \rceil$ operator indicates rounding up to the nearest integer number of cars.

4.4 Operator Hours

Two types of inputs are with respect to operator hours: the operator hours required to run each service pattern, and the maximum available number of operator hours. The latter quantity is a matter of scenario design (and ultimately agency policy), but the methods to predict operator hours for service patterns are not necessarily straightforward. This section discusses the assumptions developed to efficiently estimate the operator hours required for the various service patterns considered for the Green Line.

4.4.1 Operator Hours for Service Patterns

In a setting in which only a small number of operating schemes is being evaluated, it would be possible to schedule operators with a scheduling software such as HASTUS, and obtain accurate operator hour requirements. Unfortunately, not only are there hundreds of possible service patterns to evaluate, but operator hours include considerations not captured by the service pattern descriptions within this analysis: the off-peak headways and run times, the nature of ramp-up and ramp-down periods around the peaks, extra time required for operators to begin and end shifts in the same location, and other factors. Therefore, the approach used here to estimate operator hours for each service plan makes assumptions on the nature of these non-evaluated portions of the service day.

The calculations made in this analysis are based on Fall 2020 Green Line schedules. Although these Fall 2020 schedules were developed by the MBTA after ridership and agency resources had decreased due to the COVID-19 pandemic, most aspects of the schedule remain the same relative to pre-pandemic schedules. For example, scheduled cycle times do not reflect the decrease in run times due to the pandemic, and the schedules of the two most frequent branches (accounting for over 58% of systemwide operator hours) preserve the same headways as were scheduled in prior ratings throughout the day and during both peak periods. Calculations using estimates of prior ratings' characteristics do not suggest that the differences between Fall 2020 and pre-pandemic schedules would be high enough to significantly affect the following calculations.

Several critical assumptions are made to simplify the estimation of operator hours:

1. The length of the PM peak period (defined as the length of time in the afternoon/evening when trains are dispatched at a minimum headway) will remain consistent from Fall 2020 to future schedules for each branch.

2. The ratio of *PM peak vehicle hours* to *daily vehicle hours*, represented by the variable λ_d, will remain the same from the Fall 2020 schedule to future schedules.

3. The ratio of *daily operator hours* to *daily vehicle hours*, represented by the variable λ_v, will remain the same from the Fall 2020 schedule to future schedules.

The daily required operator hours η are then equivalent to the number of vehicle hours required during the peak, multiplied by λ_d to convert to daily vehicle hours, multiplied by λ_v to convert to daily operator hours. The number of vehicle hours required during the peak is the product of the cycle time C, the number of trips during the peak period $\frac{T}{h}$, and the length of the consist k:

$$\eta_{ijkh} = C_{ijh}\frac{T_{ij}}{h}k\lambda_d\lambda_v \tag{4.6}$$

Where η is the daily required operator hours.

Figure 4-7 shows the vehicle blocks scheduled for the D branch in Fall 2020 as an example. The blocks are arranged by number (1 to 54) on the right axis. Meanwhile, the left axis measures several relevant indicators of the peak period: the hourly frequency (in red), the total number of cars in service (in purple), and the scheduled cycle time (in blue). The length of the peak period defined in Equation 4.6 is assumed to be equivalent to the length of the peak period seen in the red frequency line, as this represents the period in which trains are dispatched at the highest rate.

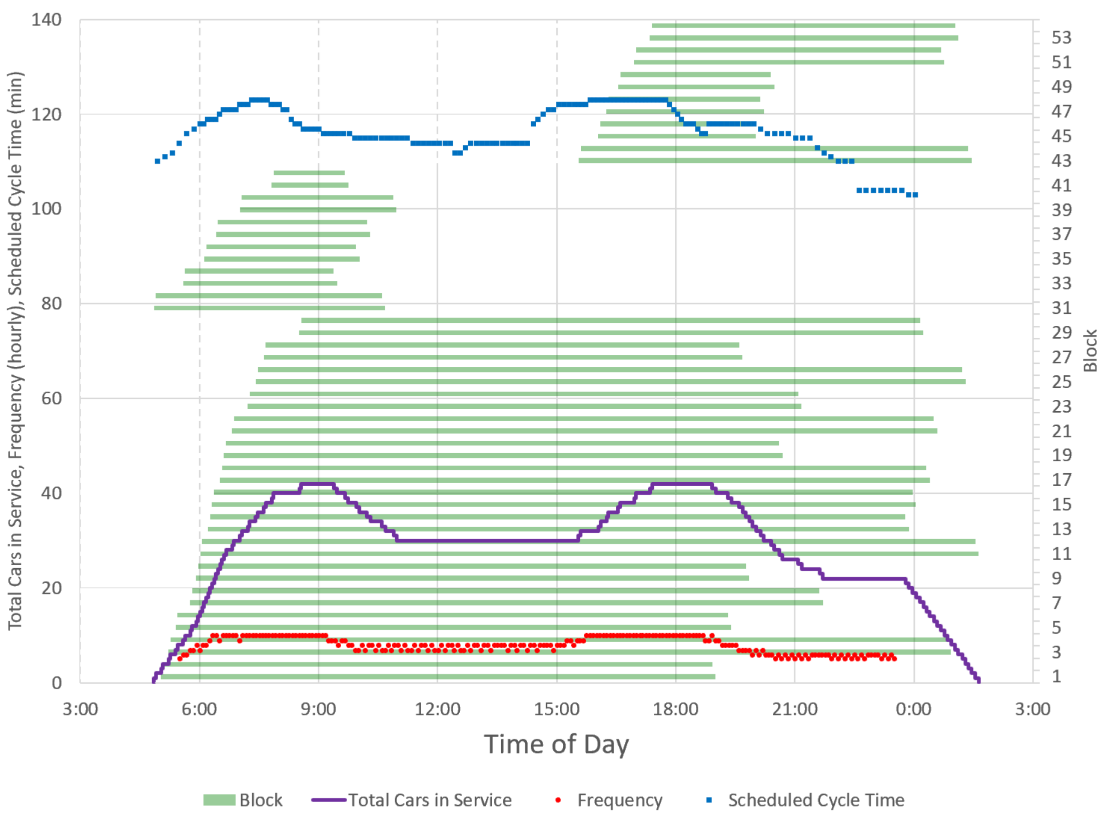

Figure 4-7: Fall 2020 D Branch Block Diagram

The scheduling calculations in the formulation require a single cycle time assumption. Therefore, the peak cycle times are used, which assumes that every train dispatched during the peak period requires the maximum cycle time. The product of the cycle time, the length of the peak period divided by the headway (to obtain the number of trips in the peak period), and the consist length (here, always 2 cars) is thus the estimate of vehicle hours used during one peak period.

Table 4.6 shows the estimation of λ_d from these data. The relevant quantities from the PM peak operations are highlighted in yellow: values in the "Total Vehicle

Hours" column are equivalent to the area below the purple line on Figure 4-7. Because the values of λ_d have only a range from 0.19 to 0.26, it is assumed, for estimation purposes, that all proposed service patterns have a λ_d value of 0.23. 0.23 is also the λ_d that is obtained when comparing the sum of peak vehicle hours across all patterns to the sum of daily vehicle hours across all patterns.

Table 4.6 also shows the total vehicle hours scheduled across all lines, which is 2,108 hours.

The Fall 2020 schedule assigned a total of 2,386 operator hours to the Green Line. λ_v is the ratio between the operator hours and the vehicle hours, or $\frac{2386}{2108}$, a value of 1.13. As stated before, it is assumed that λ_v and λ_d do not change when designing new schedules. In reality, adjustments to the length of the peak period, the "peakiness" of schedules (i.e., the difference between peak headways and off-peak headways), and other planning decisions may affect these values. Therefore, although not done in this thesis, a useful follow-up step would be the use of a scheduling program (e.g., HASTUS) to verify at least a small number of service plan outputs from the this approach to ensure that the scheduling assumptions made here are reasonable for the types of plans generated.

Table 4.6: Construction of Peak-Daily Ratio

Service	Evening Peak Duration (hours)	Evening Peak Headway (min)	Evening Peak Cycle Time (min)	Evening Peak Vehicle Hours	Total Vehicle Hours	Peak-Daily Ratio: λ_d
B	3:00	6	117	121	627	0.19
C	4:08	8	113	117	449	0.26
D	3:30	6	123	144	602	0.24
E	4:00	8	100	100	430	0.23
Sum				481	2108	0.23

4.5 Demand Forecast

Origin-destination flows are necessary to determine the impacts of changing service patterns on riders, particularly for the purposes of assessing transfer penalties. For passenger flows between existing stations, this information can be obtained from AFC transactions: the MBTA maintains origin-destination (OD) flows in a number of aggregate formats from their implementation of ODX, a model that estimates OD flows in system with AFC records (both open and closed, [5]). However, flows when the GLX is operational must be forecast. While several approaches have been proposed in the literature (e.g., [22]), the approach below combines boarding and alighting predictions from Greater Boston's Central Transportation Planning Staff (CTPS), whose regional travel demand model has been used to predict GLX ridership for past assessments, and passenger flows from the ODX model.

The end goal of this process is a single origin-destination matrix of Green Line riders with additional GLX stops included in the opening year of the GLX (i.e., 2022). To that end, it is helpful to categorize OD flows in one of four groups:

1. Riders who board at an existing (non-GLX) station and alight at an existing (non-GLX) station

2. Riders who board at an existing (non-GLX) station and alight at a GLX station

3. Riders who board at a GLX station and alight at an existing (non-GLX) station

4. Riders who board at a GLX station and alight at a GLX station (including trips between Lechmere and a GLX station)

The OD flows in Group 1 are found from existing ODX data (no factor was applied, as the existing ODX data are from 2017, and the forecast is for 2022). OD flows in Group 4 are found by applying iterative proportional fitting (IPF) to a portion of the CTPS GLX boarding and alighting estimates. Group 2 and Group 3 flows are found by assuming that travel patterns to/from the GLX are proportioned similarly to travel patterns to/from Lechmere (the station forming the border between the existing Green Line and the GLX). This section describes in-depth the procedure used to determine these flows.

4.5.1 ODX

The MBTA's implementation of ODX allows for AFC-captured boardings to be converted into flows by ways of inference and scaling. Many MBTA riders use a CharlieCard, a refillable fare medium which allows for individual stages (trips or portions of trips that may be made without transfers) and journeys (trips that may be made by transferring) to be assembled into a full itinerary over the course of a day. Tap-ins made later in the day are used to infer the locations of alightings from earlier stages and journeys, and vice-versa. Trips that cannot be inferred due to the use of other fare media (i.e., cash) or because there is only one trip in the day are accounted for by scaling up the distribution of alightings/destinations from inferred trips for all uninferred trips so that the total number of fully-inferred trips matches the sum of boardings recorded for each stop.

The inferred OD trips are aggregated through the course of the processing over predefined time periods. The latest available data that has been validated by the MBTA is from Fall 2017, which is the source of all existing OD data used in this analysis. Several levels of OD data are available, such as itinerary, journey, and stage. For the purposes of analyzing OD flows on the Green Line, stage data is most appropriate. However, at the MBTA, this is only available at the daily level, so average weekday boardings are used, and a factor is applied at the end (discussed further in the chapter) to scale daily flows to PM peak flows.

4.5.2 CTPS Forecasts

The CTPS produced a study in 2007 to estimate the impact of the GLX on travel patterns throughout Greater Boston. At this time, it was assumed that the GLX could open as early as 2015. Included in the study were forecasts for daily boarding and alighting estimates in the years 2015 and 2030 for all 6 new-build GLX stations, the reconstructed Lechmere station, North Station, and several stations in the vicinity that currently serve potential GLX riders by way of feeder bus routes — namely Wellington and Sullivan Square on the Orange Line, and Alewife, Davis, and Porter on the Red Line. While unpredictable ridership trends make individual stations hard to track, the total number of riders across all of these stations in the 2015 estimate provides a reasonably accurate prediction of what the ridership actually has been at those stations.

Table 4.7 shows the predicted boardings in 2015 and 2030 at GLX stations (including the reconstructed Lechmere station) and select stations from the CTPS forecast. The ratios between the two boarding totals are similar in both forecast years. It is assumed that the 2015 ratio of 0.432 can be used with the Fall 2017 ODX data for the existing stations highlighted above to estimate total GLX boardings for a typical day of operations (i.e., when ridership is no longer affected by COVID-19). Then, boardings at individual GLX stops can be proportioned out according to the original CTPS estimates. This process can be repeated with alightings, resulting in a set of daily boardings and alightings for the GLX stations.

Table 4.7: CTPS Boarding Totals and GLX-Existing Boarding Ratio

Year	GLX Daily Boardings Total	Select Stations Daily Boardings Total	Ratio
2015	22,350	51,790	0.432
2030	24,280	58,120	0.418

It should be noted at this point that there are now two sets of data for Lechmere: the existing data from Fall 2017, and the CTPS boarding and alighting estimates (scaled to 2017 ridership as described above). The CTPS boarding and alighting estimates can be used as the source of ridership at Lechmere, because they take into account changes in bus ridership that would not be captured within existing ODX. In addition, although the Lechmere CTPS numbers are higher than that of the ODX, there has been a large growth in the neighborhood surrounding Lechmere since Fall 2017, with several new high-rise apartments directly in the station vicinity (and located closer to the new Lechmere station than the old one), so the CTPS estimates may be a more accurate predictor of post-pandemic demand.

4.5.3 Combining ODX and CTPS

As explained earlier, the OD flows can be broken down into Groups 1, 2, 3, and 4. The flows for Group 1 (existing Green Line station to existing Green Line station) can be approximated from available ODX data. For Groups 2 and 3 (existing Green Line station to GLX station, or vice versa), flows in and out of Lechmere can be used to inform the distribution of flows to existing stations (Lechmere previously served as a "gateway" to the neighborhoods to be served by the GLX, via bus connections). Finally, iterative proportional fitting (IPF) can be used to determine the flows for Group 4.

Group 1

In the forecasted OD matrix, it is assumed that a daily Group 1 flow remains the same as the daily OD flow present in the ODX data for Fall 2017. For example, there are an average of 251 daily riders from Park Street to North Station in the Fall 2017 ODX. Because neither station is part of the GLX, the forecasted daily OD flow between these stations (assuming no adjustment is needed for the forecast year) is also 251 riders.

Group 2 and Group 3

In order to forecast trips to and from the GLX, it must be determined what proportion of the CTPS boardings and alightings represent trips that continue past Lechmere and thus originate at or are destined for existing stations.

Table 4.8 shows the proportion of *non-intra-branch-trips* for the four western (existing) branches of the Green Line. A *non-intra-branch-trip* is a trip that does not end on the same geographic branch that it originated from. For example, a trip from Boston College to Boston University Central is an intra-branch trip, because both stops are located on the B branch. A trip from Boston College to Park Street is a *non*-intra-branch trip, because Park Street is in the Central Subway (even though it may be reached on a B service).

The proportions in Table 4.8 show that, for all four lines, roughly half of trips are non-intra-branch. Therefore, it is assumed that half of GLX trips are similarly non-intra-branch trips, and therefore half of the (scaled) CTPS boardings and alightings are attributed to riders who continue past Lechmere, forming Group 2 (GLX alightings) and Group 3 (GLX boardings).

Table 4.8: Comparison of Intra-Branch Trips and Non-Intra-Branch Trips from Fall 2017 ODX

	B	C	D	E
Average daily trips boarding on branch	15427	8187	12853	9667
Average daily intra-branch trips	8826	3573	6348	4906
Average daily non-intra-branch trips	6601	4614	6505	4761
Proportion of non-intra-branch trips	0.43	0.56	0.51	0.49

These Group 2 and Group 3 riders are proportioned according to travel patterns at Lechmere. For example, if, according to the Fall 2017 data, 10% of riders boarding at Lechmere alight at Boylston, it is also assumed that 10% of riders boarding at Union Square alight at Boylston, 10% of riders boarding at East Somerville alight at Boylston, etc. This is done to reflect the fact that most neighborhoods that will be served by the GLX are currently served by the 69, 80, 87, and 88 bus routes — feeders that take riders to and from the former terminus of the Green Line at Lechmere.

It should be noted that the GLX branches are shorter than the western branches; as such, it is possible that a higher proportion of non-intra-branch trips will be observed. If this were to be the case, material differences in the optimization outputs are not expected. The total number of boardings on the GLX remains unchanged, so the objective function is not affected, and viable solutions do not involve southbound turns at Government Center or other service patterns that create large numbers of transferring GLX passengers. ODX data show that a majority (59%) of passengers coming from Lechmere alight at or before Park Street, which means only 41% GLX passengers are assumed to continue onto the most crowded sections of the line west of Park Street. Thus, the only expected effect on model results would be a slight increase in capacity required west of Park Street.

Group 4

Group 4 riders are represented by the proportion (0.5) of intra-branch trips attributed to the GLX boardings and alightings in the CTPS estimates (the half which is not attributed to Groups 2 and 3). Iterative proportional fitting (IPF) was used to estimate the flows from one GLX station to another. IPF takes as input a "base" set of flows, which are scaled iteratively by the boarding totals and alighting totals until convergence is reached. For this forecast, a *null base* is used, which initially assumes all station-to-station flows to be equal.

On larger networks, the use of a null base may not be realistic, as shorter trips are generally likelier to occur than longer trips. However, the distances traveled by Group 4 passengers are very short and demand is unlikely to be heavily affected by distance or travel time (no intra-GLX trip can be longer than six stops). Furthermore, transfers are effectively static for Group 4 passengers: no combination of potential GLX service patterns results in a different set of transfers for Group 4 passengers, as there will always be one service from Lechmere to Union Square and one service from Lechmere to Medford/Tufts, so the exact distribution of intra-GLX trips is not critical to the model results.

Combination and Scaling to Peak-Hour Flows

At this point, the flows from all four groups are available, forming a complete set of origin-destination pairs for the post-GLX Green Line. However, there is an important implication to using this approach that must be noted. First, in recent history, Lechmere has been exclusively served by E branch trains, so OD flows show a bias towards E branch stations although their ultimate destination may be served by another station on another branch. For example, a greater number of E branch riders from Lechmere choose to alight at Prudential on the E branch than Hynes Convention Center on the trunk; it is likely that this situation would be reversed should one of the other 3 services utilizing the trunk be the service that goes to Lechmere. However, the potential benefit of this OD matrix is that any existing riders likely do, in fact, have a slight preference for their current commute, all else held equal.

Figure 4-8 shows the forecasted origin-destination flows in the form of a heatmap. The intensity/darkness of shading (moving from white to yellow to green) corresponds to the flow assigned to an OD pair. Stops have been aggregated by location and are shown in order of East to West under the designated category (e.g., the upper-leftmost square is Boston College to Boston College). Several trends can be clearly seen, including the concentration of ridership within the Central Subway and the relative lack of branch-to-branch riders.

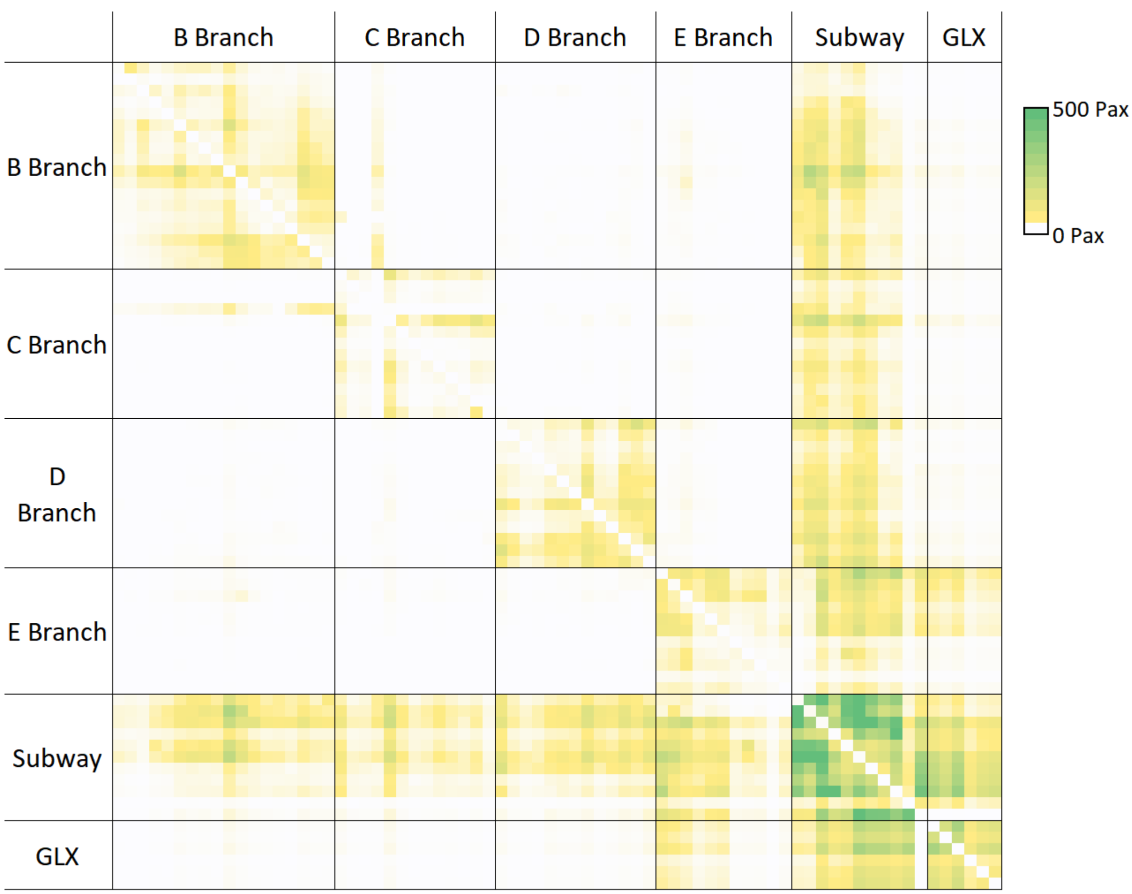

Figure 4-8: Green Line Forecasted Daily Origin-Destination Flow Heat Map

Finally, because the method in Chapter 3 analyzes peak-hour conditions, the daily OD matrix is scaled down to a peak-hour matrix by a universal factor. The factor used is 0.118, which is derived from flows at Lechmere station. The east/northbound flow into Lechmere in the PM peak hour is 11.9% of the daily flow, and the west/southbound flow out of Lechmere in the PM peak hour is 11.7% of the daily flow.

While not all stations (particularly the stations on the western branches) have similar peak hour factors in both directions, the segments with the highest volume-capacity ratios generally do. For example, the segment between Boylston and Arlington, which has the overall largest daily passenger flow, has a PM peak hour factor of 0.103 in one direction and 0.106 in the other direction. Therefore, for the purposes of ensuring that service patterns provide adequate capacity, an overall factor that does not take into account the direction of travel is appropriate.

4.6 Capacity

The hourly passenger flow capacity provided by any service pattern is a direct function of the headway and the passenger capacity of the train:

$$\phi_{hkc} = \frac{60}{h} kc \tag{4.7}$$

Where ϕ_{hkc} is the hourly passenger flow capacity for a service pattern with headway h (in minutes), k number of cars per train and c passenger capacity per car. $\frac{60}{h}$ is the hourly frequency of the service.

Although this formula assumes a consistent number of cars for all trains within a service pattern, it has been previously recommended that Green Line consists remain consistent for each service (e.g., all "B" trains should have the same number of cars, all "C" trains should have the same number of cars, etc.), and only service patterns that adhere to these guidelines have been selected for analysis [11].

According to the 2014 MBTA Blue Book, the policy capacity of a single Green Line Type 7 car or Type 8 car is 103 passengers [1]. With no information on the Type 9's capacity currently available, it is assumed that the policy capacity of a Type 9 is identical to that of the Type 7 and Type 8, given the similar car size.

The goal of finding the passenger capacity of service patterns is to ensure that adequate service is provided to meet the demand on all segments of the system. However, it should be noted that equations that assume evenly spaced headways—like the one above—will understate crowding, as headway variability could lead to some trains experiencing a much higher share of the demand than others. Figure 4-9 shows the theoretical passenger capacity available along the D branch (including all Central Subway stations up to Lechmere) and the actual demand along the segment in the PM peak hour in Fall 2019. The resulting volume-capacity ratio is at most 0.60 to 0.70 in either direction. This is also true for the other three branches and other lines of the MBTA (e.g., the Red Line). In theory, if these passenger loads were distributed evenly on trains, no train would be more crowded than 70% of its policy capacity. However, this is not reflective of actual conditions. To account for the impact of headway variability and demand spikes, the capacity constraint in the optimization states that the demand never exceeds 70% of the theoretical capacity provided by the service pattern(s) serving a segment.

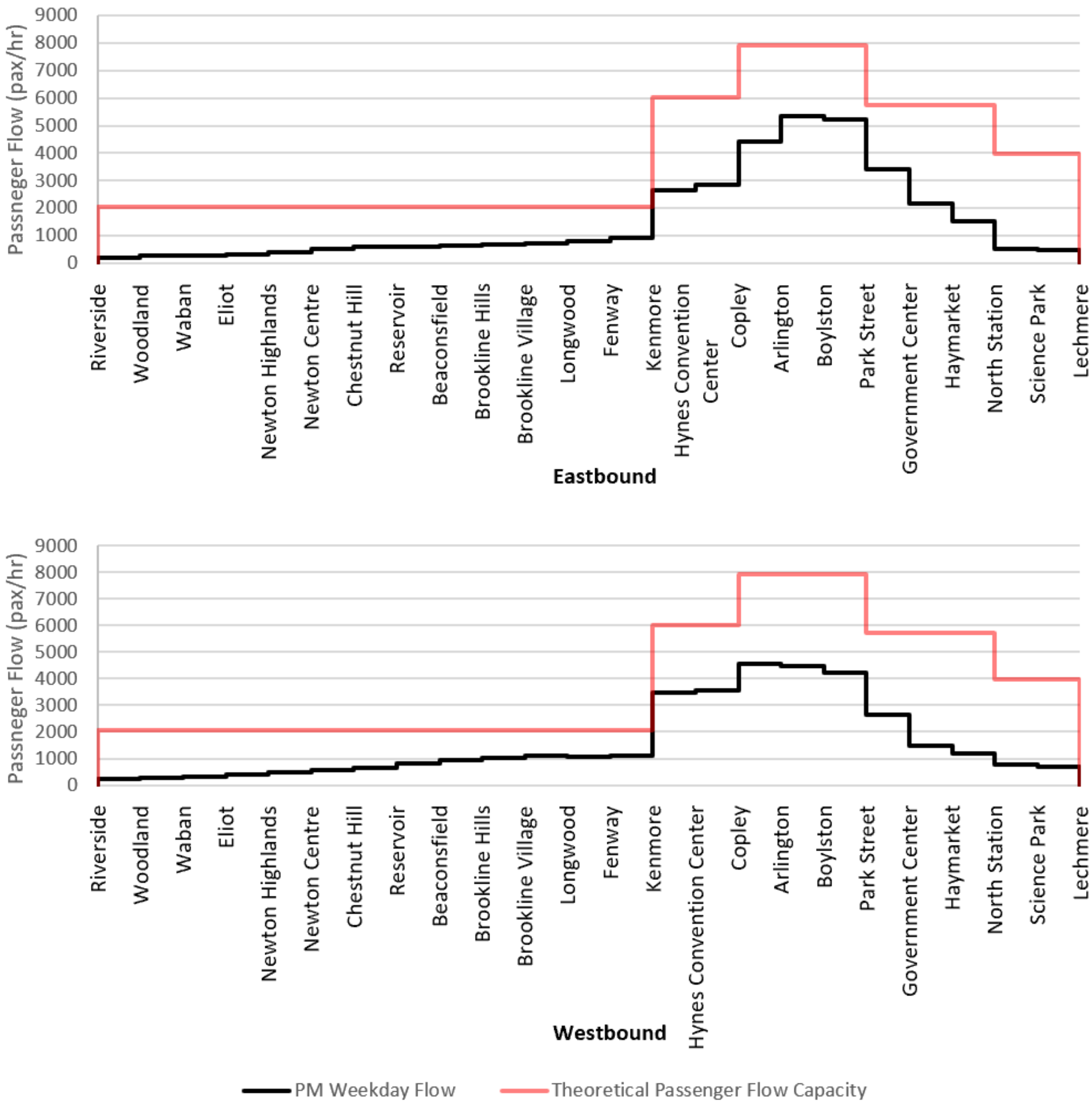

Figure 4-9: Fall 2019 Theoretical Passenger Flow Capacity versus ODX Flows

Chapter 5

GLX Case Study Results and Recommendations

For the purposes of pragmatic long-term planning, there is rarely a one-size-fits-all solution. However, the method proposed in Chapter 3 is a useful tool to identify flexible, robust, and high-performing service plans even when conditions are expected to significantly change. Appendix B details the results generated by the method as applied to the Green Line Extension case study and shows the process by which the most promising operational strategies are identified. These strategies form the basis of "Alternate Paths," which are groups of similarly-constructed service plans that can accommodate increasing demand and agency resources with minimal adjustments to the operating scheme. The goal is that these Alternate Paths provide a blueprint to not only *accommodating* increased demand, but to also *attracting new* demand through the provision of better level-of-service (LOS) for riders, and leading to a more rapid recovery of both transit service and transit revenues.

The chapter details the experimental design (including the construction of the most critical test scenarios), introduces and explains the Alternate Paths, and weighs the relative benefits and costs of the Alternate Paths against one another as well as against the Current Path (a path to pandemic recovery that assumes little-to-no change from current operating plans and practice apart from the gradual lowering of headways and higher resource use). The service plans comprising the Alternate

Paths represent a small (but most promising) fraction of the service plans investigated through the use of the methodology described in Chapter 3.

It is argued that passenger level-of-service benefits can be attained through the selective use of single-car trains. Use of the single-car trains is core to the two Alternate Paths identified. Although unconstrained replacement of two-car services with single-car services could potentially result in an expected wait time decrease of greater than 40% across the system, more targeted implementations are suggested with limited use of single-car trains which attain up to a 20% decrease and minimize the potential risks associated with single-car trains. The results suggest that pre-pandemic headways may be achieved in the short-term by pursuing the recommended strategies, even with a limited fleet and pandemic-level operator hours.

5.1 Role of Single-Car Trains

Running scheduled single-car trains on certain service patterns during the peak period is a key aspect of both of the proposed Alternate Paths. This is a deviation from recent practice in that single-car trains do not make up the majority of scheduled trips on any services; and when they are scheduled, it is generally not during the peak-period. Therefore, some analysis has been done on the potential advantages and disadvantages of the single-car trains to understand where the benefits of single-car operations are realized, as well as to anticipate issues that could arise from single-car operations and determine how to mitigate these risks.

5.1.1 Potential Advantages

Trains on the Green Line require one operator per car, as doors on a particular car can only be opened and closed from the same car's controls [14]. Therefore, from an operations standpoint, the primary advantage of single-car trains is that they require only half the operator hours per trip as a standard two-car train. Two-car trains are usually operated as a pair of cars from different types of rolling stock (a Type 7 paired to a Type 8). Incompatibilities in the Type 7 and Type 8's control systems means that the door controls are unlikely to be addressed before the cars are retired [2].

Meanwhile, from a passenger level-of-service standpoint, the primary advantage of single-car trains is that they facilitate a higher frequency and thus expected wait time is decreased. Service patterns that utilize single-car trains have lower headways than service patterns with two-car trains to provide enough capacity to meet demand. Moreover, even in situations where demand can be satisfied with high headways, the lower operator cost per trip as described above enables more frequent service to be run.

The four existing branches of the Green Line have varying characteristics. There is little reason to believe that differences will arise in operations between single-car trains and two-car trains on the mostly grade-separated D branch, or the C and B branches, both of which have protected medians for trains. However, the E branch includes the Green Line's only mixed-traffic street running section, where trains share a right-of-way with road traffic. This five-stop segment causes frequent delays during the rush hour, enough that some trains short-turn on an ad-hoc basis at Brigham Circle, the last stop on the dedicated right-of-way (these short-turns are discussed in greater detail in Chapter 3). While single-car trains will not eliminate the issues inherent with street running trains, the decreased amount of space they take up on the street may have a positive impact on traffic and run times — for example, by clearing intersections faster. Moreover, relative to the other western termini, Heath Street is extremely space-limited. Whereas Riverside, Cleveland Circle, and Boston College can store dozens of cars (see Table 2.4 in Chapter 3 for detailed counts), Heath Street can only store two two-car trains at a time. Single-car trains will free up more space for layups at Heath Street, possibly enabling easier dispatching from that end of the line.

Another benefit comes from a maintenance perspective. Of the three varieties of rolling stock on the Green Line, the ADA-accessible Type 8 trains currently require the most intensive care [2]. By cutting back on the use of non-ADA-accessible Type 7 trains, which cannot be used singularly, there may be opportunities to shift more regular maintenance towards the Type 8s to improve reliability, as well as direct resources towards associated maintenance programs, such as the ongoing replacement of trucks on the Type 8 cars.

Finally, if only two-car trains are used, there are few options, outside of raising headways or truncating service patterns, that can redistribute resources from sections with excess capacity to sections with higher demand. However, the use of single-car trains allows for more efficient resource re-allocation while lowering headways at the same time, as will be shown in the analysis later in this chapter.

5.1.2 Potential Disadvantages

Even though there is a more efficient allocation of capacity across the line when single-car trains are used, for some stations in the Central Subway — such as North Station, which has transfers to commuter rail and events at nearby TD Garden — the extra capacity may be useful to meet surges in demand. However, note that the model uses a factor of safety of 1.43 when determining minimum capacity requirements (necessitating that the passenger flow in the peak hour be met by 70% of provided capacity), so the capacity is 43% higher than the average demand over the peak hour. Moreover, as of June 2021, commuter rail has only recovered 23% of weekday ridership [7], so capacity-exceeding surges may not return until the agency is able to provide more frequent service.

Track congestion caused by the mixing of one- and two-car trains has been an issue in the past. A 1993 study of the Green Line [8] compared dwell times to both leaving passenger load (LPL) — the number of passengers in the most crowded car in a train — and boarding/alighting totals. [8] found that once the LPL exceeded the policy capacity, the dwell times for single-car trains increased and exhibited higher variability. As an example, for two-car trains, an LPL (in one car) greater than 108 passengers was observed to result in an average dwell time of 35.46 seconds and a standard deviation of 6.31 seconds. The same LPL on a single-car train was observed to result in an average dwell time of 36.00 seconds and a standard deviation of 13.31 seconds. A similar trend was observed with the total number of boarding/alighting passengers, where loading and unloading more than 25 combined passengers resulted in over double the dwell time variability for single-car trains as for two-car trains.

However, in 1993, the mixing of single-car and two-car trains was done on an ad-hoc basis, largely as a result of the unreliable Green Line fleet [8]. The fleet at that time consisted of postwar-era PCC streetcars, the problematic Boeing-Vertol streetcars, and the new (at that time) Type 7s, which did not comprise as large of a share of the fleet as they do today. The result was that these single-car trains were used across routes. Furthermore, all rolling stock at that time featured stairs to enter and exit the vehicle. The Type 8s and 9s in use today, the only cars that may be placed into service as single-car trains due to ADA requirements, feature close-to-level boarding with wide doors for better passenger throughput.

In a study of operations mixing two- and three-car trains in 2012, Malikova [11] found that the mixing of two- and three-car trains was contributing to longer dwell times. This was attributed to a lack of information to passengers regarding which trains would be two cars long and which trains would be three cars long, as passengers would not know where to wait on the platform. Even though these two- and three-car trains were intentionally scheduled, there was no way for passengers to learn over time which trains would have certain consist lengths, as two- and three-car trains were alternating within the same routes.

Due to the concerns raised by Lin and Wilson [8] and Malikova [11], any use of single-car trains should be limited to one service, with all trains in that service being single-car trains. In the event that single-car trains continue to have longer dwell times, their numbers within the Central Subway will be limited. Furthermore, the consistent use on only one route will decrease the likelihood that several single-car trains arrive in succession to create cascading delays. The planned nature (as opposed to ad-hoc nature) of these single-car trains should also help ensure adequate capacity is provided through low headways. Consistent use of single-car trains on only one route is also easier to communicate to passengers by way of generic signage and/or announcements, lowering the number of passengers waiting at an inconvenient platform location.

5.2 Experimental Design

The experimental design was shaped around four scenarios that capture the range of the GLX operating conditions in the short and long term. Current operations are marked by decreased demand and decreased agency resources due to COVID-19, but these conditions are expected to be temporary, so operational scenarios based on a return to pre-pandemic operations are also important to consider.

Trends identified from the initial results in Appendix B were used to identify the most promising operational strategies. In some cases, it was found that the addition of constraints to match aspects of service plans to existing operating practices came at a low cost to passenger LOS; results were then fine-tuned with the addition of these constraints to generate a wide variety of options with highly favorable attributes of operations and LOS. From these options, the methods described in Chapter 3 deliver a package of similarly-constructed service plans with high promise across all scenarios.

5.2.1 Scenario Dimensions

The following variables comprise the dimensions of the test scenarios:

- Demand *level* (i.e., overall magnitude of demand, not travel patterns): this also has an effect on run times (for supporting figures, please see the previous chapter).
- Available fleet: expected to increase once all newly-ordered Type 9 vehicles are delivered, tested, and provided with a dedicated maintenance facility.
- Available operator hours: expected to increase as demand returns to pre-pandemic levels.

This means that inputs not listed above are assumed to remain constant regardless of the scenario. For example:

- Travel patterns: unfortunately, AFC data on surface branches have not been available since the beginning of the pandemic. Thus, it is difficult to ascertain whether travel patterns have changed. Therefore, when scaling demand, all OD flows will be scaled by the same proportion.

- Train passenger capacity: no substantial fleet upgrades or replacements are expected beyond the remaining Type 9s, which are presumed to have identical capacity to the Type 7s and Type 8s.

- Station turnaround limits: all turning locations used are assumed to remain functional and at a constant capacity over the time horizon of the planning.

An explanation of the three selected dimensions follows with details on the selection of benchmark values for each.

Demand Levels

Two demand levels were included in the test scenarios:

1. COVID-19 Adjusted Forecast: 65% of forecasted post-GLX demand

2. Original Forecast: 100% of forecasted post-GLX demand (as derived in Chapter 4)

Passenger demand took a large hit at the beginning of the pandemic. Figure 5-1 compares entries at various gated stations on the Green Line on Tuesdays immediately prior to and during the pandemic. At this point, less than a year away from the projected full opening of the GLX, gate taps at these stations have not risen beyond 25% to 37% of pre-pandemic demand. It was assumed that demand levels might rise to around 65% of pre-COVID levels by the opening — about halfway to a full recovery relative to the current situation — so the COVID-19 Adjusted Forecast option was set to be 65% of the originally forecasted post-GLX demand.

On the other hand, in the long-term, it was assumed that 100% of pre-COVID demand would return, which is noted as the Original Forecast demand level. Chapter 4 discusses the forecasting of the demand.

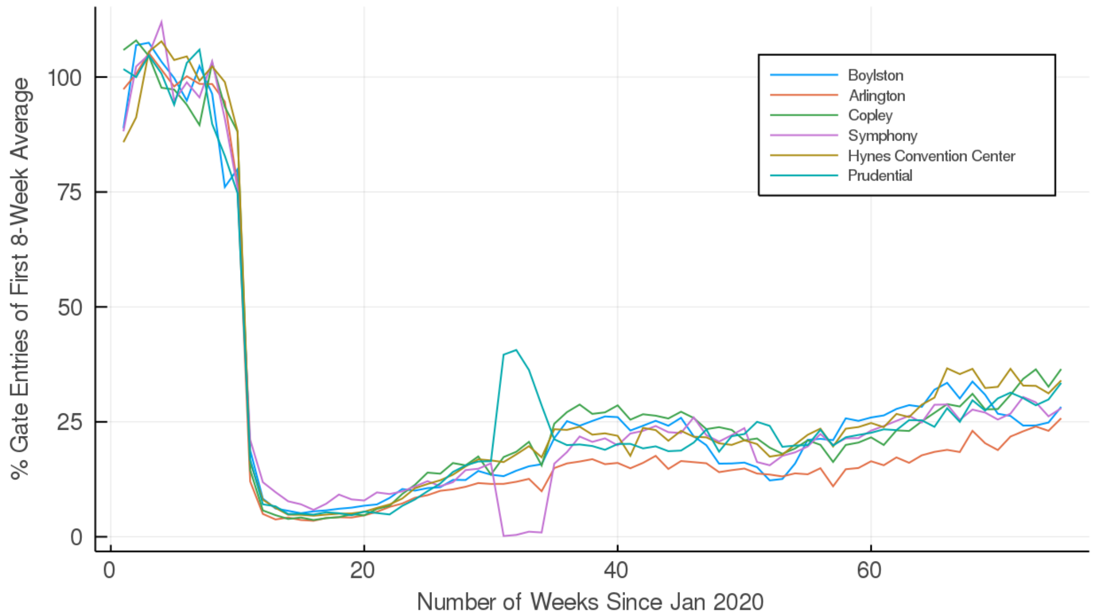

Figure 5-1: Tuesday Central Subway Gate Taps as a Proportion of Pre-Pandemic Taps

Available Fleet

Two fleet levels were included in the test scenarios. It was assumed that 10 of the 86 Type 8s (roughly 12%) must be reserved as spares [2] in both scenarios. Similar spare ratios are enforced for the more reliable Type 7s and 9s (e.g., in scenarios with nine Type 9s, one must be kept as a spare).

1. Pre-GLX: 103 Type 7s, 86 Type 8s, and 9 Type 9s

2. Full: 103 Type 7s, 86 Type 8s, and 24 Type 9s

More details on the fleet composition and associated maintenance requirements are provided in Chapter 2.

Available Operator Hours

Four available operator hour levels were included in the test scenarios:

1. Lowest: 2,052 hours; estimated to be the number of operator hours required to run the "Current Plan" — the default plan expected for day one operations.

2. Low: 2,386 hours; the actual scheduled operator hours during the pandemic-affected Fall 2020.

3. Medium: 2,678 hours; halfway between the "Low" level and the estimated number of operator hours required to run the plan described in the GLX's Environmental Assessment.

4. High: no constraint on the operator hours. Instead, results are constrained by the fleet. This is how plans for post-GLX operations were originally conceived prior to the pandemic.

Estimates of required operator hours for the Current Plan and the Environmental Impact Plan are obtained using the method outlined in Chapter 4.

5.2.2 Scenario Construction

The four most important combinations of the dimension levels of demand, fleet size, and operator hours — most likely to be representative of future states of operation — are summarized in 5.1. They are denoted as "Phases" to emphasize the sequential nature of the conditions they represent.

Table 5.1: Evolution of Conditions

Phase	Demand	Available Fleet	Available Operator Hours
I	COVID-19 Adjusted Forecast	Pre-GLX	Lowest
II	COVID-19 Adjusted Forecast	Pre-GLX	Low
III	Original Forecast	Full	Medium
IV	Original Forecast	Full	High

The scenarios represent a logical sequence of conditions. Demand, available fleet, and available operator hours are expected to rise over time. Ongoing training of new operators and maintenance staff should result in a steady rise in available resources, combined with an increase in ridership as people gradually return to their old travel habits or find new uses for public transit. It is hard to predict exactly at what points in time phases will turn over; however, it is reasonable to assume that Phase I or Phase II will be most representative of day one conditions, and Phase IV will occur at some point later but likely before any serious changes to operations and infrastructure (e.g., the provision of new rolling stock, additional extensions, etc.) come to fruition.

5.3 Assumptions

The period of the analysis is the PM peak-hour. An assumption was made based on analyses of vehicle and operator schedules discussed in Chapter 4 that conversions between PM peak vehicle hours and daily vehicle hours as well as conversions between daily vehicle hours and daily operator hours could be held constant even without explicitly defining the AM peak service, ramp-up/ramp-down service, and off-peak service. Therefore, changes to these other periods of service are not discussed in this chapter, although it is generally assumed that the AM peak service at least will follow a similar operating scheme to the PM peak service.

Expected wait time and a transfer penalty are the level-of-service (LOS) metrics used for quantitative evaluations of the service plans within the optimization-based method. Due to the linearity requirements of integer programming, the formulation takes into account only the LOS metrics that apply to passengers boarding or alighting on one of the six branches of the Green Line. While this excludes passengers who are only traveling within the central subway, headways within the central subway will always be roughly half or less of headways on the branch portions, making wait time less of a concern for these passengers.

5.4 Preliminary Analysis

The recommended alternatives in this chapter are the end product of iterations using the optimization model and qualitative analysis process described in Chapter 3. The detailed outputs of these tests are provided in Appendix B along with a more in-depth discussion on the process of identifying and testing trends, but a summary of important points from this process are provided here.

Initial model results (Appendix B) revealed several overarching trends in the solutions generated. The ubiquity and strong performance across all scenarios of one pair of service routings, Riverside to Union Square and Heath Street to Medford/Tufts, led to a determination that all selected service plans should include these two routings.

Without any constraints on the use of single-car trains beyond those imposed by fleet availability, all model outputs, regardless of scenario, included at least one single-car service. In scenarios with low demand, two and sometimes even three single-car service patterns were found to be optimal from a level-of-service perspective. In scenarios with one single-car service, a constraint on particular routings (e.g., "single-car trains may not serve the E branch") incurs a cost no greater than 2% of EWT when comparing optimal solutions, independent of other restrictions. In contrast, eliminating the option of single-car trains entirely incurs a cost no less than 12% of EWT, and as high as 36% in some scenarios. Hence, it was determined that consistent assignment of single-car trains to certain routes across scenarios was worth the small penalty in wait time.

Finally, various routing and headway constraints were tested to determine if certain operationally desirable characteristics could be achieved with minimal cost to level-of-service. Some of these, such as a preservation of existing relationships between branch headways (for example, requiring that the D branch have a lower headway than the C or E branches) or short-turning all single-car trains at Kenmore (to avoid single-car trains in the Central Subway), resulted in minimal LOS impacts and thus were either incorporated into all solutions or used to generate new alternatives. In other cases, such as short-turning single-car trains from the north at Government Center, it was found that these strategies/options provided no feasible solutions or the benefits were inconsistent across scenarios. As a result, these strategies were removed from further consideration.

This iterative process of introducing constraints with low opportunity costs results in not a single "most optimal" solution for each scenario, but a large number of options with slightly different headways and turnaround locations built around the same core attributes. These solutions are valuable as a set because the options effectively act as minor customizations of the service plan. This both illustrates the flexibility of a plan within the scenario and increases the ability of the planner to formulate a robust overall plan of service across the phases of the planning exercise.

5.5 Alternate Paths

Given the range of operating conditions to plan for, there is not a single service plan that provides adequate service in every scenario. However, there are groups of similar plans, built on the same operating strategies, that provide a high LOS in every phase.

These groups can be organized into logical progressions of service plans to smoothly transition from phase to phase, called "Alternate Paths."

There are two Alternate Paths, denoted Path A and Path B, which take advantage of scheduled single-car trains to provide a higher level-of-service than is possible with a schedule comprised entirely of two-car trains. These are compared against the Current Path. In general:

- The **Current Path** is a set of service plans using two-car trains on all service patterns, as is current practice during the peak period. Like Path A and Path B, the service plans are suggested by the optimization method, except for the plan in Phase I, which has been developed by the agency.

- **Path A** is a set of service plans that utilizes single-car trains on the E branch from Heath Street to Medford/Tufts on the GLX. The other three services use two-car trains.

- **Path B** is a set of service plans that utilizes single-car trains on the C branch from Cleveland Circle to Kenmore, avoiding the mixing of consist lengths within the Central Subway. The other services use two-car trains.

Brief descriptions of the Current Path, Path A, and Path B are provided along with descriptions of each path and relevant characteristics below. For each path, one recommended service plan per phase is highlighted. A recommended service plan provides seamless transitions from phase to phase and a high performance within its phase.

In addition, ranges of performance metrics are discussed for the solutions within each path, including headways, operator hours, fleet requirements, expected wait time (EWT), transfers, and volume-capacity ratios. These ranges are derived from the minimum and maximum values within the group of solutions generated by the optimization method in Chapter 3 (excluding solutions that do not match the definition of the paths). Such ranges are given to demonstrate the degree of flexibility within the paths. The details of the service plans, such as the headways, may be adjusted without large sacrifices to the overall LOS. The difference between the maximum and minimum EWT, in particular, can be interpreted to some degree as an indicator of the flexibility in the options available. A large range implies that deviations from the optimum will have a greater effect on LOS. Therefore, adjustments of the various other metrics may come at a greater penalty to performance.

The following abbreviations are used in tables throughout this section:

- BC: Boston College
- CC: Cleveland Circle
- R: Riverside
- HS: Heath Street
- K: Kenmore
- PS: Park Street
- GC: Government Center
- US: Union Square
- MT: Medford/Tufts

5.5.1 Current Path

The Current Path is based on strict adherence to current and former service plans. As mentioned before, the plan in Phase I has been recently proposed by the agency. As demand rises and additional resources become available to the agency, the plan adjusts by lowering headways on each branch service, increasing capacity and level of service. Service plans in the Current Path share the following characteristics:

- There are four service patterns, each utilizing two-car trains.

- The B branch in Phase I provides service from Boston College to Government Center. In phases II, III, and IV, the B branch instead terminates at Park Street.

- The C branch in all phases provides service from Cleveland Circle to Government Center.

- The D branch in all phases provides service from Riverside to Union Square.

- The E branch in all phases provides service from Heath Street to Medford/Tufts.

Figure 5-2 illustrates the routings in all four phases. As noted, the difference between these routings is the location of the Green Line B turnaround, which starts at Government Center in Phase I but is shifted to Park Street in later phases. There are multiple reasons for this switch. In Phase I, high headways are necessitated by the low resources, and the additional service to Government Center will better absorb transfer demand from the Blue Line (a line with relatively high ridership throughout the pandemic) despite the high headways. However, with the lowering of headways enabled by increased resources, this extension to Government Center is no longer as beneficial when considering the trade-off between wait time and transfers. Furthermore, Government Center has somewhat limited track capacity owing to its shared platforms between turning and through trains and its inability to temporarily store more than one turning train out of the way of through traffic (compared to Park Street's three). Therefore, turning at Park Street is likely the better option in the long run. Later in this chapter, there is a more detailed analysis finding that truncating service from Government Center to Park Street results in an average wait time decrease of 2.0% systemwide, at a cost of 5 additional transfers per thousand passengers.

Table 5.2 shows the recommended service plans within the Current Path alongside their specific performance metrics.

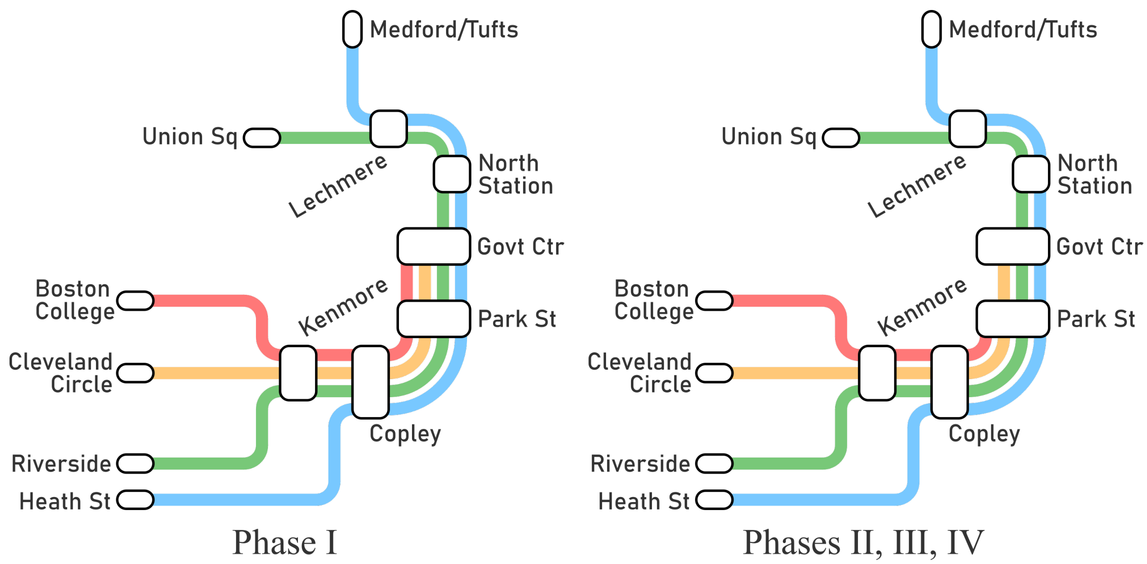

Figure 5-2: Current Path Routings

Table 5.2: Current Path Recommended Service Plans (Including Breakdown of Fleet Requirement by Rolling Stock Type)

Phase	Service Patterns				Headways (min)				Fleet Requirement Total (7, 8, 9)	Spare Ratios (7, 8, 9)			Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	BC-GC	CC-GC	R-US	HS-MT	7.50	9.00	8.00	8.50	116 (55, 55, 6)	0.47	0.36	0.33	2051	3897	40
II	BC-PS	CC-GC	R-US	HS-MT	6.50	7.50	6.80	6.80	134 (64, 64, 6)	0.38	0.26	0.33	2383	3442	45
III	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	6.60	7.00	150 (65, 65, 20)	0.37	0.24	0.17	2661	3291	45
IV	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.67	5.75	172 (76, 76, 20)	0.26	0.12	0.17	3067	2845	45

Table 5.3 shows the range of headway options available for each service pattern in the Current Path adhering to the routings above (e.g., all "C" headways shown are for services going from Cleveland Circle to Government Center), and lower headways have a darker shading. Note that the minimum and maximum headways for Phase I are identical because there is only one service plan considered (the currently planned service plan for day one of post-GLX operations). In all but one case (D Phase II to Phase III), minimum headways decrease as the phases advance, maybe due to fleet integrality or rising demand. Further, in all but one case (D Phase IV), the range of headway options for each service is at least 30 seconds, indicating that there is flexibility in the headways for all branches. Outside of Phase I, the recommended

headway option is higher than the minimum in all cases, and it is lower than the maximum in all but three cases. Therefore, generally speaking, the optimal solutions are in the middle of the headway range, in order to accommodate various operations-driven constraints such as operator hours, fleet requirement, capacity, etc.

Table 5.3: Current Path Headways

Service	Min/Max	Headways			
		Phase I	Phase II	Phase III	Phase IV
B	Min	7.50	5.20	5.00	5.00
	Recommended	7.50	6.50	5.75	5.50
	Max	7.50	7.40	5.75	7.33
C	Min	9.00	7.00	6.20	5.50
	Recommended	9.00	7.50	6.67	5.67
	Max	9.00	7.50	7.75	7.20
D	Min	8.00	6.25	6.33	5.25
	Recommended	8.00	6.80	6.60	5.67
	Max	8.00	7.20	7.00	5.67
E	Min	8.50	6.40	6.00	5.25
	Recommended	8.50	6.80	7.00	5.75
	Max	8.50	7.20	7.40	6.00

Table 5.4 shows the range of operator hour requirements and fleet requirements for the service plans. It should be noted that the method used to generate these service plans does not try to minimize either quantity; instead, a maximum quantity of both resources is set as a constraint. Therefore, it is not surprising that differences between the minimum and maximum are small.

Table 5.4: Current Path Resource Usage

Phase	Fleet Requirement			Operator Hours		
	Min	Rec	Max	Min	Rec	Max
I	116	116	116	2051	2051	2051
II	132	134	134	2365	2383	2385
III	150	150	152	2651	2661	2675
IV	170	172	172	3037	3067	3107

Table 5.5 shows the level-of-service metrics of expected wait time (EWT) and transfers for the service plans. Differences in EWT are small, with no phase having a range of more than 50 minutes of wait time per 1K passengers in the generated solutions, implying that adjustment of headways does not incur a large penalty to

LOS. Because the routings are identical within any individual phase, the minimum and maximum transfers are identical. The only change with respect to transfers between phases is the additional transfers created by truncating the B branch at Park Street in phases II, III, and IV.

Table 5.5: Current Path Level-of-Service Metrics

Phase	Expected Wait Time (min/1000 passengers)			Transfers (per 1000 passengers)		
	Min	Rec	Max	Min	Rec	Max
I	3897	3897	3897	40	40	40
II	3442	3442	3483	45	45	45
III	3291	3291	3341	45	45	45
IV	2845	2845	2885	45	45	45

Table 5.6 shows the volume-capacity ratio at select stations in the PM peak using the recommended service plans. Volume and capacity are both measured as the PM peak hour passenger flow and peak passenger capacity *into* the station from the direction specified. Capacity is calculated using the MBTA policy capacity of 103 passengers per car. Saint Mary's Street and Prudential are the highest-volume stations on their respective branches (C and E). Copley is where all four services merge, and Park Street, Government Center, and North Station are all selected for inclusion as they are all served by combinations of services.

Table 5.6: Current Path Volume-Capacity Ratios at Select Stations

Station	Volume/Capacity Ratio			
	Phase I	Phase II	Phase III	Phase IV
WB Saint Mary's Street	37%	31%	42%	37%
EB Prudential	47%	38%	60%	49%
EB Copley	43%	36%	52%	46%
EB Park Street	58%	48%	70%	61%
EB Government Center	52%	43%	63%	54%
EB North Station	33%	28%	42%	36%

The highest volume-capacity ratios are encountered in Phase III, where Park Street reaches the maximum allowed ratio of 70%. In phases I and II, demand is low and the ratio does not exceed 58%. Even in Phase III, the ratios at stations near the ends of the Central Subway, such as North Station and Saint Mary's Street, do not exceed 42%.

5.5.2 Path A

Service plans in Path A can have at most one single-car service through the Central Subway alongside three two-car services. They aim to improve expected wait time given the available resources while keeping the proportion of transferring passengers consistent with the current plan. Service plans in Path A share the following attributes:

- There are four service patterns, three of which utilize two-car trains. The fourth service pattern utilizes one-car trains.
- The B branch provides service from Boston College to Park Street.
- The C branch provides service from Cleveland Circle to Kenmore.
- The D branch provides service from Riverside to Union Square.
- The E branch provides service from Heath Street to Medford/Tufts and always utilizes single-car trains.

Figure 5-3 shows the routings described above, with a dashed line representing the single-car Green Line E. Table 5.7 shows the recommended service plans within Path A alongside their specific performance metrics.

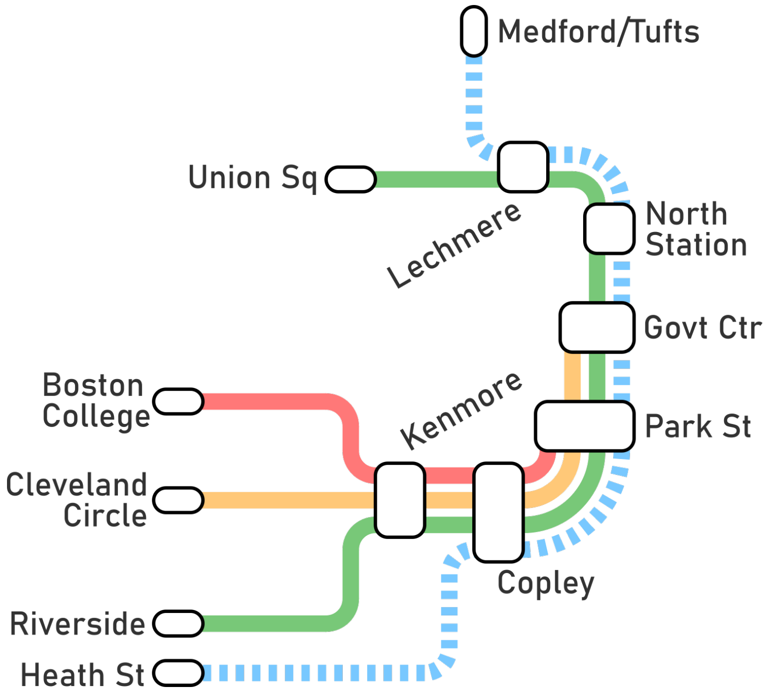

Figure 5-3: Path A Routings

Table 5.7: Path A Recommended Service Plans (Including Breakdown of Fleet Requirement by Rolling Stock Type)

Phase	Service Patterns				Headways (min)				Fleet Requirement Total (7, 8, 9)	Spare Ratios (7, 8, 9)			Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.25	116 (47, 62, 7)	0.54	0.28	0.22	2049	3295	45
II	BC-PS	CC-GC	R-US	HS-MT	5.75	7.00	6.80	4.00	135 (53, 75, 7)	0.49	0.13	0.22	2385	2811	45
III	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	6.33	4.00	152 (60, 71, 21)	0.42	0.17	0.13	2676	2666	45
IV	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	4.00	162 (65, 76, 21)	0.37	0.12	0.13	2860	2500	45

Table 5.8 shows the range of headway options available for each service pattern in Path A adhering to the routings above. In all but one case (B Phase III to Phase IV), minimum headways of two-car services (i.e., not the E branch) decrease as the phases increase. In all but two cases (D Phase II and E Phase II), the range of headway options for each service is at least 1 minute. Phase IV provides at least one option with a sub-5 minute headway on any route, and the range of headways in Phase IV is particularly large, at least 90 seconds for each service, indicating a large degree of flexibility in the selection of headways. Outside of the E branch, most recommended

headways do not fall on the minimum or maximum headway in the range; however, the E branch is recommended to have the minimum headway in Phases II, III, and IV. This is due to the efficient use of resources allocated to the E branch.

Table 5.8: Path A Headways

Service	Min/Max	Headways			
		Phase I	Phase II	Phase III	Phase IV
B	Min	5.75	5.00	4.20	4.60
	Recommended	7.00	5.75	5.20	5.20
	Max	7.40	7.00	5.75	6.50
C	Min	6.50	6.50	5.80	4.00
	Recommended	7.50	7.00	6.67	5.80
	Max	7.50	7.50	7.75	6.67
D	Min	6.50	6.25	6.20	4.80
	Recommended	7.50	6.80	6.33	5.67
	Max	7.50	6.80	7.50	6.33
E	Min	4.00	4.00	4.00	4.00
	Recommended	5.25	4.00	4.00	4.00
	Max	5.80	4.80	6.60	5.50

Table 5.9 shows the range of operator hour and fleet requirements in the service plans of Path A. Path A's notable trend is that the differences between the minimum and maximum of both resources in the generated service plans tend to increase as the phase increases. The reason for this, particularly in Phase IV where the range in the fleet requirement and the operator hours is 13 cars and 244 hours, respectively, is due to the use of single-car trains. On the three services constrained to two-car trains, the marginal contribution of one additional operator or one additional car is zero, as *two* operators or cars are required to provide an additional train and thus improve the LOS. However, only one operator and one car is required to improve service on the E branch. Therefore, solutions that focus on providing a high LOS to the E branch will use less operator hours and have a lower fleet requirement than a solution that achieves the same LOS benefits by lowering EWT on a two-car branch.

Table 5.10 shows the minimum and maximum expected wait time and transfers in each phase. Similarly to the Current Path, differences are not high, implying that flexibility does not come at a large cost to passenger LOS. However, particularly in Phase IV, for the same reasons described above, the similarity in LOS metrics implies that the large increase in operator hours and fleet requirement seen in Table 5.9 does

Table 5.9: Path A Resource Usage

Phase	Fleet Requirement			Operator Hours		
	Min	Rec	Max	Min	Rec	Max
I	114	116	116	2020	2049	2049
II	134	135	136	2374	2385	2385
III	150	152	154	2621	2676	2676
IV	160	162	173	2820	2860	3064

not actually result in an improvement in LOS, as these resources are expended on resource-intensive two-car services. For example, an investment of 244 additional operator hours and 13 more cars in Phase IV could *at most* result in a decrease of 51 minutes of wait time per 1,000 passengers. Therefore, even though the total operator hour and fleet requirement for Path A are low overall, choosing the right headway options is important to ensure that resources are expended efficiently.

Table 5.10: Path A Level-of-Service Metrics

Phase	Expected Wait Time (min/1000 passengers)			Transfers (per 1000 passengers)		
	Min	Rec	Max	Min	Rec	Max
I	3295	3295	3340	45	45	45
II	2811	2811	2842	45	45	45
III	2666	2666	2775	45	45	45
IV	2500	2500	2551	45	45	45

Table 5.11 shows the volume-capacity ratio at select stations using the recommended service plans. The highest ratios are encountered in Phase III, although Phase IV has no decrease in the ratio at EB Prudential, as single-car trains are being run at the minimum headway in both Phase III and IV. Depending on the particular phase, either Prudential or Park Street has the highest ratio. Although all stations listed below Prudential are also being partially served by the single-car trains on the Green Line E, the ratios are similar to those in the Current Path in Table 5.6, as headways on all other routes are lower relative to the Current Path, not just the E branch.

Table 5.11: Path A Volume-Capacity Ratios at Select Stations

Station	Volume/Capacity Ratio			
	Phase I	Phase II	Phase III	Phase IV
WB Saint Mary's Street	31%	29%	42%	37%
EB Prudential	58%	44%	68%	68%
EB Copley	41%	36%	52%	48%
EB Park Street	56%	48%	69%	65%
EB Government Center	50%	44%	65%	59%
EB North Station	35%	30%	44%	41%

5.5.3 Path B

Service plans in Path B require that single-car trains from the C branch utilize the Kenmore loop to avoid mixing of single-car trains and double-car trains in the Central Subway. Doing so avoids potential congestion-related concerns about the effect of mixing single-car and double-car operations in the Central Subway while reaping most of the wait time and resource benefits of a single-car train. Service plans in Path B share the following attributes:

- In Phases I and II, there are four service patterns, one of which is a single-car service that does not continue through the Central Subway. In Phases III and IV, an additional two-car service is added within the Central Subway to bring the total to five services.
- The B branch provides service from Boston College to Park Street.
- The C branch provides service from Cleveland Circle to Kenmore and always utilizes single-car trains.
- The D branch provides service from Riverside to Union Square.
- The E branch provides service from Heath Street to Medford/Tufts.
- In Phases III and IV, a fifth route provides service from Kenmore to Park Street to add capacity to the Central Subway, utilizing the Blandford Street switch on the B branch to turn.

Figure 5-4 shows the routings described in all phases. A dashed line is used to show the single-car Green Line C service. Table 5.12 shows the recommended service plans within Path B alongside their specific performance metrics.

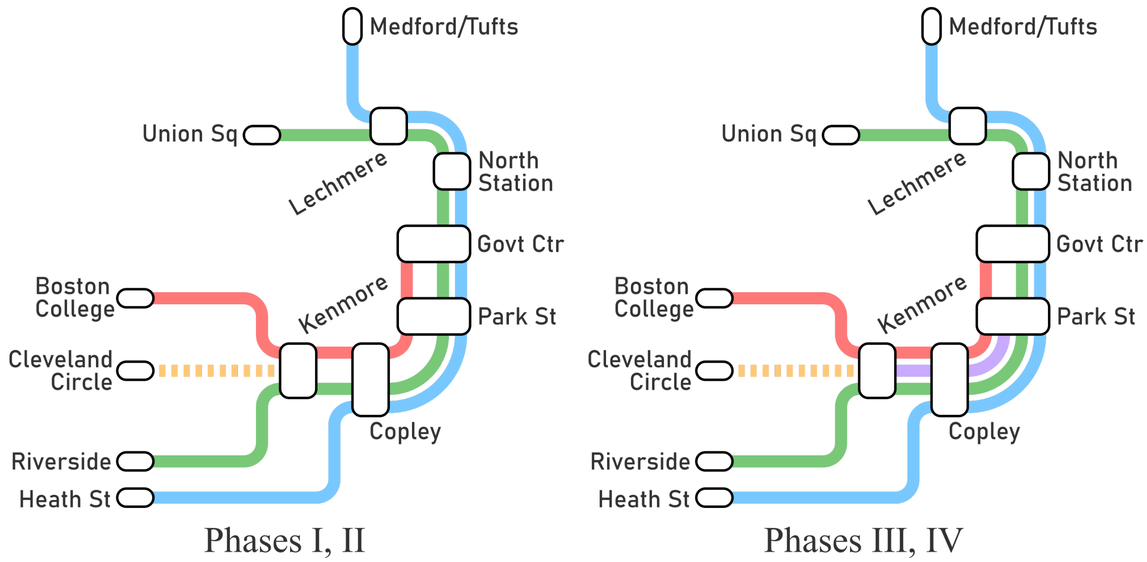

Figure 5-4: Path B Routings

Table 5.12: Path B Recommended Service Plans (Including Breakdown of Fleet Requirement by Rolling Stock Type)

Phase	Service Patterns				Headways (min)				Fleet Requirement Total (7, 8, 9)	Spare Ratios (7, 8, 9)			Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	BC-GC	CC-K	R-US	HS-MT	7.00	4.80	7.20	7.20	117 (53, 57, 7)	0.49	0.34	0.22	2046	3331	103
II	BC-GC	CC-K	R-US	HS-MT	6.20	4.00	6.00	6.40	136 (61, 68, 7)	0.41	0.21	0.22	2382	2885	103
III	BC-GC	CC-K	R-US	HS-MT	5.60	4.20	6.60	6.60	153 (66, 66, 21)	0.36	0.23	0.13	2670	2948	103
IV	BC-GC	CC-K	R-US	HS-MT	5.60	4.20	5.25	5.50	173 (76, 76, 21)	0.26	0.12	0.13	3034	2597	103

Table 5.13 shows the range of headway options available for each service pattern in Path A adhering to the routings above. Generally speaking, minimum headways of two-car services (i.e., not the C branch) decrease as phases increase; however, in the transition from Phase II to Phase III, there is a slight increase in the minimum headways of the D and E branches to accommodate the fifth service. In all but one case (D Phase III), the range of headway options for each service is at least 40 seconds, indicating a degree of flexibility in the selection of headways. Phase IV provides at

least one option for a 5-minute headway or less on any of the four branch routes. Recommended headways are usually close to the middle of the range described for the B, D, and E branches, but the single-car C branch sees a recommended headway of 4 or 4.2 minutes in Phases II, III, and IV for similar resource efficiency reasons as seen in Path A's E branch. Conversely, the recommended headway for the Kenmore - Park Street service is the maximum; this is because the headway of this service does not contribute to the LOS calculation outlined in the method, and thus its function is only to provide additional capacity.

Table 5.13: Path B Minimum and Maximum Headways

Service	Min/Max	Headways			
		Phase I	Phase II	Phase III	Phase IV
B	Min	6.20	5.60	5.60	5.00
	Recommended	7.00	6.20	5.60	5.60
	Max	7.50	6.20	6.20	6.60
C	Min	4.00	4.00	4.00	4.00
	Recommended	4.80	4.00	4.20	4.20
	Max	6.00	4.80	5.50	5.50
D	Min	6.80	5.75	6.33	4.80
	Recommended	7.20	6.00	6.60	5.25
	Max	7.50	6.80	6.60	5.67
E	Min	6.80	5.80	6.00	4.67
	Recommended	7.20	6.40	6.60	5.50
	Max	7.75	6.80	7.40	5.75
Other	Min			5.8	5.8
	Recommended			6.8	6.8
	Max			6.8	6.8

Table 5.14 shows the minimum and maximum resource usage of Path B service plans. Although Path B utilizes single-car trains like Path A, a pattern of increasing difference between the minimum and maximum resource levels is generally not seen over the course of the four phases. This is mainly attributable to the routing. The cycle time on the modified C branch to Kenmore service is around 55 minutes, requiring only 11 to 13 cars to run under both demand conditions with single-car trains. Therefore, small adjustments in headway do not as easily add or remove cars from the service as they would for a service with longer cycle times (for comparison, the cycle time of the single-car trains used in Path A on the E branch is just above 125 minutes).

Table 5.14: Path B Resource Usage

Phase	Fleet Requirement			Operator Hours		
	Min	Rec	Max	Min	Rec	Max
I	116	117	118	2037	2046	2051
II	136	136	136	2366	2382	2382
III	151	153	153	2646	2670	2675
IV	170	173	173	2995	3034	3058

Table 5.15 shows minimum and maximum expected wait time and transfers of the Path B service plans. As seen in similar tables for the Current Path and Path A, there is not a large range of EWT across the different service plans generated, with no phase having a range larger than 50 minutes per 1,000 passengers. Although a fifth service is added in phases III and IV, no additional transfers are generated: there are no trips that depend exclusively on this new service, as it completely duplicates other services over the extent of its route (e.g., the B and D services).

Table 5.15: Path B Level-of-Service Metrics

Phase	Expected Wait Time (min/1000 passengers)			Transfers (per 1000 passengers)		
	Min	Rec	Max	Min	Rec	Max
I	3331	3331	3341	103	103	103
II	2885	2885	2898	103	103	103
III	2948	2948	2980	103	103	103
IV	2593	2597	2640	103	103	103

Table 5.16 shows the volume-capacity ratio at select stations for phases of Path B using the recommended service plans. The highest volume-capacity ratios are encountered in Phase III, although Copley and Park Street see similarly high ratios in Phase I. This is due to the number of service patterns present at these stations — despite a lower demand in phases I and II, EB Copley and EB Park Street are served only by three inbound services as opposed to four services in phases III and IV. Notable as well is the relatively high volume-capacity ratio at Saint Mary's Street in Phase III and Phase IV, which is higher than that of both North Station and Copley. This is due to the use of single-car trains on the C branch.

Table 5.16: Path B Volume-Capacity Ratios at Select Stations

Station	Volume/Capacity Ratio			
	Phase I	Phase II	Phase III	Phase IV
WB Saint Mary's Street	40%	33%	54%	54%
EB Prudential	40%	35%	56%	47%
EB Copley	50%	43%	51%	46%
EB Park Street	67%	58%	69%	62%
EB Government Center	48%	41%	66%	57%
EB North Station	29%	25%	41%	33%

5.6 Comparison of Solutions

The Current Path alongside the two Alternate Paths represent three viable approaches to post-GLX operations. However, a quantitative comparison of the options reveals significant differences in the passenger level-of-service (LOS) provided by the Current Path and the two Alternate Paths.

Table 5.17 summarizes the key information and metrics for the recommended service plans within the three paths.

Table 5.17: Comparison of Alternate Paths at Each Phase

Phase	Path	Service Patterns				Headways (min)				Fleet Requirement Total (7, 8, 9)	Spare Ratios (7, 8, 9)			Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	Current	BC-GC	CC-GC	R-US	HS-MT	7.50	9.00	8.00	8.50	116 (55, 55, 6)	0.47	0.36	0.33	2051	3897	40
	A	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.25	116 (47, 62, 7)	0.54	0.28	0.22	2049	3295	45
	B	BC-GC	CC-K	R-US	HS-MT	7.00	4.80	7.20	7.20	117 (53, 57, 7)	0.49	0.34	0.22	2046	3331	103
II	Current	BC-PS	CC-GC	R-US	HS-MT	6.50	7.50	6.80	6.80	134 (64, 64, 6)	0.38	0.26	0.33	2383	3442	45
	A	BC-PS	CC-GC	R-US	HS-MT	5.75	7.00	6.80	4.00	135 (53, 75, 7)	0.49	0.13	0.22	2385	2811	45
	B	BC-GC	CC-K	R-US	HS-MT	6.20	4.00	6.00	6.40	136 (61, 68, 7)	0.41	0.21	0.22	2382	2885	103
III	Current	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	6.60	7.00	150 (65, 65, 20)	0.37	0.24	0.17	2661	3291	45
	A	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	6.33	4.00	152 (60, 71, 21)	0.42	0.17	0.13	2676	2666	45
	B	BC-GC	CC-K	R-US	HS-MT	5.60	4.20	6.60	6.60	153 (66, 66, 21)	0.36	0.23	0.13	2670	2948	103
IV	Current	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.67	5.75	172 (76, 76, 20)	0.26	0.12	0.17	3067	2845	45
	A	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	4.00	162 (65, 76, 21)	0.37	0.12	0.13	2860	2500	45
	B	BC-GC	CC-K	R-US	HS-MT	5.60	4.20	5.25	5.50	173 (76, 76, 21)	0.26	0.12	0.13	3034	2597	103

Headways are lower in both Path A and Path B solutions relative to the Current Path, particularly in the early phases of recovery. For example, in phase I, the average of the four headways is 8.25 minutes in the Current Path, whereas it is 6.81 minutes in Path A and 6.55 minutes in Path B. This translates to a 15% decrease in expected wait time for both paths relative to the Current Path. For comparison, the PM peak average of the four branch headways immediately prior to the pandemic was

6.39 minutes, placing the headways of the two Alternate Paths plans closer to that of pre-pandemic operations, even under the most pessimistic assumptions of agency resources.

Path A achieves these headways with almost no additional transfers among branch riders relatively to the Current Path, as they share the same pattern-routes in all phases apart from phase I. Path B results in approximately an additional 58 out of every 1,000 branch riders requiring a transfer to complete their trip relatively to the Current Path and Path A. These riders, however, can take advantage of a cross-platform transfer at Kenmore, which is less disruptive than a "typical" subway transfer (which usually involves stairs and/or passageways), and they also benefit from a 47% reduction in headways (from 9 minutes to 4.8 minutes). The additional transfers incurred by passengers in Path B can be thought of as the "cost" of avoiding single-car operations in the Central Subway while preserving the wait time benefits of single-car trains, a topic that will be discussed in the next section.

The Fleet Requirement and Estimated Total Operator Hours columns confirm that each service plan is maximizing its use of available resources at every phase, which is a product of the optimization-based methods used to identify promising service plans. However, a difference between the values in these two columns appears in phase IV, where Path A shows lower fleet and operator hours requirements than both the Current Path and Path B. This is because Path A uses more accessible cars than are available in the Type 9 fleet, requiring that the Type 8 fleet be used partially for single-car operations as well; this puts additional Type 7s out of service as they may no longer be paired to a Type 8. Despite this arrangement, however, Path A still achieves a lower expected wait time than either alternative in Phase IV.

Figure 5-5 summarizes the performance of each service plan in terms of wait time as a function of the operator hours. The results indicate that:

- In phases I and II, Path A and Path B achieve roughly the same expected wait time as the Current Path does in phase III and phase IV, respectively, but with an estimated savings of over 600 operator hours. This highlights the ability of paths A and B to provide a high LOS with less resources.

- Between phases II and III, the expected wait time (for branch passengers) rises slightly for Path B whereas it continues to decrease for Path A and the Current Path. This is the result of the shift in resources under Path B towards the Central Subway required to provide capacity in high-demand scenarios, implemented as an additional service between Kenmore and Park Street.

- Path A's phases II, III, and IV provide better expected wait time than the phase IV implementation of the Current Path. This implies that even with unlimited operator hours, the Current Path will not achieve the same wait time benefits as Path A, even when a Path A implementation is run with lower resources. There are simply not enough cars in the fleet for the Current Path to support headways comparably low to Path A.

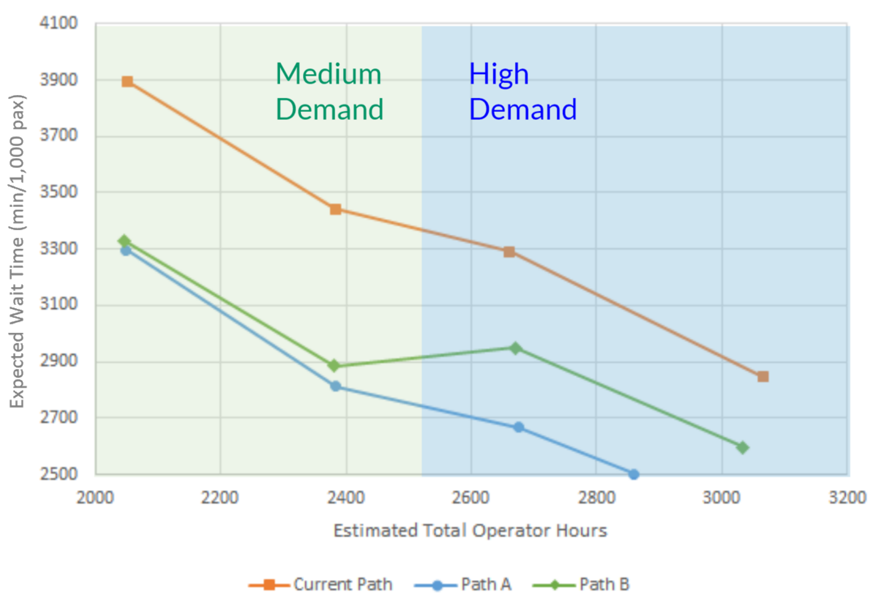

Figure 5-5: Wait Time as a function of Operator Hours for the Alternate Plans

Table 5.18 compares the volume/capacity ratios for the recommended service plans in the Current Path, Path A, and Path B in Phase III, which is the phase that features the highest volume-capacity ratios for all three paths. In general, the Alternative Paths allocate capacity more efficiently than the Current Path. While the ratios on sections with the highest volume-capacity ratios remain the same, the Alternative

Paths (particularly Path A) utilize more of the excess capacity provided on other sections. At all stations except the WB Saint Mary's Street station, the Current Path and Path B have the same number of services and the same train lengths serving all stations; therefore, differences in the volume-capacity ratio are attributable to differences in headways. However, in Path A, the use of single-car trains on the E branch affect the ratios at all stations other than WB Saint Mary's Street. Despite the lower capacity of a single-car train, the low headways across all Path A service plans, enabled by the single-car trains, means that the volume-capacity ratio increases only by a maximum of 0.02 (or 4.0%) at any station in the Central Subway relatively to the Current Path. The largest change is at Prudential, which in Path A is served exclusively by single-car trains; the ratio is 0.08 higher than for the Current Path and 0.12 higher than Path B. Conversely, the largest difference in Path B exists for WB Saint Mary's Street, which is served exclusively by single-car trains in Path B; the ratio is 0.12 higher than in the Current Path and Path A. However, as stated above, the increase in volume-capacity ratio occurs at stations where the volume-capacity ratio is lower than the maximum allowed (at least 0.10 below the constrained limit of 0.70).

Table 5.18: Comparison of Volume/Capacity Ratios in Phase III at Select Stations

Station	**Volume/Capacity Ratio**		
	Current Path	Path A	Path B
WB Saint Mary's Street	0.42	0.42	0.54
EB Prudential	0.60	0.68	0.56
EB Copley	0.52	0.52	0.51
EB Park Street	0.70	0.69	0.69
EB Government Center	0.63	0.65	0.66
EB North Station	0.42	0.44	0.41

5.7 Important Operational Considerations

The analysis in the previous section indicates that Path A and Path B have a number of advantages over the Current Path — particularly Path A. However, the traits that define service plans in Path A and Path B were chosen not only for their quantitative strength, but also because of how they fit in with the unique operational considerations of the Green Line. What follows is a discussion of these qualitative attributes, and where benefits and/or drawbacks to the Alternate Paths may be realized.

5.7.1 Single-Car Trains

The most unique aspect of Path A and Path B relative to the Current Path is the scheduled use of single-car trains during the peak periods. Both Path A and Path B are designed in part to take advantage of the benefits of single-car trains mentioned in Section 5.1 while avoiding the disadvantages and risks highlighted there.

Path A uses single-car trains only on the E branch. The use of single-car trains on the E branch means that both Type 9 and Type 8 rolling stock are required to run the service, thus keeping more unpaired Type 7s in storage and possibly resulting in more space and labor for Type 8 maintenance and rehabilitation. The E branch features street running on its western end, and as mentioned earlier in the chapter, the use of single-car trains may reduce run time variability on the corridor and even improve traffic conditions at the problematic intersection of Huntington Avenue and South Huntington Avenue. Finally, also as discussed, plans are consistent in their assignment of single-car trains to the E branch only, limiting the number of single-car trains in the central subway and decreasing the risk of delays relatively to operating schemes that mix single-car trains throughout the system.

Path B uses single-car trains only on a truncated version of the C branch that short-turns at Kenmore, avoiding entering the main tunnel of the Central Subway east of Kenmore. This is a strategy that enables some of the benefits of single-car trains to be realized without risking the potential disadvantages of single-car operations highlighted in Section 5.1. This comes at the penalty of an extra transfer for C branch riders; however, C branch riders will be on trains with the lowest headways in the system. Furthermore, it is possible that the service can use exclusively the new Type 9 cars since it only requires 10 - 13 cars (the full order of Type 9s will bring the total to 24 cars). A potentially operationally challenging aspect of Plan B is that the short-turning of single-car trains at Kenmore requires the addition of the two-car service between Kenmore and Park Street in phases III and IV. The turnaround at Kenmore requires trains to exit Kenmore through the B branch portal and turn using the layup track at the next station, Blandford Street (this track does not have platforms, so no passenger service to the Blandford Street station would be provided by this service). This will require staffing of the Blandford Street switch anytime the service pattern is put into effect (i.e., peak hours); however, permanent staffing of switches on the Green Line is not a new practice (as shown in Figure 2-2 in Chapter 2, short-turns occur throughout the day at Brigham Circle, which requires manual activation of switches).

5.7.2 Track Congestion

It has previously been presented in Chapter 2 that track congestion can create breakdowns in service. Specifically, Figure 5-6 compares the service rate (defined as departures out of the Central Subway within a ten-minute period) centered around measurements of the number of trains in the Central Subway from weekday AVL data in Fall 2019. The data suggest that the Green Line experiences peak service rate when there are between 25 and 30 two-car trains in the Central Subway at a given time. More than 30 trains within the Central Subway at a given time is capable of causing congestion, leading to increased run times and decreased service rate.

Phases III and IV of Path A along with Phase IV of the Current Path feature headways lower than that of pre-pandemic conditions, possibly increasing the chances of service breakdowns. As an indicator of the breakdown potential of these service plans, Zhou [24] used a Green Line simulation tool originally developed by Fabian [4] to study the congestion implications of low headways. When unimpeded, the simulation assumes trains move at free-flow speeds, but links and nodes have capacities that force trains to wait for track clearance (e.g., stations only allow one train in each direction at a time). Dwell times at stations are calculated based on boarding and alighting passenger volumes, and for the purposes of these tests, the dwell time module was modified to include the Central Subway dwell time findings in Lin and

Wilson [8], therefore assuming that single-car trains at capacity have higher variability in dwell times compared to two-car trains with identical car loads. Demand was consistent with the GLX forecasts.

For calculations, the number of trains in the Central Subway was measured using of the "equivalent number of double-car trains." It was assumed that a single-car train is equivalent, from a congestion perspective, to 7/10ths of a double-car train. The simulation results indicate that, even with single-car trains, the service rate is similar, around 7 to 8 trains per 10-minute period, as in Figure 5-6. The simulation results do not show a service breakdown beyond 30 trains. Overall, the simulation analysis does not suggest that single-car trains nor high headways will, by themselves, result in a degradation of service.

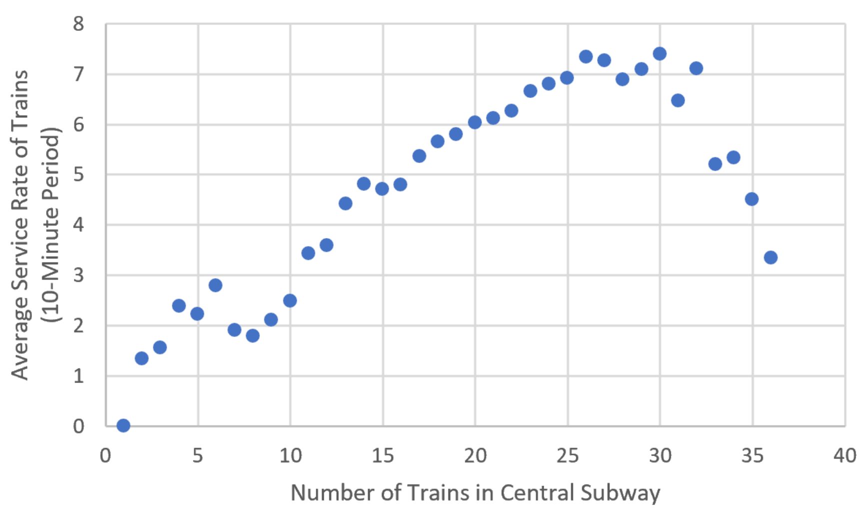

Figure 5-6: Fall 2019 AVL Central Subway Service Rate Versus Number of Trains in the Central Subway

5.7.3 Route Consistency

Path A and the Current Path are advantageous in that the service patterns remain highly consistent from Phase I to Phase IV. The Current Path suggests one minor change after Phase I in the B service terminus from Government Center to Park Street; Path A retains entirely the same routings regardless of the phase. In addition, Phase I maintains a strong degree of consistency with current operating patterns; besides serving the GLX, the only change between recent (pre-GLX construction) service and Phase I of Path A, for example, is the C branch turning at Government Center, a difference in two stops from the C branch's current turnaround at North Station.

Path B, on the other hand, terminates the C branch service at Kenmore rather than North Station; this is a big change from the status quo as C branch trains would no longer serve any sections of the Central Subway. However, this occurs at the same time as the aforementioned 47% reduction of headways on the C branch. Between Phase II and Phase III, a new service from Kenmore to Park Street must be introduced to provide capacity for higher demand. This is a minor change, and the only service reduction is a modest rise in headways on the surface portions of the branches — an additional 12 seconds on the C branch, 40 seconds on the D branch, and 12 seconds on the E branch. However, this is accompanied by a decrease in average headways within the central subway of nearly 30 seconds.

Other routing options were considered as well, including the use of the Brattle Loop at Government Center, which turns southbound trains back towards the GLX. Similarly to Path B, use of the loop with single-car trains on the GLX would avoid mixing single-car and two-car operations on most segments of the Central Subway. However, these service plans are not capable of providing the necessary capacity under scenarios with limited agency resources, so assuming the GLX initially opens under conditions of limited resources, an alternative path comprised of these solutions would introduce an additional transfer for GLX riders partway through the phase progression. Moreover, use of the Brattle Loop still requires C branch trains to turn at Kenmore *and* requires an additional service within the Central Subway similar to Path B, resulting in more transfers than Path B solutions.

5.7.4 Transfer Penalty

The solutions generated by the model assume that a transfer is equivalent to five minutes of wait time based on the results of Guo [6] (and discussion of the choice of penalty is in Chapter 3). However, for reasons such as agency policy, reduction of transfers may be more desirable. Within the optimization framework proposed in this thesis, this can be accomplished by using a higher transfer penalty.

Even without increasing the transfer penalty, there are some examples of alternate turnaround locations present within the results. Table 5.19 shows solutions with alternate turnarounds at Government Center for both the Current Path and Path A. For each phase, two sets of service patterns are provided for each plan: one in which the B service turns at Park Street, and one, in the row directly below, in which the B service turns at Government Center. Only the optimal solution fitting the routing described is included.

In all cases, extending the B branch to Government Center reduces transfers by 5 passengers per 1,000. In five out of the six cases shown in the figure, there is an an EWT increase between 1.0% and 1.6%, corresponding to a net headway increase of 15 to 41 seconds. In Phase III of Path A, the increase is larger at 4.8% (69 seconds), possibly caused by headway integrality requirements.

Table 5.19: Comparison of Government Center versus Park Street Turnarounds

Phase	Path	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)	Total Headway Added (sec)	EWT Increase
I	A	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.25	116	2049	3295	45	30	1.6%
		BC-GC	CC-GC	R-US	HS-MT	7.50	7.50	7.50	5.25	116	2049	3347	40		
II	Current	BC-PS	CC-GC	R-US	HS-MT	6.50	7.50	6.80	6.80	134	2383	3442	45	30	1.5%
		BC-GC	CC-GC	R-US	HS-MT	7.00	7.50	6.80	6.80	134	2383	3493	40		
	A	BC-PS	CC-GC	R-US	HS-MT	5.75	7.50	6.50	4.00	135	2379	2828	45	15	1.0%
		BC-GC	CC-GC	R-US	HS-MT	6.20	7.00	6.80	4.00	135	2385	2857	40		
III	A	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	6.33	4.00	152	2676	2666	45	69	4.8%
		BC-GC	CC-GC	R-US	HS-MT	4.40	7.75	7.20	4.00	154	2668	2796	40		
IV	Current	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.67	5.75	172	3067	2845	45	41	1.7%
		BC-GC	CC-GC	R-US	HS-MT	6.60	5.80	5.50	5.50	172	3081	2894	40		
	A	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	4.00	162	2860	2500	45	24	1.6%
		BC-GC	CC-GC	R-US	HS-MT	5.60	5.80	5.67	4.00	162	2860	2541	40		
													Average:	35	2.0%

If reducing transfers is a priority, small adjustments like the extension of the B branch to Government Center are possible. However, the increased headways may raise the volume-capacity ratio, such as in Phase III, where the Current Plan is unable to support an extension to Government Center as it would exceed the allowable ratio.

For an even greater trade-off, a higher transfer penalty may be used in the optimization. Table 5.20 shows solutions for the Current Path and Path A with B branch turnarounds at North Station generated by raising the transfer penalty to 11.0 compared to the solution with a transfer penalty of 5 directly below. In all cases, transfers decrease by 14 per 1,000 (31%). However, the total increase in headways across all services is between 63 seconds and 78 seconds, corresponding to an increase in expected wait time from 3.7% to 5.3% systemwide.

Table 5.20: Comparison of North Station versus Park Street Turnarounds

Phase	Path	Service Patterns	Headways (min)	Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)	Total Headway Added (sec)	EWT Increase
I	A	BC-PS CC-GC R-US HS-MT	7.00 7.50 7.50 5.25	116	2049	3295	45	78	5.3%
		BC-NS CC-GC R-US HS-MT	7.75 7.50 7.50 5.80	116	2040	3471	31		
II	Current	BC-PS CC-GC R-US HS-MT	6.50 7.50 6.80 6.80	134	2383	3442	45	75	3.7%
		BC-NS CC-GC R-US HS-MT	7.75 7.50 6.80 6.80	134	2383	3570	31		
	A	BC-PS CC-GC R-US HS-MT	5.75 7.50 6.50 4.00	135	2379	2828	45	63	3.9%
		BC-NS CC-GC R-US HS-MT	7.00 7.00 6.80 4.00	135	2385	2939	31		
IV	Current	BC-PS CC-GC R-US HS-MT	5.50 5.80 5.67 5.75	172	3067	2845	45	70	4.2%
		BC-NS CC-GC R-US HS-MT	6.67 5.80 5.67 5.75	172	3067	2965	31		
	A	BC-PS CC-GC R-US HS-MT	5.20 5.80 5.67 4.00	162	2860	2500	45	68	4.7%
		BC-NS CC-GC R-US HS-MT	6.33 5.80 5.67 4.00	162	2860	2617	31		
							Average:	71	4.4%

If the transfer penalty is increased to 11.0 (and other model parameters are not changed), fifty-three of the top 100 outputs now have one or both of the trains turning at North Station, and just two feature both the B and C turning at Park Street and Government Center. Note that North Station has a 4-minute longer turnaround time than Government Center.

In this case, further reductions in transfers are possible under some conditions by raising headways. However, in both paths, it is impossible to extend the B branch to North Station in Phase III without exceeding the allowable volume-capacity ratio. An increase in total operator hours would be necessary to maintain service to North Station and concurrently provide sufficient capacity in the Central Subway.

In general, the Alternate Paths provide greater flexibility in potential turnaround locations than the Current Path does, owing to the more efficient use of resources enabled by single-car trains. This translates to a greater ability to reduce transfers by extending the services further into the Central Subway, as seen in the cases above where only Path A provides an option to extend a service without exceeding the allowable volume-capacity ratio.

Chapter 6

Conclusions

Planning under uncertainty and planning for complex networks presents challenges to service planners. Using traditional planning methods to address either problem may result in sub-par solutions. In particular, while raising headways to address shortages in agency resources or increased run times may present short-term fixes to these problems operationally, passenger level-of-service suffers as a result.

This thesis describes a method by which service plans for complex trunks-with-branches networks may be analyzed efficiently and without the need for manual selection of service combinations. The combined qualitative-algorithmic approach enables service planners to account for the uncertainty of changing conditions while focusing on delivering solutions with good LOS.

The MBTA Green Line requires new service patterns due to a substantial network modification, the Green Line Extension (GLX). Resources must be allocated equitably across the four existing branches as well as the two new GLX branches while providing adequate capacity within the trunk section. This is occurring in the context of recovery from the COVID-19 pandemic, which has created a (likely temporary) decrease in demand and agency resources. The proposed service planning method has been used to develop recommendations for MBTA Green Line operations upon completion of the GLX. The recommended service plans are likely to provide a higher level-of-service than service plans that adhere closely to pre-GLX operations, all while taking into account the uncertain nature of future conditions.

6.1 Research Summary

The goal of this thesis was to create a general method of service planning for trunk-with-branches transit networks that could be used to propose service plans for the post-GLX Green Line.

A four-step service planning method was developed to address the problem. A scenario planning exercise was used to determine likely states of operation in the short- and long-term. Then, an integer linear program was developed to evaluate the level-of-service impacts of different combinations of service plans under constraints such as the fleet requirement, operator hours, and capacity. A qualitative analysis of the proposed solutions followed, in which overarching trends across scenarios were used to identify robust strategies or further operational constraints. Finally, sets of similar service plans were identified from the robust strategies that provided a high level-of-service under all scenarios.

A detailed analysis of current and recent operating practices was conducted to determine the range of potential solutions to consider as well as to identify important operational considerations. Run times, origin-destination flows, and other unknown aspects of post-GLX operations were estimated by combining existing data sources with various methods of estimation, including simulation. The resulting inputs informed not only the eventual results but also the design of the scenarios and the development of the integer program.

6.2 Research Findings

Four key scenarios were identified, denoted Phases I through IV, that represent a likely progression of operating conditions from the opening of the GLX to long-term forecasts of demand and agency resources. The strength of the highlighted operating strategies was determined in large part by the existence of high-performing solutions utilizing those strategies in every phase. Two operating strategies in particular, denoted Path A and Path B, provide solutions that are robust to changing conditions and provide good LOS under all likely conditions.

The proposed solutions share a number of characteristics:

- Operating D branch service through the Central Subway to Union Square on the GLX
- Operating E branch service through the Central Subway to Medford/Tufts on the GLX
- Scheduling single-car trains on one service (and using them exclusively on that service)
- Opening the GLX with peak-hour headways between 7 and 7.5 minutes for any two-car train services and between 4.8 and 5.25 minutes for the single-car service
- Prioritizing use of the ADA-accessible fleet over use of the non-accessible Type 7s

Other aspects of operations, such as the turnaround locations assigned to the B branch and C branch, are dependent on the particular strategy pursued.

Through the use of single-car trains during the peak period, operating strategies for the post-GLX Green Line exist that reduce expected wait time (EWT) systemwide relatively to solutions that adhere strictly to use of two-car trains. The findings also reveal a trade-off between wait time and transfers when choosing the turnaround locations of services.

6.2.1 Use of Single-Car Trains

The use of single-car trains on specific branches of the Green Line results in systemwide LOS benefits due to lower headways. Two-car trains require two operators, whereas a single-car train requires only one operator, so the marginal cost of adding an additional single-car train to the network is lower than that of a two-car train. By scheduling for adequate capacity and limiting the use of single-car trains to one service pattern (and using single-car trains exclusively within that service pattern), the potential disadvantages of single-car trains identified in previous research is likely to be avoided.

Specifically, running a single-car train on the E branch from Heath Street through the Central Subway to Medford/Tufts on the GLX is identified as a promising strategy, called "Path A." Under forecasted opening conditions, the Path A solution is estimated to result in a 15% decrease in wait time systemwide relatively to current plans while maintaining a similar number of transfers. Moreover, even under scenarios with the least agency resources, Path A solutions are able to support headways similar to those of pre-pandemic operations despite the larger post-GLX network.

Alternatively, a "Path B" is also identified that takes advantage of some of the wait time benefits seen in Path A while avoiding any potential risks of mixing single-car and two-car train operations in the Central Subway. These solutions use single-car trains exclusively on a truncated C branch service that short-turns at Kenmore. While this results in a higher number of transfers, headways and wait times are still lower than those required to maintain two-car operations everywhere.

Overall, the single-car options proposed (in particular, Path A) provide a higher level-of-service than is attainable by the Current Plan. Even as demand and agency resources increase over time, Path A is expected to reduce wait time by 18% in Phases II and III relative to the Current Plan without any increase in transfers. By Phase II, which assumes the same level of agency resources as were scheduled in the pandemic-affected Fall 2020 rating, headways in either path will overall be *lower* than that of pre-pandemic schedules. A swift return to a full level of service, which can be more easily facilitated by the Alternate Paths than by the Current Path, will be critical to building back a consistent base of ridership. Moreover, these level-of-service benefits extend to the GLX, where a high quality service from the beginning of operations will be important to encourage mode shift.

6.2.2 Trade-Off Between Transfers and EWT

The results include several examples where the option exists to extend or truncate a service to a different turnaround location. Extending a service results in fewer transfers; however, this comes at the cost of wait time, as headways must be raised to accommodate the longer run time. By using the proposed method, the options to compare are optimal from a systemwide LOS perspective. Comparison of the options reveals that an extension of the B branch from Park Street to Government Center results, on average, in a 2% increase in overall EWT and a reduction of transfers by 5 per 1,000 passengers. A further extension of this service to North Station results in an average 4.4% increase in overall EWT and a reduction of transfers by 14 per 1,000 passengers.

However, the proposed method also finds that a B branch extension to North Station is infeasible under certain high-demand scenarios as it is accommodated only under higher headways that do not provide the required capacity. Therefore, although the number of transfers may be a matter of policy, there are limits to the actions the agency may take. Furthermore, these actions result in a higher wait time even under the most optimal service configurations.

6.3 Discussion

The analyses in this thesis suggest that the use of single-car trains may improve LOS and result in a more efficient use of agency resources. However, the analysis that was done was limited to the PM peak period, so further (and more targeted) investigation is necessary to determine final service plans and could identify opportunities that can support the use of single-car trains.

It is possible that further efficiencies may be realized by the use of less peaky schedules to match recovering demand patterns. The lower per-train operator hour cost of single-car trains relative to two-car trains may also help to reduce the "peakiness" of operator schedules if more single-car trains are put into service in the ramp-ups to the peak periods.

Ridership on the individual branches should be monitored as demand increases. Given the disparate land use patterns between the different branches, demand could return at different rates across the various branches, possibly leading to slight revisions of headways from what has been recommended. This analysis assumed that the distribution of travel patterns would remain the same on the Green Line network even as the overall demand level changed.

To shorten dwell times in the Central Subway, passengers should be made aware (by announcements and/or by signs at appropriate stations) that a particular service is being run with single-car trains. This will help passengers anticipate where to stand on the platform to board a single-car train.

Under short-term conditions, the service plans with single-car trains use larger numbers of accessible vehicles than service plans that exclusively use two-car trains. Having the space and labor to maintain the accessible vehicles is critical to keep up with rising demand. Availability of the full fleet of twenty-four Type 9s as well as the completion of the East Somerville Maintenance Facility are important.

The implementation of AFC 1.5 as an interim measure before the implementation of AFC 2.0 can help improve operating conditions. At equal levels of demand, the unusual center-door boarding patterns on the GLX mean that dwell times are likely to be higher on the GLX relatively to the western branches. Path A solutions recommend that the Medford Branch be served by single-car trains; because there is only one farebox on a single-car train, implementing AFC 1.5 will facilitate the deployment. At minimum, AFC 1.5 should be pursued at the busier GLX stops (e.g., Lechmere).

6.4 Future Research

The optimization program at the core of the qualitative-algorithmic service planning approach can be adapted for many trunks-with-branches networks, including further analyses of the Green Line. However, the model itself can use further refinement, with aspects of the input preparation or model constraints relying on assumptions or simplification of real-world situations. The following future research topics are broken down into two categories: model improvements and other applications.

6.4.1 Model Improvements

Trunk Congestion

Trunk-with-branches networks often take advantage of through-running from branches onto the trunk, as this improves the efficiency of the service for both passengers (by reducing transfers) and for the agency (by reducing turnarounds). However, this can also lead to congestion in the trunk section due to many services sharing infrastructure. This is particularly true for the Green Line, where the branches have traffic interactions, on-board fare collection, and other features that increase run time variability, making any attempt at coordinating schedules within the trunk difficult.

The formulation currently does not take into account the effects of congestion on run times. A preliminary analysis on congestion within the Green Line suggests that high congestion can lead to breakdowns in the rate of trains exiting the Central Subway, but given an adequately high level of agency resources, the formulation assumes that trains continue to provide the same throughput and consume the same resources despite any real-world congestion impacts. A more robust model would take into account these impacts and schedule accordingly, most likely by the introduction of a track congestion constraint or a service-pattern/segment-specific penalty.

Operator Hours Estimation

The estimation of operator hours for the service patterns considered included three key assumptions: one, that the length of the peak period would remain unchanged; two, that the ratio between the peak vehicle hours and the daily vehicle hours would remain unchanged; and three, that the ratio between the daily vehicle hours and the daily operator hours would remain unchanged. While the former assumption is a matter of travel demand patterns and agency policy, the latter two assumptions may be related in some way to the properties of the service pattern being scheduled (e.g., the peak headway, the difference between the peak headway and the off-peak headway, the consist length, etc.). Further investigation of these relationships could lead to a more precise estimation of the required operator hours.

Demand Forecasts

A more formal analysis of future demand could result in a more targeted implementation strategy or further adjustment of the recommended service plans. The demand forecast used in this analysis includes several key assumptions, such as the applicability of 2007 CTPS estimates and 2017 ODX to a 2022 demand forecast with minimal scaling; the proportion of intra-branch trips on the GLX, and the lack of a long-term shift in intra-system travel patterns following the COVID-19 pandemic, among other assumptions.

Additional analysis could involve closer scrutiny of the data sources and associated ridership trends over time to develop a more targeted method of scaling, as well as the incorporation of more recent (i.e., post-pandemic) ridership data. Alternatively, travel demand models (such as the four-step model, or a direct demand model) could be used instead to predict ridership based on land use, demographic, and infrastructure characteristics not directly captured within existing ODX data.

6.4.2 Other Applications

Future Extensions

Numerous extensions to the Green Line have been discussed in published planning documents, popular media, and other circles. This model is well-equipped to suggest efficient service plans for any of these possible extensions, as they generally continue to fit within the trunk-with-branches type of networks.

The Green Line Extension's Environmental Assessment [12] investigated the possibility of a one-stop extension of the Medford Branch to Route 16 along with a park-and-ride facility. Years before, this proposal had been somewhat controversial due to fears that a park-and-ride would increase traffic in the community [10], but such an extension could theoretically be completed without a park-and-ride, as the right-of-way for it exists. Similarly, the Union Square branch could proceed along the existing commuter rail right-of-way to Porter (on the Red Line) and further towards Watertown or Waltham on existing rights-of-way.

On the southern end of the E branch, the current Heath Street terminus of the Green Line could be extended south along its former right-of-way towards Hyde Square, a partial restoration of the E branch service to Arborway that was lost decades ago.

Finally, another interesting possibility is the creation of a third GLX branch, also splitting at Lechmere, that would proceed down the Grand Junction Railroad right-of-way to serve East Cambridge, Kendall Square, Cambridgeport, and eventually the proposed West Boston commuter rail station in Allston (using the existing Grand Junction Railroad Bridge over the Charles River, which has empty space for an additional track). Alternatively, additional service could be extended west from Kenmore following the B branch until diverging in Allston to reach the proposed commuter rail station.

Type 10 Vehicles and Other Investments

The MBTA is planning for a full fleet replacement with longer, higher-capacity vehicles in the Green Line's future (the GLX is being built with 225-foot platforms for this reason). This large change would warrant another evaluation of Green Line operating schemes, especially as some of the considerations that influenced these results — such as one operator being required per train, or the ADA accessibility considerations — would presumably be rendered obsolete with the acquisition of new rolling stock. Furthermore, this service planning method should be considered as a tool to test the performance of future rolling stock in advance of and during the procurement process — for example, to compare optimal solutions between trains of different lengths or different projected dwell times/run times.

More generally, the algorithmic-qualitative approach can be used to suggest the shadow prices of various constraints, including the fleet, but also provided capacity or run times (which affect the fleet requirement and operator hours), among other potential improvements. Modification of the constraints can reveal the value of potential service plans under relaxed conditions, particularly when evaluating investments that warrant significant shifts in operations. Alternatively, tightening constraints — for example, by removing vehicles from the fleet — could reveal vulnerabilities in the system, which is a critical context when deciding the value of investments (e.g., purchasing more cars to protect against the loss of rolling stock).

Equity Trade-Offs

In Chapter 3, two constraints are discussed as having potential equity implications, namely the branch headway constraint and the LOS constraint. Strictly speaking, implementing new constraints will always make the resulting solutions the same or worse than the solutions without those constraints, purely from the perspective of the objective function. This is not unrealistic: real-life efforts to address equity often require sacrifice of efficiency, operational desirability, or (in the case of this objective function) the overall quality of a delivered service. In some cases, however, the costs are perceived to be so severe that the equity concerns are not addressed.

The qualitative-algorithmic approach is helpful in this context. Similarly to determining the value of investments, the approach can provide the system-level cost context for efforts to address equity. However, the qualitative-algorithmic approach can further help to avoid inflation of the perceived costs of achieving equity. Traditional service planning methods may not take into consideration possible service plans that accommodate the equity goals without major sacrifice. In some cases, it may even be found that the adoption of novel operating strategies (such as the use of single-car trains) could improve service *at the same time as* equity goals are addressed.

Appendix A

Input Service Patterns

A.1 Service Patterns (Run Times Based on Original Demand Forecast)

A.1.1 Service Patterns Terminating at Boston College

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Boston Col	Park St	1	4	413	28	1545
Boston Col	Park St	1	4.2	383	26	1471
Boston Col	Park St	1	4.4	368	25	1405
Boston Col	Park St	1	4.6	354	24	1343
Boston Col	Park St	1	4.75	339	23	1301
Boston Col	Park St	1	5	324	22	1236
Boston Col	Park St	1	5.2	310	21	1188
Boston Col	Park St	1	5.5	295	20	1124
Boston Col	Park St	1	5.75	280	19	1075
Boston Col	Park St	1	6.2	265	18	997
Boston Col	Park St	1	6.5	251	17	951

Boston Col	Park St	1	7	236	16	883
Boston Col	Park St	1	7.33	221	15	843
Boston Col	Park St	1	7.8	206	14	792
Boston Col	Park St	2	4	825	56	3090
Boston Col	Park St	2	4.2	766	52	2943
Boston Col	Park St	2	4.4	737	50	2809
Boston Col	Park St	2	4.6	707	48	2687
Boston Col	Park St	2	4.75	678	46	2602
Boston Col	Park St	2	5	649	44	2472
Boston Col	Park St	2	5.2	619	42	2377
Boston Col	Park St	2	5.5	590	40	2247
Boston Col	Park St	2	5.75	560	38	2150
Boston Col	Park St	2	6.2	531	36	1994
Boston Col	Park St	2	6.5	501	34	1902
Boston Col	Park St	2	7	472	32	1766
Boston Col	Park St	2	7.33	442	30	1685
Boston Col	Park St	2	7.8	413	28	1585
Boston Col	Govt Ctr	1	4	442	30	1545
Boston Col	Govt Ctr	1	4.2	413	28	1471
Boston Col	Govt Ctr	1	4.4	398	27	1405
Boston Col	Govt Ctr	1	4.6	383	26	1343
Boston Col	Govt Ctr	1	4.75	368	25	1301
Boston Col	Govt Ctr	1	5	354	24	1236
Boston Col	Govt Ctr	1	5.2	339	23	1188
Boston Col	Govt Ctr	1	5.4	324	22	1144
Boston Col	Govt Ctr	1	5.6	310	21	1104
Boston Col	Govt Ctr	1	6	295	20	1030
Boston Col	Govt Ctr	1	6.2	280	19	997

Boston Col	Govt Ctr	1	6.6	265	18	936
Boston Col	Govt Ctr	1	7	251	17	883
Boston Col	Govt Ctr	1	7.4	236	16	835
Boston Col	Govt Ctr	2	4	884	60	3090
Boston Col	Govt Ctr	2	4.2	825	56	2943
Boston Col	Govt Ctr	2	4.4	796	54	2809
Boston Col	Govt Ctr	2	4.6	766	52	2687
Boston Col	Govt Ctr	2	4.75	737	50	2602
Boston Col	Govt Ctr	2	5	707	48	2472
Boston Col	Govt Ctr	2	5.2	678	46	2377
Boston Col	Govt Ctr	2	5.4	649	44	2289
Boston Col	Govt Ctr	2	5.6	619	42	2207
Boston Col	Govt Ctr	2	6	590	40	2060
Boston Col	Govt Ctr	2	6.2	560	38	1994
Boston Col	Govt Ctr	2	6.6	531	36	1873
Boston Col	Govt Ctr	2	7	501	34	1766
Boston Col	Govt Ctr	2	7.4	472	32	1670
Boston Col	North Sta	1	4	501	34	1545
Boston Col	North Sta	1	4.2	472	32	1471
Boston Col	North Sta	1	4.33	457	31	1426
Boston Col	North Sta	1	4.5	442	30	1373
Boston Col	North Sta	1	4.6	427	29	1343
Boston Col	North Sta	1	4.75	413	28	1301
Boston Col	North Sta	1	5	398	27	1236
Boston Col	North Sta	1	5.2	383	26	1188
Boston Col	North Sta	1	5.33	368	25	1159
Boston Col	North Sta	1	5.6	354	24	1104
Boston Col	North Sta	1	5.75	339	23	1075

Boston Col	North Sta	1	6.2	324	22	997
Boston Col	North Sta	1	6.33	310	21	976
Boston Col	North Sta	1	6.67	295	20	927
Boston Col	North Sta	1	7	280	19	883
Boston Col	North Sta	1	7.4	265	18	835
Boston Col	North Sta	1	7.8	251	17	792
Boston Col	North Sta	2	4	1002	68	3090
Boston Col	North Sta	2	4.2	943	64	2943
Boston Col	North Sta	2	4.33	914	62	2852
Boston Col	North Sta	2	4.5	884	60	2747
Boston Col	North Sta	2	4.6	855	58	2687
Boston Col	North Sta	2	4.75	825	56	2602
Boston Col	North Sta	2	5	796	54	2472
Boston Col	North Sta	2	5.2	766	52	2377
Boston Col	North Sta	2	5.33	737	50	2318
Boston Col	North Sta	2	5.6	707	48	2207
Boston Col	North Sta	2	5.75	678	46	2150
Boston Col	North Sta	2	6.2	649	44	1994
Boston Col	North Sta	2	6.33	619	42	1952
Boston Col	North Sta	2	6.67	590	40	1854
Boston Col	North Sta	2	7	560	38	1766
Boston Col	North Sta	2	7.4	531	36	1670
Boston Col	North Sta	2	7.8	501	34	1585
Boston Col	Union Sq	1	4	575	39	1545
Boston Col	Union Sq	1	4.2	545	37	1471
Boston Col	Union Sq	1	4.33	531	36	1426
Boston Col	Union Sq	1	4.4	516	35	1405
Boston Col	Union Sq	1	4.6	501	34	1343

Boston Col	Union Sq	1	4.67	486	33	1324
Boston Col	Union Sq	1	5	457	31	1236
Boston Col	Union Sq	1	5.2	442	30	1188
Boston Col	Union Sq	1	5.33	427	29	1159
Boston Col	Union Sq	1	5.5	413	28	1124
Boston Col	Union Sq	1	5.75	398	27	1075
Boston Col	Union Sq	1	6	383	26	1030
Boston Col	Union Sq	1	6.2	368	25	997
Boston Col	Union Sq	1	6.5	354	24	951
Boston Col	Union Sq	1	6.75	339	23	916
Boston Col	Union Sq	1	7	324	22	883
Boston Col	Union Sq	1	7.33	310	21	843
Boston Col	Union Sq	1	7.75	295	20	797
Boston Col	Union Sq	2	4	1150	78	3090
Boston Col	Union Sq	2	4.2	1091	74	2943
Boston Col	Union Sq	2	4.33	1061	72	2852
Boston Col	Union Sq	2	4.4	1032	70	2809
Boston Col	Union Sq	2	4.6	1002	68	2687
Boston Col	Union Sq	2	4.67	973	66	2649
Boston Col	Union Sq	2	5	914	62	2472
Boston Col	Union Sq	2	5.2	884	60	2377
Boston Col	Union Sq	2	5.33	855	58	2318
Boston Col	Union Sq	2	5.5	825	56	2247
Boston Col	Union Sq	2	5.75	796	54	2150
Boston Col	Union Sq	2	6	766	52	2060
Boston Col	Union Sq	2	6.2	737	50	1994
Boston Col	Union Sq	2	6.5	707	48	1902
Boston Col	Union Sq	2	6.75	678	46	1831

Boston Col	Union Sq	2	7	649	44	1766
Boston Col	Union Sq	2	7.33	619	42	1685
Boston Col	Union Sq	2	7.75	590	40	1595
Boston Col	Medford/Tufts	1	4	604	41	1545
Boston Col	Medford/Tufts	1	4.2	575	39	1471
Boston Col	Medford/Tufts	1	4.33	560	38	1426
Boston Col	Medford/Tufts	1	4.4	545	37	1405
Boston Col	Medford/Tufts	1	4.5	531	36	1373
Boston Col	Medford/Tufts	1	4.67	516	35	1324
Boston Col	Medford/Tufts	1	4.8	501	34	1288
Boston Col	Medford/Tufts	1	5	486	33	1236
Boston Col	Medford/Tufts	1	5.2	472	32	1188
Boston Col	Medford/Tufts	1	5.25	457	31	1177
Boston Col	Medford/Tufts	1	5.4	442	30	1144
Boston Col	Medford/Tufts	1	5.6	427	29	1104
Boston Col	Medford/Tufts	1	5.8	413	28	1066
Boston Col	Medford/Tufts	1	6	398	27	1030
Boston Col	Medford/Tufts	1	6.25	383	26	989
Boston Col	Medford/Tufts	1	6.5	368	25	951
Boston Col	Medford/Tufts	1	6.75	354	24	916
Boston Col	Medford/Tufts	1	7.2	339	23	858
Boston Col	Medford/Tufts	1	7.4	324	22	835
Boston Col	Medford/Tufts	1	7.75	310	21	797
Boston Col	Medford/Tufts	2	4	1209	82	3090
Boston Col	Medford/Tufts	2	4.2	1150	78	2943
Boston Col	Medford/Tufts	2	4.33	1120	76	2852
Boston Col	Medford/Tufts	2	4.4	1091	74	2809
Boston Col	Medford/Tufts	2	4.5	1061	72	2747

Boston Col	Medford/Tufts	2	4.67	1032	70	2649
Boston Col	Medford/Tufts	2	4.8	1002	68	2575
Boston Col	Medford/Tufts	2	5	973	66	2472
Boston Col	Medford/Tufts	2	5.2	943	64	2377
Boston Col	Medford/Tufts	2	5.25	914	62	2354
Boston Col	Medford/Tufts	2	5.4	884	60	2289
Boston Col	Medford/Tufts	2	5.6	855	58	2207
Boston Col	Medford/Tufts	2	5.8	825	56	2131
Boston Col	Medford/Tufts	2	6	796	54	2060
Boston Col	Medford/Tufts	2	6.25	766	52	1978
Boston Col	Medford/Tufts	2	6.5	737	50	1902
Boston Col	Medford/Tufts	2	6.75	707	48	1831
Boston Col	Medford/Tufts	2	7.2	678	46	1717
Boston Col	Medford/Tufts	2	7.4	649	44	1670
Boston Col	Medford/Tufts	2	7.75	619	42	1595

A.1.2 Service Patterns Terminating at Cleveland Circle

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Cleveland Cir	Kenmore	1	4	284	14	1545
Cleveland Cir	Kenmore	1	4.2	264	13	1471
Cleveland Cir	Kenmore	1	4.6	243	12	1343
Cleveland Cir	Kenmore	1	5	223	11	1236
Cleveland Cir	Kenmore	1	5.5	203	10	1124
Cleveland Cir	Kenmore	1	6.2	183	9	997
Cleveland Cir	Kenmore	1	6.8	162	8	909
Cleveland Cir	Kenmore	1	7.75	142	7	797
Cleveland Cir	Kenmore	2	4	568	28	3090
Cleveland Cir	Kenmore	2	4.2	528	26	2943
Cleveland Cir	Kenmore	2	4.6	487	24	2687
Cleveland Cir	Kenmore	2	5	446	22	2472
Cleveland Cir	Kenmore	2	5.5	406	20	2247
Cleveland Cir	Kenmore	2	6.2	365	18	1994
Cleveland Cir	Kenmore	2	6.8	325	16	1818
Cleveland Cir	Kenmore	2	7.75	284	14	1595
Cleveland Cir	Park St	1	4	446	22	1545
Cleveland Cir	Park St	1	4.2	426	21	1471
Cleveland Cir	Park St	1	4.25	406	20	1454
Cleveland Cir	Park St	1	4.5	386	19	1373
Cleveland Cir	Park St	1	4.75	365	18	1301
Cleveland Cir	Park St	1	5	345	17	1236
Cleveland Cir	Park St	1	5.33	325	16	1159
Cleveland Cir	Park St	1	5.67	304	15	1091

Cleveland Cir	Park St	1	6.2	284	14	997
Cleveland Cir	Park St	1	6.6	264	13	936
Cleveland Cir	Park St	1	7.2	243	12	858
Cleveland Cir	Park St	1	7.75	223	11	797
Cleveland Cir	Park St	2	4	893	44	3090
Cleveland Cir	Park St	2	4.2	852	42	2943
Cleveland Cir	Park St	2	4.25	812	40	2908
Cleveland Cir	Park St	2	4.5	771	38	2747
Cleveland Cir	Park St	2	4.75	730	36	2602
Cleveland Cir	Park St	2	5	690	34	2472
Cleveland Cir	Park St	2	5.33	649	32	2318
Cleveland Cir	Park St	2	5.67	609	30	2181
Cleveland Cir	Park St	2	6.2	568	28	1994
Cleveland Cir	Park St	2	6.6	528	26	1873
Cleveland Cir	Park St	2	7.2	487	24	1717
Cleveland Cir	Park St	2	7.75	446	22	1595
Cleveland Cir	Govt Ctr	1	4	487	24	1545
Cleveland Cir	Govt Ctr	1	4.2	467	23	1471
Cleveland Cir	Govt Ctr	1	4.25	446	22	1454
Cleveland Cir	Govt Ctr	1	4.5	426	21	1373
Cleveland Cir	Govt Ctr	1	4.67	406	20	1324
Cleveland Cir	Govt Ctr	1	5	386	19	1236
Cleveland Cir	Govt Ctr	1	5.2	365	18	1188
Cleveland Cir	Govt Ctr	1	5.5	345	17	1124
Cleveland Cir	Govt Ctr	1	5.8	325	16	1066
Cleveland Cir	Govt Ctr	1	6.2	304	15	997
Cleveland Cir	Govt Ctr	1	6.67	284	14	927
Cleveland Cir	Govt Ctr	1	7.2	264	13	858

Cleveland Cir	Govt Ctr	1	7.75	243	12	797
Cleveland Cir	Govt Ctr	2	4	974	48	3090
Cleveland Cir	Govt Ctr	2	4.2	933	46	2943
Cleveland Cir	Govt Ctr	2	4.25	893	44	2908
Cleveland Cir	Govt Ctr	2	4.5	852	42	2747
Cleveland Cir	Govt Ctr	2	4.67	812	40	2649
Cleveland Cir	Govt Ctr	2	5	771	38	2472
Cleveland Cir	Govt Ctr	2	5.2	730	36	2377
Cleveland Cir	Govt Ctr	2	5.5	690	34	2247
Cleveland Cir	Govt Ctr	2	5.8	649	32	2131
Cleveland Cir	Govt Ctr	2	6.2	609	30	1994
Cleveland Cir	Govt Ctr	2	6.67	568	28	1854
Cleveland Cir	Govt Ctr	2	7.2	528	26	1717
Cleveland Cir	Govt Ctr	2	7.75	487	24	1595
Cleveland Cir	North Sta	1	4	548	27	1545
Cleveland Cir	North Sta	1	4.2	528	26	1471
Cleveland Cir	North Sta	1	4.33	507	25	1426
Cleveland Cir	North Sta	1	4.5	487	24	1373
Cleveland Cir	North Sta	1	4.75	467	23	1301
Cleveland Cir	North Sta	1	5	446	22	1236
Cleveland Cir	North Sta	1	5.2	426	21	1188
Cleveland Cir	North Sta	1	5.4	406	20	1144
Cleveland Cir	North Sta	1	5.75	386	19	1075
Cleveland Cir	North Sta	1	6	365	18	1030
Cleveland Cir	North Sta	1	6.4	345	17	966
Cleveland Cir	North Sta	1	6.75	325	16	916
Cleveland Cir	North Sta	1	7.2	304	15	858
Cleveland Cir	North Sta	1	7.75	284	14	797

Cleveland Cir	North Sta	2	4	1096	54	3090
Cleveland Cir	North Sta	2	4.2	1055	52	2943
Cleveland Cir	North Sta	2	4.33	1015	50	2852
Cleveland Cir	North Sta	2	4.5	974	48	2747
Cleveland Cir	North Sta	2	4.75	933	46	2602
Cleveland Cir	North Sta	2	5	893	44	2472
Cleveland Cir	North Sta	2	5.2	852	42	2377
Cleveland Cir	North Sta	2	5.4	812	40	2289
Cleveland Cir	North Sta	2	5.75	771	38	2150
Cleveland Cir	North Sta	2	6	730	36	2060
Cleveland Cir	North Sta	2	6.4	690	34	1931
Cleveland Cir	North Sta	2	6.75	649	32	1831
Cleveland Cir	North Sta	2	7.2	609	30	1717
Cleveland Cir	North Sta	2	7.75	568	28	1595
Cleveland Cir	Union Sq	1	4	670	33	1545
Cleveland Cir	Union Sq	1	4.2	629	31	1471
Cleveland Cir	Union Sq	1	4.33	609	30	1426
Cleveland Cir	Union Sq	1	4.5	588	29	1373
Cleveland Cir	Union Sq	1	4.67	568	28	1324
Cleveland Cir	Union Sq	1	4.8	548	27	1288
Cleveland Cir	Union Sq	1	5	528	26	1236
Cleveland Cir	Union Sq	1	5.2	507	25	1188
Cleveland Cir	Union Sq	1	5.4	487	24	1144
Cleveland Cir	Union Sq	1	5.67	467	23	1091
Cleveland Cir	Union Sq	1	6	446	22	1030
Cleveland Cir	Union Sq	1	6.2	426	21	997
Cleveland Cir	Union Sq	1	6.5	406	20	951
Cleveland Cir	Union Sq	1	7	386	19	883

Cleveland Cir	Union Sq	1	7.2	365	18	858
Cleveland Cir	Union Sq	1	7.67	345	17	806
Cleveland Cir	Union Sq	2	4	1339	66	3090
Cleveland Cir	Union Sq	2	4.2	1258	62	2943
Cleveland Cir	Union Sq	2	4.33	1217	60	2852
Cleveland Cir	Union Sq	2	4.5	1177	58	2747
Cleveland Cir	Union Sq	2	4.67	1136	56	2649
Cleveland Cir	Union Sq	2	4.8	1096	54	2575
Cleveland Cir	Union Sq	2	5	1055	52	2472
Cleveland Cir	Union Sq	2	5.2	1015	50	2377
Cleveland Cir	Union Sq	2	5.4	974	48	2289
Cleveland Cir	Union Sq	2	5.67	933	46	2181
Cleveland Cir	Union Sq	2	6	893	44	2060
Cleveland Cir	Union Sq	2	6.2	852	42	1994
Cleveland Cir	Union Sq	2	6.5	812	40	1902
Cleveland Cir	Union Sq	2	7	771	38	1766
Cleveland Cir	Union Sq	2	7.2	730	36	1717
Cleveland Cir	Union Sq	2	7.67	690	34	1612
Cleveland Cir	Medford/Tufts	1	4	710	35	1545
Cleveland Cir	Medford/Tufts	1	4.2	670	33	1471
Cleveland Cir	Medford/Tufts	1	4.33	649	32	1426
Cleveland Cir	Medford/Tufts	1	4.5	629	31	1373
Cleveland Cir	Medford/Tufts	1	4.6	609	30	1343
Cleveland Cir	Medford/Tufts	1	4.75	588	29	1301
Cleveland Cir	Medford/Tufts	1	5	568	28	1236
Cleveland Cir	Medford/Tufts	1	5.2	548	27	1188
Cleveland Cir	Medford/Tufts	1	5.33	528	26	1159
Cleveland Cir	Medford/Tufts	1	5.5	507	25	1124

Cleveland Cir	Medford/Tufts	1	5.75	487	24	1075
Cleveland Cir	Medford/Tufts	1	6	467	23	1030
Cleveland Cir	Medford/Tufts	1	6.25	446	22	989
Cleveland Cir	Medford/Tufts	1	6.6	426	21	936
Cleveland Cir	Medford/Tufts	1	7	406	20	883
Cleveland Cir	Medford/Tufts	1	7.25	386	19	852
Cleveland Cir	Medford/Tufts	1	7.67	365	18	806
Cleveland Cir	Medford/Tufts	2	4	1420	70	3090
Cleveland Cir	Medford/Tufts	2	4.2	1339	66	2943
Cleveland Cir	Medford/Tufts	2	4.33	1299	64	2852
Cleveland Cir	Medford/Tufts	2	4.5	1258	62	2747
Cleveland Cir	Medford/Tufts	2	4.6	1217	60	2687
Cleveland Cir	Medford/Tufts	2	4.75	1177	58	2602
Cleveland Cir	Medford/Tufts	2	5	1136	56	2472
Cleveland Cir	Medford/Tufts	2	5.2	1096	54	2377
Cleveland Cir	Medford/Tufts	2	5.33	1055	52	2318
Cleveland Cir	Medford/Tufts	2	5.5	1015	50	2247
Cleveland Cir	Medford/Tufts	2	5.75	974	48	2150
Cleveland Cir	Medford/Tufts	2	6	933	46	2060
Cleveland Cir	Medford/Tufts	2	6.25	893	44	1978
Cleveland Cir	Medford/Tufts	2	6.6	852	42	1873
Cleveland Cir	Medford/Tufts	2	7	812	40	1766
Cleveland Cir	Medford/Tufts	2	7.25	771	38	1705
Cleveland Cir	Medford/Tufts	2	7.67	730	36	1612

A.1.3 Service Patterns Terminating at Riverside

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Riverside	Kenmore	1	4	361	21	1545
Riverside	Kenmore	1	4.2	344	20	1471
Riverside	Kenmore	1	4.4	327	19	1405
Riverside	Kenmore	1	4.67	310	18	1324
Riverside	Kenmore	1	5	292	17	1236
Riverside	Kenmore	1	5.2	275	16	1188
Riverside	Kenmore	1	5.6	258	15	1104
Riverside	Kenmore	1	6	241	14	1030
Riverside	Kenmore	1	6.4	224	13	966
Riverside	Kenmore	1	7	206	12	883
Riverside	Kenmore	1	7.6	189	11	813
Riverside	Kenmore	2	4	722	42	3090
Riverside	Kenmore	2	4.2	688	40	2943
Riverside	Kenmore	2	4.4	653	38	2809
Riverside	Kenmore	2	4.67	619	36	2649
Riverside	Kenmore	2	5	585	34	2472
Riverside	Kenmore	2	5.2	550	32	2377
Riverside	Kenmore	2	5.6	516	30	2207
Riverside	Kenmore	2	6	481	28	2060
Riverside	Kenmore	2	6.4	447	26	1931
Riverside	Kenmore	2	7	413	24	1766
Riverside	Kenmore	2	7.6	378	22	1626
Riverside	Park St	1	4	499	29	1545
Riverside	Park St	1	4.2	464	27	1471

Riverside	Park St	1	4.4	447	26	1405
Riverside	Park St	1	4.6	430	25	1343
Riverside	Park St	1	4.75	413	24	1301
Riverside	Park St	1	5	395	23	1236
Riverside	Park St	1	5.2	378	22	1188
Riverside	Park St	1	5.4	361	21	1144
Riverside	Park St	1	5.67	344	20	1091
Riverside	Park St	1	6	327	19	1030
Riverside	Park St	1	6.33	310	18	976
Riverside	Park St	1	6.67	292	17	927
Riverside	Park St	1	7.2	275	16	858
Riverside	Park St	1	7.6	258	15	813
Riverside	Park St	2	4	997	58	3090
Riverside	Park St	2	4.2	929	54	2943
Riverside	Park St	2	4.4	894	52	2809
Riverside	Park St	2	4.6	860	50	2687
Riverside	Park St	2	4.75	825	48	2602
Riverside	Park St	2	5	791	46	2472
Riverside	Park St	2	5.2	757	44	2377
Riverside	Park St	2	5.4	722	42	2289
Riverside	Park St	2	5.67	688	40	2181
Riverside	Park St	2	6	653	38	2060
Riverside	Park St	2	6.33	619	36	1952
Riverside	Park St	2	6.67	585	34	1854
Riverside	Park St	2	7.2	550	32	1717
Riverside	Park St	2	7.6	516	30	1626
Riverside	Govt Ctr	1	4	533	31	1545
Riverside	Govt Ctr	1	4.2	499	29	1471

Riverside	Govt Ctr	1	4.33	481	28	1426
Riverside	Govt Ctr	1	4.5	464	27	1373
Riverside	Govt Ctr	1	4.67	447	26	1324
Riverside	Govt Ctr	1	5	430	25	1236
Riverside	Govt Ctr	1	5.2	413	24	1188
Riverside	Govt Ctr	1	5.33	395	23	1159
Riverside	Govt Ctr	1	5.6	378	22	1104
Riverside	Govt Ctr	1	5.8	361	21	1066
Riverside	Govt Ctr	1	6.2	344	20	997
Riverside	Govt Ctr	1	6.4	327	19	966
Riverside	Govt Ctr	1	6.75	310	18	916
Riverside	Govt Ctr	1	7.2	292	17	858
Riverside	Govt Ctr	1	7.6	275	16	813
Riverside	Govt Ctr	2	4	1066	62	3090
Riverside	Govt Ctr	2	4.2	997	58	2943
Riverside	Govt Ctr	2	4.33	963	56	2852
Riverside	Govt Ctr	2	4.5	929	54	2747
Riverside	Govt Ctr	2	4.67	894	52	2649
Riverside	Govt Ctr	2	5	860	50	2472
Riverside	Govt Ctr	2	5.2	825	48	2377
Riverside	Govt Ctr	2	5.33	791	46	2318
Riverside	Govt Ctr	2	5.6	757	44	2207
Riverside	Govt Ctr	2	5.8	722	42	2131
Riverside	Govt Ctr	2	6.2	688	40	1994
Riverside	Govt Ctr	2	6.4	653	38	1931
Riverside	Govt Ctr	2	6.75	619	36	1831
Riverside	Govt Ctr	2	7.2	585	34	1717
Riverside	Govt Ctr	2	7.6	550	32	1626

Riverside	North Sta	1	4	585	34	1545
Riverside	North Sta	1	4.2	567	33	1471
Riverside	North Sta	1	4.25	550	32	1454
Riverside	North Sta	1	4.4	533	31	1405
Riverside	North Sta	1	4.6	516	30	1343
Riverside	North Sta	1	4.75	499	29	1301
Riverside	North Sta	1	5	481	28	1236
Riverside	North Sta	1	5.2	464	27	1188
Riverside	North Sta	1	5.25	447	26	1177
Riverside	North Sta	1	5.5	430	25	1124
Riverside	North Sta	1	5.67	413	24	1091
Riverside	North Sta	1	6	395	23	1030
Riverside	North Sta	1	6.2	378	22	997
Riverside	North Sta	1	6.5	361	21	951
Riverside	North Sta	1	6.8	344	20	909
Riverside	North Sta	1	7.2	327	19	858
Riverside	North Sta	1	7.6	310	18	813
Riverside	North Sta	2	4	1169	68	3090
Riverside	North Sta	2	4.2	1135	66	2943
Riverside	North Sta	2	4.25	1101	64	2908
Riverside	North Sta	2	4.4	1066	62	2809
Riverside	North Sta	2	4.6	1032	60	2687
Riverside	North Sta	2	4.75	997	58	2602
Riverside	North Sta	2	5	963	56	2472
Riverside	North Sta	2	5.2	929	54	2377
Riverside	North Sta	2	5.25	894	52	2354
Riverside	North Sta	2	5.5	860	50	2247
Riverside	North Sta	2	5.67	825	48	2181

Riverside	North Sta	2	6	791	46	2060
Riverside	North Sta	2	6.2	757	44	1994
Riverside	North Sta	2	6.5	722	42	1902
Riverside	North Sta	2	6.8	688	40	1818
Riverside	North Sta	2	7.2	653	38	1717
Riverside	North Sta	2	7.6	619	36	1626
Riverside	Union Sq	1	4	688	40	1545
Riverside	Union Sq	1	4.2	653	38	1471
Riverside	Union Sq	1	4.33	636	37	1426
Riverside	Union Sq	1	4.4	619	36	1405
Riverside	Union Sq	1	4.5	602	35	1373
Riverside	Union Sq	1	4.67	585	34	1324
Riverside	Union Sq	1	4.8	567	33	1288
Riverside	Union Sq	1	5	550	32	1236
Riverside	Union Sq	1	5.2	533	31	1188
Riverside	Union Sq	1	5.25	516	30	1177
Riverside	Union Sq	1	5.5	499	29	1124
Riverside	Union Sq	1	5.67	481	28	1091
Riverside	Union Sq	1	6	464	27	1030
Riverside	Union Sq	1	6.2	447	26	997
Riverside	Union Sq	1	6.33	430	25	976
Riverside	Union Sq	1	6.6	413	24	936
Riverside	Union Sq	1	7	395	23	883
Riverside	Union Sq	1	7.2	378	22	858
Riverside	Union Sq	1	7.5	361	21	824
Riverside	Union Sq	2	4	1376	80	3090
Riverside	Union Sq	2	4.2	1307	76	2943
Riverside	Union Sq	2	4.33	1272	74	2852

Riverside	Union Sq	2	4.4	1238	72	2809
Riverside	Union Sq	2	4.5	1204	70	2747
Riverside	Union Sq	2	4.67	1169	68	2649
Riverside	Union Sq	2	4.8	1135	66	2575
Riverside	Union Sq	2	5	1101	64	2472
Riverside	Union Sq	2	5.2	1066	62	2377
Riverside	Union Sq	2	5.25	1032	60	2354
Riverside	Union Sq	2	5.5	997	58	2247
Riverside	Union Sq	2	5.67	963	56	2181
Riverside	Union Sq	2	6	929	54	2060
Riverside	Union Sq	2	6.2	894	52	1994
Riverside	Union Sq	2	6.33	860	50	1952
Riverside	Union Sq	2	6.6	825	48	1873
Riverside	Union Sq	2	7	791	46	1766
Riverside	Union Sq	2	7.2	757	44	1717
Riverside	Union Sq	2	7.5	722	42	1648
Riverside	Medford/Tufts	1	4	722	42	1545
Riverside	Medford/Tufts	1	4.2	688	40	1471
Riverside	Medford/Tufts	1	4.25	671	39	1454
Riverside	Medford/Tufts	1	4.4	653	38	1405
Riverside	Medford/Tufts	1	4.5	636	37	1373
Riverside	Medford/Tufts	1	4.6	619	36	1343
Riverside	Medford/Tufts	1	4.75	602	35	1301
Riverside	Medford/Tufts	1	5	567	33	1236
Riverside	Medford/Tufts	1	5.2	550	32	1188
Riverside	Medford/Tufts	1	5.33	533	31	1159
Riverside	Medford/Tufts	1	5.5	516	30	1124
Riverside	Medford/Tufts	1	5.75	499	29	1075

Riverside	Medford/Tufts	1	6	481	28	1030
Riverside	Medford/Tufts	1	6.2	464	27	997
Riverside	Medford/Tufts	1	6.4	447	26	966
Riverside	Medford/Tufts	1	6.6	430	25	936
Riverside	Medford/Tufts	1	7	413	24	883
Riverside	Medford/Tufts	1	7.2	395	23	858
Riverside	Medford/Tufts	1	7.5	378	22	824
Riverside	Medford/Tufts	2	4	1444	84	3090
Riverside	Medford/Tufts	2	4.2	1376	80	2943
Riverside	Medford/Tufts	2	4.25	1341	78	2908
Riverside	Medford/Tufts	2	4.4	1307	76	2809
Riverside	Medford/Tufts	2	4.5	1272	74	2747
Riverside	Medford/Tufts	2	4.6	1238	72	2687
Riverside	Medford/Tufts	2	4.75	1204	70	2602
Riverside	Medford/Tufts	2	5	1135	66	2472
Riverside	Medford/Tufts	2	5.2	1101	64	2377
Riverside	Medford/Tufts	2	5.33	1066	62	2318
Riverside	Medford/Tufts	2	5.5	1032	60	2247
Riverside	Medford/Tufts	2	5.75	997	58	2150
Riverside	Medford/Tufts	2	6	963	56	2060
Riverside	Medford/Tufts	2	6.2	929	54	1994
Riverside	Medford/Tufts	2	6.4	894	52	1931
Riverside	Medford/Tufts	2	6.6	860	50	1873
Riverside	Medford/Tufts	2	7	825	48	1766
Riverside	Medford/Tufts	2	7.2	791	46	1717
Riverside	Medford/Tufts	2	7.5	757	44	1648

A.1.4 Service Patterns Terminating at Heath Street

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Heath St	Park St	1	4	373	19	1545
Heath St	Park St	1	4.2	354	18	1471
Heath St	Park St	1	4.4	334	17	1405
Heath St	Park St	1	4.67	314	16	1324
Heath St	Park St	1	5	295	15	1236
Heath St	Park St	1	5.33	275	14	1159
Heath St	Park St	1	5.75	255	13	1075
Heath St	Park St	1	6.2	236	12	997
Heath St	Park St	1	6.8	216	11	909
Heath St	Park St	1	7.5	197	10	824
Heath St	Park St	2	4	747	38	3090
Heath St	Park St	2	4.2	707	36	2943
Heath St	Park St	2	4.4	668	34	2809
Heath St	Park St	2	4.67	629	32	2649
Heath St	Park St	2	5	590	30	2472
Heath St	Park St	2	5.33	550	28	2318
Heath St	Park St	2	5.75	511	26	2150
Heath St	Park St	2	6.2	472	24	1994
Heath St	Park St	2	6.8	432	22	1818
Heath St	Park St	2	7.5	393	20	1648
Heath St	Govt Ctr	1	4	413	21	1545
Heath St	Govt Ctr	1	4.2	393	20	1471
Heath St	Govt Ctr	1	4.33	373	19	1426
Heath St	Govt Ctr	1	4.6	354	18	1343

Heath St	Govt Ctr	1	5	334	17	1236
Heath St	Govt Ctr	1	5.2	314	16	1188
Heath St	Govt Ctr	1	5.5	295	15	1124
Heath St	Govt Ctr	1	6	275	14	1030
Heath St	Govt Ctr	1	6.33	255	13	976
Heath St	Govt Ctr	1	7	236	12	883
Heath St	Govt Ctr	1	7.5	216	11	824
Heath St	Govt Ctr	2	4	825	42	3090
Heath St	Govt Ctr	2	4.2	786	40	2943
Heath St	Govt Ctr	2	4.33	747	38	2852
Heath St	Govt Ctr	2	4.6	707	36	2687
Heath St	Govt Ctr	2	5	668	34	2472
Heath St	Govt Ctr	2	5.2	629	32	2377
Heath St	Govt Ctr	2	5.5	590	30	2247
Heath St	Govt Ctr	2	6	550	28	2060
Heath St	Govt Ctr	2	6.33	511	26	1952
Heath St	Govt Ctr	2	7	472	24	1766
Heath St	Govt Ctr	2	7.5	432	22	1648
Heath St	North Sta	1	4	472	24	1545
Heath St	North Sta	1	4.2	452	23	1471
Heath St	North Sta	1	4.4	432	22	1405
Heath St	North Sta	1	4.6	413	21	1343
Heath St	North Sta	1	4.8	393	20	1288
Heath St	North Sta	1	5.2	373	19	1188
Heath St	North Sta	1	5.33	354	18	1159
Heath St	North Sta	1	5.67	334	17	1091
Heath St	North Sta	1	6	314	16	1030
Heath St	North Sta	1	6.4	295	15	966

Heath St	North Sta	1	7	275	14	883
Heath St	North Sta	1	7.4	255	13	835
Heath St	North Sta	2	4	943	48	3090
Heath St	North Sta	2	4.2	904	46	2943
Heath St	North Sta	2	4.4	865	44	2809
Heath St	North Sta	2	4.6	825	42	2687
Heath St	North Sta	2	4.8	786	40	2575
Heath St	North Sta	2	5.2	747	38	2377
Heath St	North Sta	2	5.33	707	36	2318
Heath St	North Sta	2	5.67	668	34	2181
Heath St	North Sta	2	6	629	32	2060
Heath St	North Sta	2	6.4	590	30	1931
Heath St	North Sta	2	7	550	28	1766
Heath St	North Sta	2	7.4	511	26	1670
Heath St	Union Sq	1	4	590	30	1545
Heath St	Union Sq	1	4.2	570	29	1471
Heath St	Union Sq	1	4.25	550	28	1454
Heath St	Union Sq	1	4.4	531	27	1405
Heath St	Union Sq	1	4.6	511	26	1343
Heath St	Union Sq	1	4.75	491	25	1301
Heath St	Union Sq	1	5	472	24	1236
Heath St	Union Sq	1	5.2	452	23	1188
Heath St	Union Sq	1	5.4	432	22	1144
Heath St	Union Sq	1	5.67	413	21	1091
Heath St	Union Sq	1	6	393	20	1030
Heath St	Union Sq	1	6.25	373	19	989
Heath St	Union Sq	1	6.6	354	18	936
Heath St	Union Sq	1	7	334	17	883

Heath St	Union Sq	1	7.4	314	16	835
Heath St	Union Sq	2	4	1179	60	3090
Heath St	Union Sq	2	4.2	1140	58	2943
Heath St	Union Sq	2	4.25	1101	56	2908
Heath St	Union Sq	2	4.4	1061	54	2809
Heath St	Union Sq	2	4.6	1022	52	2687
Heath St	Union Sq	2	4.75	983	50	2602
Heath St	Union Sq	2	5	943	48	2472
Heath St	Union Sq	2	5.2	904	46	2377
Heath St	Union Sq	2	5.4	865	44	2289
Heath St	Union Sq	2	5.67	825	42	2181
Heath St	Union Sq	2	6	786	40	2060
Heath St	Union Sq	2	6.25	747	38	1978
Heath St	Union Sq	2	6.6	707	36	1873
Heath St	Union Sq	2	7	668	34	1766
Heath St	Union Sq	2	7.4	629	32	1670
Heath St	Medford/Tufts	1	4	629	32	1545
Heath St	Medford/Tufts	1	4.2	590	30	1471
Heath St	Medford/Tufts	1	4.33	570	29	1426
Heath St	Medford/Tufts	1	4.5	550	28	1373
Heath St	Medford/Tufts	1	4.67	531	27	1324
Heath St	Medford/Tufts	1	5	511	26	1236
Heath St	Medford/Tufts	1	5.2	491	25	1188
Heath St	Medford/Tufts	1	5.25	472	24	1177
Heath St	Medford/Tufts	1	5.5	452	23	1124
Heath St	Medford/Tufts	1	5.75	432	22	1075
Heath St	Medford/Tufts	1	6	413	21	1030
Heath St	Medford/Tufts	1	6.33	393	20	976

Heath St	Medford/Tufts	1	6.6	373	19	936
Heath St	Medford/Tufts	1	7	354	18	883
Heath St	Medford/Tufts	1	7.4	334	17	835
Heath St	Medford/Tufts	2	4	1258	64	3090
Heath St	Medford/Tufts	2	4.2	1179	60	2943
Heath St	Medford/Tufts	2	4.33	1140	58	2852
Heath St	Medford/Tufts	2	4.5	1101	56	2747
Heath St	Medford/Tufts	2	4.67	1061	54	2649
Heath St	Medford/Tufts	2	5	1022	52	2472
Heath St	Medford/Tufts	2	5.2	983	50	2377
Heath St	Medford/Tufts	2	5.25	943	48	2354
Heath St	Medford/Tufts	2	5.5	904	46	2247
Heath St	Medford/Tufts	2	5.75	865	44	2150
Heath St	Medford/Tufts	2	6	825	42	2060
Heath St	Medford/Tufts	2	6.33	786	40	1952
Heath St	Medford/Tufts	2	6.6	747	38	1873
Heath St	Medford/Tufts	2	7	707	36	1766
Heath St	Medford/Tufts	2	7.4	668	34	1670

A.1.5 Service Patterns Terminating at Kenmore

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Kenmore	Park St	1	4	197	11	1545
Kenmore	Park St	1	4.2	179	10	1471
Kenmore	Park St	1	4.6	161	9	1343
Kenmore	Park St	1	5.2	143	8	1188
Kenmore	Park St	1	5.8	126	7	1066
Kenmore	Park St	1	6.8	108	6	909
Kenmore	Park St	2	4	395	22	3090
Kenmore	Park St	2	4.2	359	20	2943
Kenmore	Park St	2	4.6	323	18	2687
Kenmore	Park St	2	5.2	287	16	2377
Kenmore	Park St	2	5.8	251	14	2131
Kenmore	Park St	2	6.8	215	12	1818
Kenmore	Govt Ctr	1	4	233	13	1545
Kenmore	Govt Ctr	1	4.2	215	12	1471
Kenmore	Govt Ctr	1	4.5	197	11	1373
Kenmore	Govt Ctr	1	5	179	10	1236
Kenmore	Govt Ctr	1	5.5	161	9	1124
Kenmore	Govt Ctr	1	6.2	143	8	997
Kenmore	Govt Ctr	1	7.2	126	7	858
Kenmore	Govt Ctr	2	4	466	26	3090
Kenmore	Govt Ctr	2	4.2	430	24	2943
Kenmore	Govt Ctr	2	4.5	395	22	2747
Kenmore	Govt Ctr	2	5	359	20	2472
Kenmore	Govt Ctr	2	5.5	323	18	2247

Kenmore	Govt Ctr	2	6.2	287	16	1994
Kenmore	Govt Ctr	2	7.2	251	14	1717
Kenmore	North Sta	1	4	305	17	1545
Kenmore	North Sta	1	4.2	287	16	1471
Kenmore	North Sta	1	4.33	269	15	1426
Kenmore	North Sta	1	4.67	251	14	1324
Kenmore	North Sta	1	5	233	13	1236
Kenmore	North Sta	1	5.4	215	12	1144
Kenmore	North Sta	1	6	197	11	1030
Kenmore	North Sta	1	6.5	179	10	951
Kenmore	North Sta	1	7.2	161	9	858
Kenmore	North Sta	2	4	610	34	3090
Kenmore	North Sta	2	4.2	574	32	2943
Kenmore	North Sta	2	4.33	538	30	2852
Kenmore	North Sta	2	4.67	502	28	2649
Kenmore	North Sta	2	5	466	26	2472
Kenmore	North Sta	2	5.4	430	24	2289
Kenmore	North Sta	2	6	395	22	2060
Kenmore	North Sta	2	6.5	359	20	1902
Kenmore	North Sta	2	7.2	323	18	1717
Union Sq	Kenmore	1	4	395	22	1545
Union Sq	Kenmore	1	4.2	377	21	1471
Union Sq	Kenmore	1	4.33	359	20	1426
Union Sq	Kenmore	1	4.6	341	19	1343
Union Sq	Kenmore	1	4.8	323	18	1288
Union Sq	Kenmore	1	5.2	305	17	1188
Union Sq	Kenmore	1	5.4	287	16	1144
Union Sq	Kenmore	1	5.75	269	15	1075

Union Sq	Kenmore	1	6.2	251	14	997
Union Sq	Kenmore	1	6.67	233	13	927
Union Sq	Kenmore	1	7.2	215	12	858
Union Sq	Kenmore	2	4	789	44	3090
Union Sq	Kenmore	2	4.2	753	42	2943
Union Sq	Kenmore	2	4.33	717	40	2852
Union Sq	Kenmore	2	4.6	681	38	2687
Union Sq	Kenmore	2	4.8	646	36	2575
Union Sq	Kenmore	2	5.2	610	34	2377
Union Sq	Kenmore	2	5.4	574	32	2289
Union Sq	Kenmore	2	5.75	538	30	2150
Union Sq	Kenmore	2	6.2	502	28	1994
Union Sq	Kenmore	2	6.67	466	26	1854
Union Sq	Kenmore	2	7.2	430	24	1717

A.1.6 Service Patterns Terminating at Union Square

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Union Sq	Kenmore	1	4	395	22	1545
Union Sq	Kenmore	1	4.2	377	21	1471
Union Sq	Kenmore	1	4.33	359	20	1426
Union Sq	Kenmore	1	4.6	341	19	1343
Union Sq	Kenmore	1	4.8	323	18	1288
Union Sq	Kenmore	1	5.2	305	17	1188
Union Sq	Kenmore	1	5.4	287	16	1144
Union Sq	Kenmore	1	5.75	269	15	1075
Union Sq	Kenmore	1	6.2	251	14	997
Union Sq	Kenmore	1	6.67	233	13	927
Union Sq	Kenmore	1	7.2	215	12	858
Union Sq	Kenmore	2	4	789	44	3090
Union Sq	Kenmore	2	4.2	753	42	2943
Union Sq	Kenmore	2	4.33	717	40	2852
Union Sq	Kenmore	2	4.6	681	38	2687
Union Sq	Kenmore	2	4.8	646	36	2575
Union Sq	Kenmore	2	5.2	610	34	2377
Union Sq	Kenmore	2	5.4	574	32	2289
Union Sq	Kenmore	2	5.75	538	30	2150
Union Sq	Kenmore	2	6.2	502	28	1994
Union Sq	Kenmore	2	6.67	466	26	1854
Union Sq	Kenmore	2	7.2	430	24	1717
Union Sq	Govt Ctr	1	4	197	11	1545
Union Sq	Govt Ctr	1	4.4	179	10	1405

Union Sq	Govt Ctr	1	5	161	9	1236
Union Sq	Govt Ctr	1	5.5	143	8	1124
Union Sq	Govt Ctr	1	6.33	126	7	976
Union Sq	Govt Ctr	1	7.33	108	6	843
Union Sq	Govt Ctr	2	4	395	22	3090
Union Sq	Govt Ctr	2	4.4	359	20	2809
Union Sq	Govt Ctr	2	5	323	18	2472
Union Sq	Govt Ctr	2	5.5	287	16	2247
Union Sq	Govt Ctr	2	6.33	251	14	1952
Union Sq	Govt Ctr	2	7.33	215	12	1685

A.1.7 Service Patterns Terminating at Medford/Tufts

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Medford/Tufts	Kenmore	1	4	430	24	1545
Medford/Tufts	Kenmore	1	4.2	412	23	1471
Medford/Tufts	Kenmore	1	4.33	395	22	1426
Medford/Tufts	Kenmore	1	4.5	377	21	1373
Medford/Tufts	Kenmore	1	4.75	359	20	1301
Medford/Tufts	Kenmore	1	5	341	19	1236
Medford/Tufts	Kenmore	1	5.25	323	18	1177
Medford/Tufts	Kenmore	1	5.6	305	17	1104
Medford/Tufts	Kenmore	1	6	287	16	1030
Medford/Tufts	Kenmore	1	6.25	269	15	989
Medford/Tufts	Kenmore	1	6.75	251	14	916
Medford/Tufts	Kenmore	1	7.25	233	13	852
Medford/Tufts	Kenmore	2	4	861	48	3090
Medford/Tufts	Kenmore	2	4.2	825	46	2943
Medford/Tufts	Kenmore	2	4.33	789	44	2852
Medford/Tufts	Kenmore	2	4.5	753	42	2747
Medford/Tufts	Kenmore	2	4.75	717	40	2602
Medford/Tufts	Kenmore	2	5	681	38	2472
Medford/Tufts	Kenmore	2	5.25	646	36	2354
Medford/Tufts	Kenmore	2	5.6	610	34	2207
Medford/Tufts	Kenmore	2	6	574	32	2060
Medford/Tufts	Kenmore	2	6.25	538	30	1978
Medford/Tufts	Kenmore	2	6.75	502	28	1831
Medford/Tufts	Kenmore	2	7.25	466	26	1705

Medford/Tufts	Govt Ctr	1	4	233	13	1545
Medford/Tufts	Govt Ctr	1	4.33	215	12	1426
Medford/Tufts	Govt Ctr	1	4.67	197	11	1324
Medford/Tufts	Govt Ctr	1	5.2	179	10	1188
Medford/Tufts	Govt Ctr	1	5.75	161	9	1075
Medford/Tufts	Govt Ctr	1	6.4	143	8	966
Medford/Tufts	Govt Ctr	1	7.33	126	7	843
Medford/Tufts	Govt Ctr	2	4	466	26	3090
Medford/Tufts	Govt Ctr	2	4.33	430	24	2852
Medford/Tufts	Govt Ctr	2	4.67	395	22	2649
Medford/Tufts	Govt Ctr	2	5.2	359	20	2377
Medford/Tufts	Govt Ctr	2	5.75	323	18	2150
Medford/Tufts	Govt Ctr	2	6.4	287	16	1931
Medford/Tufts	Govt Ctr	2	7.33	251	14	1685

A.2 Service Patterns (Run Times Based on COVID-19 Adjusted Demand Forecast)

A.2.1 Service Patterns Terminating at Boston College

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Boston Col	Park St	1	4	383	26	1545
Boston Col	Park St	1	4.2	368	25	1471
Boston Col	Park St	1	4.33	354	24	1426
Boston Col	Park St	1	4.5	339	23	1373
Boston Col	Park St	1	4.75	324	22	1301
Boston Col	Park St	1	5	310	21	1236
Boston Col	Park St	1	5.2	295	20	1188
Boston Col	Park St	1	5.5	280	19	1124
Boston Col	Park St	1	5.75	265	18	1075
Boston Col	Park St	1	6.2	251	17	997
Boston Col	Park St	1	6.5	236	16	951
Boston Col	Park St	1	7	221	15	883
Boston Col	Park St	1	7.4	206	14	835
Boston Col	Park St	2	4	766	52	3090
Boston Col	Park St	2	4.2	737	50	2943
Boston Col	Park St	2	4.33	707	48	2852
Boston Col	Park St	2	4.5	678	46	2747
Boston Col	Park St	2	4.75	649	44	2602
Boston Col	Park St	2	5	619	42	2472
Boston Col	Park St	2	5.2	590	40	2377
Boston Col	Park St	2	5.5	560	38	2247

Boston Col	Park St	2	5.75	531	36	2150
Boston Col	Park St	2	6.2	501	34	1994
Boston Col	Park St	2	6.5	472	32	1902
Boston Col	Park St	2	7	442	30	1766
Boston Col	Park St	2	7.4	413	28	1670
Boston Col	Govt Ctr	1	4	413	28	1545
Boston Col	Govt Ctr	1	4.2	398	27	1471
Boston Col	Govt Ctr	1	4.33	383	26	1426
Boston Col	Govt Ctr	1	4.5	368	25	1373
Boston Col	Govt Ctr	1	4.67	354	24	1324
Boston Col	Govt Ctr	1	5	339	23	1236
Boston Col	Govt Ctr	1	5.2	324	22	1188
Boston Col	Govt Ctr	1	5.33	310	21	1159
Boston Col	Govt Ctr	1	5.6	295	20	1104
Boston Col	Govt Ctr	1	6	280	19	1030
Boston Col	Govt Ctr	1	6.2	265	18	997
Boston Col	Govt Ctr	1	6.6	251	17	936
Boston Col	Govt Ctr	1	7	236	16	883
Boston Col	Govt Ctr	1	7.5	221	15	824
Boston Col	Govt Ctr	2	4	825	56	3090
Boston Col	Govt Ctr	2	4.2	796	54	2943
Boston Col	Govt Ctr	2	4.33	766	52	2852
Boston Col	Govt Ctr	2	4.5	737	50	2747
Boston Col	Govt Ctr	2	4.67	707	48	2649
Boston Col	Govt Ctr	2	5	678	46	2472
Boston Col	Govt Ctr	2	5.2	649	44	2377
Boston Col	Govt Ctr	2	5.33	619	42	2318
Boston Col	Govt Ctr	2	5.6	590	40	2207

Boston Col	Govt Ctr	2	6	560	38	2060
Boston Col	Govt Ctr	2	6.2	531	36	1994
Boston Col	Govt Ctr	2	6.6	501	34	1873
Boston Col	Govt Ctr	2	7	472	32	1766
Boston Col	Govt Ctr	2	7.5	442	30	1648
Boston Col	North Sta	1	4	457	31	1545
Boston Col	North Sta	1	4.2	442	30	1471
Boston Col	North Sta	1	4.33	427	29	1426
Boston Col	North Sta	1	4.5	413	28	1373
Boston Col	North Sta	1	4.6	398	27	1343
Boston Col	North Sta	1	4.8	383	26	1288
Boston Col	North Sta	1	5	368	25	1236
Boston Col	North Sta	1	5.2	354	24	1188
Boston Col	North Sta	1	5.4	339	23	1144
Boston Col	North Sta	1	5.67	324	22	1091
Boston Col	North Sta	1	6	310	21	1030
Boston Col	North Sta	1	6.2	295	20	997
Boston Col	North Sta	1	6.6	280	19	936
Boston Col	North Sta	1	7	265	18	883
Boston Col	North Sta	1	7.33	251	17	843
Boston Col	North Sta	1	7.75	236	16	797
Boston Col	North Sta	2	4	914	62	3090
Boston Col	North Sta	2	4.2	884	60	2943
Boston Col	North Sta	2	4.33	855	58	2852
Boston Col	North Sta	2	4.5	825	56	2747
Boston Col	North Sta	2	4.6	796	54	2687
Boston Col	North Sta	2	4.8	766	52	2575
Boston Col	North Sta	2	5	737	50	2472

Boston Col	North Sta	2	5.2	707	48	2377
Boston Col	North Sta	2	5.4	678	46	2289
Boston Col	North Sta	2	5.67	649	44	2181
Boston Col	North Sta	2	6	619	42	2060
Boston Col	North Sta	2	6.2	590	40	1994
Boston Col	North Sta	2	6.6	560	38	1873
Boston Col	North Sta	2	7	531	36	1766
Boston Col	North Sta	2	7.33	501	34	1685
Boston Col	North Sta	2	7.75	472	32	1595
Boston Col	Union Sq	1	4	545	37	1545
Boston Col	Union Sq	1	4.2	516	35	1471
Boston Col	Union Sq	1	4.33	501	34	1426
Boston Col	Union Sq	1	4.4	486	33	1405
Boston Col	Union Sq	1	4.6	472	32	1343
Boston Col	Union Sq	1	4.75	457	31	1301
Boston Col	Union Sq	1	5	442	30	1236
Boston Col	Union Sq	1	5.2	413	28	1188
Boston Col	Union Sq	1	5.4	398	27	1144
Boston Col	Union Sq	1	5.6	383	26	1104
Boston Col	Union Sq	1	6	368	25	1030
Boston Col	Union Sq	1	6.2	354	24	997
Boston Col	Union Sq	1	6.33	339	23	976
Boston Col	Union Sq	1	6.6	324	22	936
Boston Col	Union Sq	1	7	310	21	883
Boston Col	Union Sq	1	7.33	295	20	843
Boston Col	Union Sq	1	7.67	280	19	806
Boston Col	Union Sq	2	4	1091	74	3090
Boston Col	Union Sq	2	4.2	1032	70	2943

Boston Col	Union Sq	2	4.33	1002	68	2852
Boston Col	Union Sq	2	4.4	973	66	2809
Boston Col	Union Sq	2	4.6	943	64	2687
Boston Col	Union Sq	2	4.75	914	62	2602
Boston Col	Union Sq	2	5	884	60	2472
Boston Col	Union Sq	2	5.2	825	56	2377
Boston Col	Union Sq	2	5.4	796	54	2289
Boston Col	Union Sq	2	5.6	766	52	2207
Boston Col	Union Sq	2	6	737	50	2060
Boston Col	Union Sq	2	6.2	707	48	1994
Boston Col	Union Sq	2	6.33	678	46	1952
Boston Col	Union Sq	2	6.6	649	44	1873
Boston Col	Union Sq	2	7	619	42	1766
Boston Col	Union Sq	2	7.33	590	40	1685
Boston Col	Union Sq	2	7.67	560	38	1612
Boston Col	Medford/Tufts	1	4	575	39	1545
Boston Col	Medford/Tufts	1	4.2	545	37	1471
Boston Col	Medford/Tufts	1	4.33	531	36	1426
Boston Col	Medford/Tufts	1	4.4	516	35	1405
Boston Col	Medford/Tufts	1	4.6	501	34	1343
Boston Col	Medford/Tufts	1	4.67	486	33	1324
Boston Col	Medford/Tufts	1	4.8	472	32	1288
Boston Col	Medford/Tufts	1	5	457	31	1236
Boston Col	Medford/Tufts	1	5.2	442	30	1188
Boston Col	Medford/Tufts	1	5.33	427	29	1159
Boston Col	Medford/Tufts	1	5.5	413	28	1124
Boston Col	Medford/Tufts	1	5.75	398	27	1075
Boston Col	Medford/Tufts	1	6	383	26	1030

Boston Col	Medford/Tufts	1	6.2	368	25	997
Boston Col	Medford/Tufts	1	6.4	354	24	966
Boston Col	Medford/Tufts	1	6.67	339	23	927
Boston Col	Medford/Tufts	1	7	324	22	883
Boston Col	Medford/Tufts	1	7.33	310	21	843
Boston Col	Medford/Tufts	1	7.67	295	20	806
Boston Col	Medford/Tufts	2	4	1150	78	3090
Boston Col	Medford/Tufts	2	4.2	1091	74	2943
Boston Col	Medford/Tufts	2	4.33	1061	72	2852
Boston Col	Medford/Tufts	2	4.4	1032	70	2809
Boston Col	Medford/Tufts	2	4.6	1002	68	2687
Boston Col	Medford/Tufts	2	4.67	973	66	2649
Boston Col	Medford/Tufts	2	4.8	943	64	2575
Boston Col	Medford/Tufts	2	5	914	62	2472
Boston Col	Medford/Tufts	2	5.2	884	60	2377
Boston Col	Medford/Tufts	2	5.33	855	58	2318
Boston Col	Medford/Tufts	2	5.5	825	56	2247
Boston Col	Medford/Tufts	2	5.75	796	54	2150
Boston Col	Medford/Tufts	2	6	766	52	2060
Boston Col	Medford/Tufts	2	6.2	737	50	1994
Boston Col	Medford/Tufts	2	6.4	707	48	1931
Boston Col	Medford/Tufts	2	6.67	678	46	1854
Boston Col	Medford/Tufts	2	7	649	44	1766
Boston Col	Medford/Tufts	2	7.33	619	42	1685
Boston Col	Medford/Tufts	2	7.67	590	40	1612

A.2.2 Service Patterns Terminating at Cleveland Circle

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Cleveland Cir	Kenmore	1	4	284	14	1545
Cleveland Cir	Kenmore	1	4.2	264	13	1471
Cleveland Cir	Kenmore	1	4.4	243	12	1405
Cleveland Cir	Kenmore	1	4.8	223	11	1288
Cleveland Cir	Kenmore	1	5.33	203	10	1159
Cleveland Cir	Kenmore	1	6	183	9	1030
Cleveland Cir	Kenmore	1	6.6	162	8	936
Cleveland Cir	Kenmore	1	7.6	142	7	813
Cleveland Cir	Kenmore	2	4	568	28	3090
Cleveland Cir	Kenmore	2	4.2	528	26	2943
Cleveland Cir	Kenmore	2	4.4	487	24	2809
Cleveland Cir	Kenmore	2	4.8	446	22	2575
Cleveland Cir	Kenmore	2	5.33	406	20	2318
Cleveland Cir	Kenmore	2	6	365	18	2060
Cleveland Cir	Kenmore	2	6.6	325	16	1873
Cleveland Cir	Kenmore	2	7.6	284	14	1626
Cleveland Cir	Park St	1	4	426	21	1545
Cleveland Cir	Park St	1	4.2	406	20	1471
Cleveland Cir	Park St	1	4.33	386	19	1426
Cleveland Cir	Park St	1	4.6	365	18	1343
Cleveland Cir	Park St	1	4.8	345	17	1288
Cleveland Cir	Park St	1	5.2	325	16	1188
Cleveland Cir	Park St	1	5.5	304	15	1124
Cleveland Cir	Park St	1	5.8	284	14	1066

Cleveland Cir	Park St	1	6.25	264	13	989
Cleveland Cir	Park St	1	6.8	243	12	909
Cleveland Cir	Park St	1	7.4	223	11	835
Cleveland Cir	Park St	2	4	852	42	3090
Cleveland Cir	Park St	2	4.2	812	40	2943
Cleveland Cir	Park St	2	4.33	771	38	2852
Cleveland Cir	Park St	2	4.6	730	36	2687
Cleveland Cir	Park St	2	4.8	690	34	2575
Cleveland Cir	Park St	2	5.2	649	32	2377
Cleveland Cir	Park St	2	5.5	609	30	2247
Cleveland Cir	Park St	2	5.8	568	28	2131
Cleveland Cir	Park St	2	6.25	528	26	1978
Cleveland Cir	Park St	2	6.8	487	24	1818
Cleveland Cir	Park St	2	7.4	446	22	1670
Cleveland Cir	Govt Ctr	1	4	467	23	1545
Cleveland Cir	Govt Ctr	1	4.2	446	22	1471
Cleveland Cir	Govt Ctr	1	4.33	426	21	1426
Cleveland Cir	Govt Ctr	1	4.5	406	20	1373
Cleveland Cir	Govt Ctr	1	4.75	386	19	1301
Cleveland Cir	Govt Ctr	1	5	365	18	1236
Cleveland Cir	Govt Ctr	1	5.33	345	17	1159
Cleveland Cir	Govt Ctr	1	5.67	325	16	1091
Cleveland Cir	Govt Ctr	1	6	304	15	1030
Cleveland Cir	Govt Ctr	1	6.5	284	14	951
Cleveland Cir	Govt Ctr	1	7	264	13	883
Cleveland Cir	Govt Ctr	1	7.5	243	12	824
Cleveland Cir	Govt Ctr	2	4	933	46	3090
Cleveland Cir	Govt Ctr	2	4.2	893	44	2943

Cleveland Cir	Govt Ctr	2	4.33	852	42	2852
Cleveland Cir	Govt Ctr	2	4.5	812	40	2747
Cleveland Cir	Govt Ctr	2	4.75	771	38	2602
Cleveland Cir	Govt Ctr	2	5	730	36	2472
Cleveland Cir	Govt Ctr	2	5.33	690	34	2318
Cleveland Cir	Govt Ctr	2	5.67	649	32	2181
Cleveland Cir	Govt Ctr	2	6	609	30	2060
Cleveland Cir	Govt Ctr	2	6.5	568	28	1902
Cleveland Cir	Govt Ctr	2	7	528	26	1766
Cleveland Cir	Govt Ctr	2	7.5	487	24	1648
Cleveland Cir	North Sta	1	4	528	26	1545
Cleveland Cir	North Sta	1	4.2	507	25	1471
Cleveland Cir	North Sta	1	4.33	487	24	1426
Cleveland Cir	North Sta	1	4.5	467	23	1373
Cleveland Cir	North Sta	1	4.67	446	22	1324
Cleveland Cir	North Sta	1	5	426	21	1236
Cleveland Cir	North Sta	1	5.2	406	20	1188
Cleveland Cir	North Sta	1	5.4	386	19	1144
Cleveland Cir	North Sta	1	5.75	365	18	1075
Cleveland Cir	North Sta	1	6.2	345	17	997
Cleveland Cir	North Sta	1	6.4	325	16	966
Cleveland Cir	North Sta	1	7	304	15	883
Cleveland Cir	North Sta	1	7.33	284	14	843
Cleveland Cir	North Sta	2	4	1055	52	3090
Cleveland Cir	North Sta	2	4.2	1015	50	2943
Cleveland Cir	North Sta	2	4.33	974	48	2852
Cleveland Cir	North Sta	2	4.5	933	46	2747
Cleveland Cir	North Sta	2	4.67	893	44	2649

Cleveland Cir	North Sta	2	5	852	42	2472
Cleveland Cir	North Sta	2	5.2	812	40	2377
Cleveland Cir	North Sta	2	5.4	771	38	2289
Cleveland Cir	North Sta	2	5.75	730	36	2150
Cleveland Cir	North Sta	2	6.2	690	34	1994
Cleveland Cir	North Sta	2	6.4	649	32	1931
Cleveland Cir	North Sta	2	7	609	30	1766
Cleveland Cir	North Sta	2	7.33	568	28	1685
Cleveland Cir	Union Sq	1	4	629	31	1545
Cleveland Cir	Union Sq	1	4.2	609	30	1471
Cleveland Cir	Union Sq	1	4.33	588	29	1426
Cleveland Cir	Union Sq	1	4.5	568	28	1373
Cleveland Cir	Union Sq	1	4.6	548	27	1343
Cleveland Cir	Union Sq	1	4.75	528	26	1301
Cleveland Cir	Union Sq	1	5	507	25	1236
Cleveland Cir	Union Sq	1	5.2	487	24	1188
Cleveland Cir	Union Sq	1	5.4	467	23	1144
Cleveland Cir	Union Sq	1	5.67	446	22	1091
Cleveland Cir	Union Sq	1	6	426	21	1030
Cleveland Cir	Union Sq	1	6.2	406	20	997
Cleveland Cir	Union Sq	1	6.5	386	19	951
Cleveland Cir	Union Sq	1	7	365	18	883
Cleveland Cir	Union Sq	1	7.33	345	17	843
Cleveland Cir	Union Sq	1	7.75	325	16	797
Cleveland Cir	Union Sq	2	4	1258	62	3090
Cleveland Cir	Union Sq	2	4.2	1217	60	2943
Cleveland Cir	Union Sq	2	4.33	1177	58	2852
Cleveland Cir	Union Sq	2	4.5	1136	56	2747

Cleveland Cir	Union Sq	2	4.6	1096	54	2687
Cleveland Cir	Union Sq	2	4.75	1055	52	2602
Cleveland Cir	Union Sq	2	5	1015	50	2472
Cleveland Cir	Union Sq	2	5.2	974	48	2377
Cleveland Cir	Union Sq	2	5.4	933	46	2289
Cleveland Cir	Union Sq	2	5.67	893	44	2181
Cleveland Cir	Union Sq	2	6	852	42	2060
Cleveland Cir	Union Sq	2	6.2	812	40	1994
Cleveland Cir	Union Sq	2	6.5	771	38	1902
Cleveland Cir	Union Sq	2	7	730	36	1766
Cleveland Cir	Union Sq	2	7.33	690	34	1685
Cleveland Cir	Union Sq	2	7.75	649	32	1595
Cleveland Cir	Medford/Tufts	1	4	670	33	1545
Cleveland Cir	Medford/Tufts	1	4.2	649	32	1471
Cleveland Cir	Medford/Tufts	1	4.25	629	31	1454
Cleveland Cir	Medford/Tufts	1	4.4	609	30	1405
Cleveland Cir	Medford/Tufts	1	4.6	588	29	1343
Cleveland Cir	Medford/Tufts	1	4.75	568	28	1301
Cleveland Cir	Medford/Tufts	1	5	548	27	1236
Cleveland Cir	Medford/Tufts	1	5.2	528	26	1188
Cleveland Cir	Medford/Tufts	1	5.33	507	25	1159
Cleveland Cir	Medford/Tufts	1	5.5	487	24	1124
Cleveland Cir	Medford/Tufts	1	5.75	467	23	1075
Cleveland Cir	Medford/Tufts	1	6	446	22	1030
Cleveland Cir	Medford/Tufts	1	6.33	426	21	976
Cleveland Cir	Medford/Tufts	1	6.6	406	20	936
Cleveland Cir	Medford/Tufts	1	7	386	19	883
Cleveland Cir	Medford/Tufts	1	7.33	365	18	843

Cleveland Cir	Medford/Tufts	1	7.75	345	17	797
Cleveland Cir	Medford/Tufts	2	4	1339	66	3090
Cleveland Cir	Medford/Tufts	2	4.2	1299	64	2943
Cleveland Cir	Medford/Tufts	2	4.25	1258	62	2908
Cleveland Cir	Medford/Tufts	2	4.4	1217	60	2809
Cleveland Cir	Medford/Tufts	2	4.6	1177	58	2687
Cleveland Cir	Medford/Tufts	2	4.75	1136	56	2602
Cleveland Cir	Medford/Tufts	2	5	1096	54	2472
Cleveland Cir	Medford/Tufts	2	5.2	1055	52	2377
Cleveland Cir	Medford/Tufts	2	5.33	1015	50	2318
Cleveland Cir	Medford/Tufts	2	5.5	974	48	2247
Cleveland Cir	Medford/Tufts	2	5.75	933	46	2150
Cleveland Cir	Medford/Tufts	2	6	893	44	2060
Cleveland Cir	Medford/Tufts	2	6.33	852	42	1952
Cleveland Cir	Medford/Tufts	2	6.6	812	40	1873
Cleveland Cir	Medford/Tufts	2	7	771	38	1766
Cleveland Cir	Medford/Tufts	2	7.33	730	36	1685
Cleveland Cir	Medford/Tufts	2	7.75	690	34	1595

A.2.3 Service Patterns Terminating at Riverside

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Riverside	Kenmore	1	4	344	20	1545
Riverside	Kenmore	1	4.2	327	19	1471
Riverside	Kenmore	1	4.4	310	18	1405
Riverside	Kenmore	1	4.67	292	17	1324
Riverside	Kenmore	1	5	275	16	1236
Riverside	Kenmore	1	5.25	258	15	1177
Riverside	Kenmore	1	5.67	241	14	1091
Riverside	Kenmore	1	6.2	224	13	997
Riverside	Kenmore	1	6.6	206	12	936
Riverside	Kenmore	1	7.2	189	11	858
Riverside	Kenmore	2	4	688	40	3090
Riverside	Kenmore	2	4.2	653	38	2943
Riverside	Kenmore	2	4.4	619	36	2809
Riverside	Kenmore	2	4.67	585	34	2649
Riverside	Kenmore	2	5	550	32	2472
Riverside	Kenmore	2	5.25	516	30	2354
Riverside	Kenmore	2	5.67	481	28	2181
Riverside	Kenmore	2	6.2	447	26	1994
Riverside	Kenmore	2	6.6	413	24	1873
Riverside	Kenmore	2	7.2	378	22	1717
Riverside	Park St	1	4	464	27	1545
Riverside	Park St	1	4.2	447	26	1471
Riverside	Park St	1	4.33	430	25	1426
Riverside	Park St	1	4.5	413	24	1373

Riverside	Park St	1	4.67	395	23	1324
Riverside	Park St	1	5	378	22	1236
Riverside	Park St	1	5.2	361	21	1188
Riverside	Park St	1	5.33	344	20	1159
Riverside	Park St	1	5.67	327	19	1091
Riverside	Park St	1	6	310	18	1030
Riverside	Park St	1	6.33	292	17	976
Riverside	Park St	1	6.67	275	16	927
Riverside	Park St	1	7.2	258	15	858
Riverside	Park St	1	7.67	241	14	806
Riverside	Park St	2	4	929	54	3090
Riverside	Park St	2	4.2	894	52	2943
Riverside	Park St	2	4.33	860	50	2852
Riverside	Park St	2	4.5	825	48	2747
Riverside	Park St	2	4.67	791	46	2649
Riverside	Park St	2	5	757	44	2472
Riverside	Park St	2	5.2	722	42	2377
Riverside	Park St	2	5.33	688	40	2318
Riverside	Park St	2	5.67	653	38	2181
Riverside	Park St	2	6	619	36	2060
Riverside	Park St	2	6.33	585	34	1952
Riverside	Park St	2	6.67	550	32	1854
Riverside	Park St	2	7.2	516	30	1717
Riverside	Park St	2	7.67	481	28	1612
Riverside	Govt Ctr	1	4	499	29	1545
Riverside	Govt Ctr	1	4.2	481	28	1471
Riverside	Govt Ctr	1	4.33	464	27	1426
Riverside	Govt Ctr	1	4.5	447	26	1373

Riverside	Govt Ctr	1	4.67	430	25	1324
Riverside	Govt Ctr	1	5	413	24	1236
Riverside	Govt Ctr	1	5.2	395	23	1188
Riverside	Govt Ctr	1	5.25	378	22	1177
Riverside	Govt Ctr	1	5.5	361	21	1124
Riverside	Govt Ctr	1	5.8	344	20	1066
Riverside	Govt Ctr	1	6.2	327	19	997
Riverside	Govt Ctr	1	6.5	310	18	951
Riverside	Govt Ctr	1	6.8	292	17	909
Riverside	Govt Ctr	1	7.25	275	16	852
Riverside	Govt Ctr	1	7.75	258	15	797
Riverside	Govt Ctr	2	4	997	58	3090
Riverside	Govt Ctr	2	4.2	963	56	2943
Riverside	Govt Ctr	2	4.33	929	54	2852
Riverside	Govt Ctr	2	4.5	894	52	2747
Riverside	Govt Ctr	2	4.67	860	50	2649
Riverside	Govt Ctr	2	5	825	48	2472
Riverside	Govt Ctr	2	5.2	791	46	2377
Riverside	Govt Ctr	2	5.25	757	44	2354
Riverside	Govt Ctr	2	5.5	722	42	2247
Riverside	Govt Ctr	2	5.8	688	40	2131
Riverside	Govt Ctr	2	6.2	653	38	1994
Riverside	Govt Ctr	2	6.5	619	36	1902
Riverside	Govt Ctr	2	6.8	585	34	1818
Riverside	Govt Ctr	2	7.25	550	32	1705
Riverside	Govt Ctr	2	7.75	516	30	1595
Riverside	North Sta	1	4	550	32	1545
Riverside	North Sta	1	4.2	533	31	1471

Riverside	North Sta	1	4.33	516	30	1426
Riverside	North Sta	1	4.5	499	29	1373
Riverside	North Sta	1	4.6	481	28	1343
Riverside	North Sta	1	4.75	464	27	1301
Riverside	North Sta	1	5	447	26	1236
Riverside	North Sta	1	5.2	430	25	1188
Riverside	North Sta	1	5.33	413	24	1159
Riverside	North Sta	1	5.6	395	23	1104
Riverside	North Sta	1	6	378	22	1030
Riverside	North Sta	1	6.2	361	21	997
Riverside	North Sta	1	6.4	344	20	966
Riverside	North Sta	1	6.75	327	19	916
Riverside	North Sta	1	7.2	310	18	858
Riverside	North Sta	1	7.6	292	17	813
Riverside	North Sta	2	4	1101	64	3090
Riverside	North Sta	2	4.2	1066	62	2943
Riverside	North Sta	2	4.33	1032	60	2852
Riverside	North Sta	2	4.5	997	58	2747
Riverside	North Sta	2	4.6	963	56	2687
Riverside	North Sta	2	4.75	929	54	2602
Riverside	North Sta	2	5	894	52	2472
Riverside	North Sta	2	5.2	860	50	2377
Riverside	North Sta	2	5.33	825	48	2318
Riverside	North Sta	2	5.6	791	46	2207
Riverside	North Sta	2	6	757	44	2060
Riverside	North Sta	2	6.2	722	42	1994
Riverside	North Sta	2	6.4	688	40	1931
Riverside	North Sta	2	6.75	653	38	1831

Riverside	North Sta	2	7.2	619	36	1717
Riverside	North Sta	2	7.6	585	34	1626
Riverside	Union Sq	1	4	653	38	1545
Riverside	Union Sq	1	4.2	619	36	1471
Riverside	Union Sq	1	4.33	602	35	1426
Riverside	Union Sq	1	4.4	585	34	1405
Riverside	Union Sq	1	4.6	567	33	1343
Riverside	Union Sq	1	4.67	550	32	1324
Riverside	Union Sq	1	5	516	30	1236
Riverside	Union Sq	1	5.2	499	29	1188
Riverside	Union Sq	1	5.33	481	28	1159
Riverside	Union Sq	1	5.6	464	27	1104
Riverside	Union Sq	1	5.75	447	26	1075
Riverside	Union Sq	1	6	430	25	1030
Riverside	Union Sq	1	6.25	413	24	989
Riverside	Union Sq	1	6.5	395	23	951
Riverside	Union Sq	1	6.8	378	22	909
Riverside	Union Sq	1	7.2	361	21	858
Riverside	Union Sq	1	7.5	344	20	824
Riverside	Union Sq	2	4	1307	76	3090
Riverside	Union Sq	2	4.2	1238	72	2943
Riverside	Union Sq	2	4.33	1204	70	2852
Riverside	Union Sq	2	4.4	1169	68	2809
Riverside	Union Sq	2	4.6	1135	66	2687
Riverside	Union Sq	2	4.67	1101	64	2649
Riverside	Union Sq	2	5	1032	60	2472
Riverside	Union Sq	2	5.2	997	58	2377
Riverside	Union Sq	2	5.33	963	56	2318

Riverside	Union Sq	2	5.6	929	54	2207
Riverside	Union Sq	2	5.75	894	52	2150
Riverside	Union Sq	2	6	860	50	2060
Riverside	Union Sq	2	6.25	825	48	1978
Riverside	Union Sq	2	6.5	791	46	1902
Riverside	Union Sq	2	6.8	757	44	1818
Riverside	Union Sq	2	7.2	722	42	1717
Riverside	Union Sq	2	7.5	688	40	1648
Riverside	Medford/Tufts	1	4	688	40	1545
Riverside	Medford/Tufts	1	4.2	653	38	1471
Riverside	Medford/Tufts	1	4.25	636	37	1454
Riverside	Medford/Tufts	1	4.4	619	36	1405
Riverside	Medford/Tufts	1	4.5	602	35	1373
Riverside	Medford/Tufts	1	4.67	585	34	1324
Riverside	Medford/Tufts	1	4.8	567	33	1288
Riverside	Medford/Tufts	1	5	550	32	1236
Riverside	Medford/Tufts	1	5.2	533	31	1188
Riverside	Medford/Tufts	1	5.25	516	30	1177
Riverside	Medford/Tufts	1	5.5	499	29	1124
Riverside	Medford/Tufts	1	5.67	481	28	1091
Riverside	Medford/Tufts	1	6	464	27	1030
Riverside	Medford/Tufts	1	6.2	447	26	997
Riverside	Medford/Tufts	1	6.33	430	25	976
Riverside	Medford/Tufts	1	6.6	413	24	936
Riverside	Medford/Tufts	1	7	395	23	883
Riverside	Medford/Tufts	1	7.2	378	22	858
Riverside	Medford/Tufts	1	7.5	361	21	824
Riverside	Medford/Tufts	2	4	1376	80	3090

Riverside	Medford/Tufts	2	4.2	1307	76	2943
Riverside	Medford/Tufts	2	4.25	1272	74	2908
Riverside	Medford/Tufts	2	4.4	1238	72	2809
Riverside	Medford/Tufts	2	4.5	1204	70	2747
Riverside	Medford/Tufts	2	4.67	1169	68	2649
Riverside	Medford/Tufts	2	4.8	1135	66	2575
Riverside	Medford/Tufts	2	5	1101	64	2472
Riverside	Medford/Tufts	2	5.2	1066	62	2377
Riverside	Medford/Tufts	2	5.25	1032	60	2354
Riverside	Medford/Tufts	2	5.5	997	58	2247
Riverside	Medford/Tufts	2	5.67	963	56	2181
Riverside	Medford/Tufts	2	6	929	54	2060
Riverside	Medford/Tufts	2	6.2	894	52	1994
Riverside	Medford/Tufts	2	6.33	860	50	1952
Riverside	Medford/Tufts	2	6.6	825	48	1873
Riverside	Medford/Tufts	2	7	791	46	1766
Riverside	Medford/Tufts	2	7.2	757	44	1717
Riverside	Medford/Tufts	2	7.5	722	42	1648

A.2.4 Service Patterns Terminating at Heath Street

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Heath St	Park St	1	4	334	17	1545
Heath St	Park St	1	4.2	314	16	1471
Heath St	Park St	1	4.5	295	15	1373
Heath St	Park St	1	4.8	275	14	1288
Heath St	Park St	1	5.2	255	13	1188
Heath St	Park St	1	5.6	236	12	1104
Heath St	Park St	1	6.2	216	11	997
Heath St	Park St	1	6.75	197	10	916
Heath St	Park St	1	7.5	177	9	824
Heath St	Park St	2	4	668	34	3090
Heath St	Park St	2	4.2	629	32	2943
Heath St	Park St	2	4.5	590	30	2747
Heath St	Park St	2	4.8	550	28	2575
Heath St	Park St	2	5.2	511	26	2377
Heath St	Park St	2	5.6	472	24	2207
Heath St	Park St	2	6.2	432	22	1994
Heath St	Park St	2	6.75	393	20	1831
Heath St	Park St	2	7.5	354	18	1648
Heath St	Govt Ctr	1	4	373	19	1545
Heath St	Govt Ctr	1	4.2	354	18	1471
Heath St	Govt Ctr	1	4.5	334	17	1373
Heath St	Govt Ctr	1	4.75	314	16	1301
Heath St	Govt Ctr	1	5	295	15	1236
Heath St	Govt Ctr	1	5.4	275	14	1144

Heath St	Govt Ctr	1	5.8	255	13	1066
Heath St	Govt Ctr	1	6.25	236	12	989
Heath St	Govt Ctr	1	7	216	11	883
Heath St	Govt Ctr	1	7.5	197	10	824
Heath St	Govt Ctr	2	4	747	38	3090
Heath St	Govt Ctr	2	4.2	707	36	2943
Heath St	Govt Ctr	2	4.5	668	34	2747
Heath St	Govt Ctr	2	4.75	629	32	2602
Heath St	Govt Ctr	2	5	590	30	2472
Heath St	Govt Ctr	2	5.4	550	28	2289
Heath St	Govt Ctr	2	5.8	511	26	2131
Heath St	Govt Ctr	2	6.25	472	24	1978
Heath St	Govt Ctr	2	7	432	22	1766
Heath St	Govt Ctr	2	7.5	393	20	1648
Heath St	North Sta	1	4	432	22	1545
Heath St	North Sta	1	4.2	413	21	1471
Heath St	North Sta	1	4.33	393	20	1426
Heath St	North Sta	1	4.6	373	19	1343
Heath St	North Sta	1	5	354	18	1236
Heath St	North Sta	1	5.2	334	17	1188
Heath St	North Sta	1	5.5	314	16	1124
Heath St	North Sta	1	5.8	295	15	1066
Heath St	North Sta	1	6.2	275	14	997
Heath St	North Sta	1	6.67	255	13	927
Heath St	North Sta	1	7.25	236	12	852
Heath St	North Sta	2	4	865	44	3090
Heath St	North Sta	2	4.2	825	42	2943
Heath St	North Sta	2	4.33	786	40	2852

Heath St	North Sta	2	4.6	747	38	2687
Heath St	North Sta	2	5	707	36	2472
Heath St	North Sta	2	5.2	668	34	2377
Heath St	North Sta	2	5.5	629	32	2247
Heath St	North Sta	2	5.8	590	30	2131
Heath St	North Sta	2	6.2	550	28	1994
Heath St	North Sta	2	6.67	511	26	1854
Heath St	North Sta	2	7.25	472	24	1705
Heath St	Union Sq	1	4	531	27	1545
Heath St	Union Sq	1	4.2	511	26	1471
Heath St	Union Sq	1	4.33	491	25	1426
Heath St	Union Sq	1	4.5	472	24	1373
Heath St	Union Sq	1	4.75	452	23	1301
Heath St	Union Sq	1	5	432	22	1236
Heath St	Union Sq	1	5.2	413	21	1188
Heath St	Union Sq	1	5.4	393	20	1144
Heath St	Union Sq	1	5.67	373	19	1091
Heath St	Union Sq	1	6	354	18	1030
Heath St	Union Sq	1	6.33	334	17	976
Heath St	Union Sq	1	6.75	314	16	916
Heath St	Union Sq	1	7.2	295	15	858
Heath St	Union Sq	1	7.75	275	14	797
Heath St	Union Sq	2	4	1061	54	3090
Heath St	Union Sq	2	4.2	1022	52	2943
Heath St	Union Sq	2	4.33	983	50	2852
Heath St	Union Sq	2	4.5	943	48	2747
Heath St	Union Sq	2	4.75	904	46	2602
Heath St	Union Sq	2	5	865	44	2472

Heath St	Union Sq	2	5.2	825	42	2377
Heath St	Union Sq	2	5.4	786	40	2289
Heath St	Union Sq	2	5.67	747	38	2181
Heath St	Union Sq	2	6	707	36	2060
Heath St	Union Sq	2	6.33	668	34	1952
Heath St	Union Sq	2	6.75	629	32	1831
Heath St	Union Sq	2	7.2	590	30	1717
Heath St	Union Sq	2	7.75	550	28	1595
Heath St	Medford/Tufts	1	4	570	29	1545
Heath St	Medford/Tufts	1	4.2	550	28	1471
Heath St	Medford/Tufts	1	4.33	531	27	1426
Heath St	Medford/Tufts	1	4.5	511	26	1373
Heath St	Medford/Tufts	1	4.67	491	25	1324
Heath St	Medford/Tufts	1	4.8	472	24	1288
Heath St	Medford/Tufts	1	5.2	452	23	1188
Heath St	Medford/Tufts	1	5.25	432	22	1177
Heath St	Medford/Tufts	1	5.5	413	21	1124
Heath St	Medford/Tufts	1	5.8	393	20	1066
Heath St	Medford/Tufts	1	6.2	373	19	997
Heath St	Medford/Tufts	1	6.4	354	18	966
Heath St	Medford/Tufts	1	6.8	334	17	909
Heath St	Medford/Tufts	1	7.2	314	16	858
Heath St	Medford/Tufts	1	7.75	295	15	797
Heath St	Medford/Tufts	2	4	1140	58	3090
Heath St	Medford/Tufts	2	4.2	1101	56	2943
Heath St	Medford/Tufts	2	4.33	1061	54	2852
Heath St	Medford/Tufts	2	4.5	1022	52	2747
Heath St	Medford/Tufts	2	4.67	983	50	2649

Heath St	Medford/Tufts	2	4.8	943	48	2575
Heath St	Medford/Tufts	2	5.2	904	46	2377
Heath St	Medford/Tufts	2	5.25	865	44	2354
Heath St	Medford/Tufts	2	5.5	825	42	2247
Heath St	Medford/Tufts	2	5.8	786	40	2131
Heath St	Medford/Tufts	2	6.2	747	38	1994
Heath St	Medford/Tufts	2	6.4	707	36	1931
Heath St	Medford/Tufts	2	6.8	668	34	1818
Heath St	Medford/Tufts	2	7.2	629	32	1717
Heath St	Medford/Tufts	2	7.75	590	30	1595

A.2.5 Service Patterns Terminating at Kenmore

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Kenmore	Park St	1	4	179	10	1545
Kenmore	Park St	1	4.2	161	9	1471
Kenmore	Park St	1	4.6	143	8	1343
Kenmore	Park St	1	5.33	126	7	1159
Kenmore	Park St	1	6.2	108	6	997
Kenmore	Park St	1	7.4	90	5	835
Kenmore	Park St	2	4	359	20	3090
Kenmore	Park St	2	4.2	323	18	2943
Kenmore	Park St	2	4.6	287	16	2687
Kenmore	Park St	2	5.33	251	14	2318
Kenmore	Park St	2	6.2	215	12	1994
Kenmore	Park St	2	7.4	179	10	1670
Kenmore	Govt Ctr	1	4	215	12	1545
Kenmore	Govt Ctr	1	4.2	197	11	1471
Kenmore	Govt Ctr	1	4.6	179	10	1343
Kenmore	Govt Ctr	1	5.2	161	9	1188
Kenmore	Govt Ctr	1	5.75	143	8	1075
Kenmore	Govt Ctr	1	6.6	126	7	936
Kenmore	Govt Ctr	1	7.6	108	6	813
Kenmore	Govt Ctr	2	4	430	24	3090
Kenmore	Govt Ctr	2	4.2	395	22	2943
Kenmore	Govt Ctr	2	4.6	359	20	2687
Kenmore	Govt Ctr	2	5.2	323	18	2377
Kenmore	Govt Ctr	2	5.75	287	16	2150

Kenmore	Govt Ctr	2	6.6	251	14	1873
Kenmore	Govt Ctr	2	7.6	215	12	1626
Kenmore	North Sta	1	4	269	15	1545
Kenmore	North Sta	1	4.2	251	14	1471
Kenmore	North Sta	1	4.5	233	13	1373
Kenmore	North Sta	1	5	215	12	1236
Kenmore	North Sta	1	5.33	197	11	1159
Kenmore	North Sta	1	5.8	179	10	1066
Kenmore	North Sta	1	6.5	161	9	951
Kenmore	North Sta	1	7.25	143	8	852
Kenmore	North Sta	2	4	538	30	3090
Kenmore	North Sta	2	4.2	502	28	2943
Kenmore	North Sta	2	4.5	466	26	2747
Kenmore	North Sta	2	5	430	24	2472
Kenmore	North Sta	2	5.33	395	22	2318
Kenmore	North Sta	2	5.8	359	20	2131
Kenmore	North Sta	2	6.5	323	18	1902
Kenmore	North Sta	2	7.25	287	16	1705

A.2.6 Service Patterns Terminating at Union Square

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Union Sq	Kenmore	1	4	359	20	1545
Union Sq	Kenmore	1	4.2	341	19	1471
Union Sq	Kenmore	1	4.5	323	18	1373
Union Sq	Kenmore	1	4.75	305	17	1301
Union Sq	Kenmore	1	5	287	16	1236
Union Sq	Kenmore	1	5.33	269	15	1159
Union Sq	Kenmore	1	5.75	251	14	1075
Union Sq	Kenmore	1	6.2	233	13	997
Union Sq	Kenmore	1	6.67	215	12	927
Union Sq	Kenmore	1	7.25	197	11	852
Union Sq	Kenmore	2	4	717	40	3090
Union Sq	Kenmore	2	4.2	681	38	2943
Union Sq	Kenmore	2	4.5	646	36	2747
Union Sq	Kenmore	2	4.75	610	34	2602
Union Sq	Kenmore	2	5	574	32	2472
Union Sq	Kenmore	2	5.33	538	30	2318
Union Sq	Kenmore	2	5.75	502	28	2150
Union Sq	Kenmore	2	6.2	466	26	1994
Union Sq	Kenmore	2	6.67	430	24	1854
Union Sq	Kenmore	2	7.25	395	22	1705
Union Sq	Govt Ctr	1	4	179	10	1545
Union Sq	Govt Ctr	1	4.4	161	9	1405
Union Sq	Govt Ctr	1	5	143	8	1236
Union Sq	Govt Ctr	1	5.67	126	7	1091

Union Sq	Govt Ctr	1	6.6	108	6	936
Union Sq	Govt Ctr	2	4	359	20	3090
Union Sq	Govt Ctr	2	4.4	323	18	2809
Union Sq	Govt Ctr	2	5	287	16	2472
Union Sq	Govt Ctr	2	5.67	251	14	2181
Union Sq	Govt Ctr	2	6.6	215	12	1873

A.2.7 Service Patterns Terminating at Medford/Tufts

Terminus	Turn-around Location	Consist Length	Head-way (min)	Operator Hours Req.	Fleet Req.	Flow Capacity (pax/hr)
Medford/Tufts	Kenmore	1	4	395	22	1545
Medford/Tufts	Kenmore	1	4.2	377	21	1471
Medford/Tufts	Kenmore	1	4.4	359	20	1405
Medford/Tufts	Kenmore	1	4.6	341	19	1343
Medford/Tufts	Kenmore	1	5	323	18	1236
Medford/Tufts	Kenmore	1	5.2	305	17	1188
Medford/Tufts	Kenmore	1	5.5	287	16	1124
Medford/Tufts	Kenmore	1	6	269	15	1030
Medford/Tufts	Kenmore	1	6.25	251	14	989
Medford/Tufts	Kenmore	1	6.75	233	13	916
Medford/Tufts	Kenmore	1	7.33	215	12	843
Medford/Tufts	Kenmore	2	4	789	44	3090
Medford/Tufts	Kenmore	2	4.2	753	42	2943
Medford/Tufts	Kenmore	2	4.4	717	40	2809
Medford/Tufts	Kenmore	2	4.6	681	38	2687
Medford/Tufts	Kenmore	2	5	646	36	2472
Medford/Tufts	Kenmore	2	5.2	610	34	2377
Medford/Tufts	Kenmore	2	5.5	574	32	2247
Medford/Tufts	Kenmore	2	6	538	30	2060
Medford/Tufts	Kenmore	2	6.25	502	28	1978
Medford/Tufts	Kenmore	2	6.75	466	26	1831
Medford/Tufts	Kenmore	2	7.33	430	24	1685
Medford/Tufts	Govt Ctr	1	4	215	12	1545
Medford/Tufts	Govt Ctr	1	4.25	197	11	1454

Medford/Tufts	Govt Ctr	1	4.67	179	10	1324
Medford/Tufts	Govt Ctr	1	5.2	161	9	1188
Medford/Tufts	Govt Ctr	1	6	143	8	1030
Medford/Tufts	Govt Ctr	1	6.67	126	7	927
Medford/Tufts	Govt Ctr	1	7.8	108	6	792
Medford/Tufts	Govt Ctr	2	4	430	24	3090
Medford/Tufts	Govt Ctr	2	4.25	395	22	2908
Medford/Tufts	Govt Ctr	2	4.67	359	20	2649
Medford/Tufts	Govt Ctr	2	5.2	323	18	2377
Medford/Tufts	Govt Ctr	2	6	287	16	2060
Medford/Tufts	Govt Ctr	2	6.67	251	14	1854
Medford/Tufts	Govt Ctr	2	7.8	215	12	1585

Appendix B

Preliminary Results

B.1 Introduction

The Alternate Paths presented in Chapter 5 are the product of several rounds of iteration in the proposed approach. Initial runs of the optimization program detailed in Chapter 3 had minimal constraints on the types of solutions generated, resulting in some solutions with potentially risky or undesirable operational characteristics. These characteristics were identified during the qualitative analysis stage. Additional runs were completed with new constraints limiting the solution space to more operationally favorable solutions, and the opportunity costs of these restrictions were quantified by comparison to previous (less restricted) outputs. In cases where impacts to passenger level-of-service were small, these restrictions could be incorporated into the Alternative Plans.

This Appendix includes the relevant solution outputs for the stages of analysis that led to the development of the Alternative Plans. Each section consists of a description of the constraints included in the generation of the solutions within, an analysis of the trends observed, and a list of the solutions generated with associated performance metrics.

For every scenario, 100 of the most optimal solutions were generated according to the method described in Chapter 3. All solutions are generated with the "core constraints" described in Chapter 3. The core constraints require solutions to satisfy conditions of fleet availability, operator hours, capacity, and turnarounds at stations. Additional "restrictions" refer not to the presence of core constraints, but instead to specific constraints applied to generate more operationally desirable solutions, such as specific branch headways or the number of single-car services allowed.

The following abbreviations are used in tables throughout this section:

- BC: Boston College
- CC: Cleveland Circle
- R: Riverside
- HS: Heath Street
- K: Kenmore
- PS: Park Street
- GC: Government Center
- US: Union Square
- MT: Medford/Tufts

B.2 Solutions Unrestricted Beyond Core Constraints

The first set of solutions generated introduced no restrictions on the types of solutions generated beyond those enforced by core constraints. The high efficiency of single-car services results in solutions with up to three proposed single-car services in phases I and II, where demand is low. Larger capacity requirements in phases III and IV limit solutions to one single-car train.

Table B.1 shows the number of solutions in each phase that are assigned a particular GLX branch routing combination. For example, the first row shows the number of solutions in each phase that feature the D branch serving the Union

Square Branch and the E branch serving the Medford Branch. In cases where a GLX branch service is turned within the Central Subway (e.g., Government Center), that station is written instead.

Table B.1: Summary of GLX Routings by Occurrence, Unrestricted Solutions

Union Square Branch	Medford Branch	Number of Occurrences			
		Phase I	Phase II	Phase III	Phase IV
D	E	71	80	39	8
B	E	10	8	44	4
C	E	19	12	0	88
Govt Ctr	E	0	0	17	0

Of the four GLX routing combinations that appear, only "D to Union Square, E to Medford" and "B to Union Square, E to Medford" appear in the 100 most optimal solutions in every phase. Of these, the former has a larger number of occurrences in all phases outside of Phase III. As discussed in Chapter 3, this provides insight into the robustness of a solution, as the presence of more solutions implies a greater range of options and a greater ability to customize solutions to more specific outcomes (e.g., the use of a particular Central Subway turnaround location or a particular headway on a branch).

Table B.2 and Table B.3 show the minimum EWT and minimum transfers attained, respectively, by each of the GLX routing combinations. The range of the minimum wait times within any phase is small, with no phase showing a range larger than 59 minutes per thousand passengers between the different routing combinations. This implies that any under-performance in wait time due to the selection of the GLX routing combination is small. Similarly, the range of transferring passengers is small, particularly between the two routing combinations present in all four phases. The difference in minimum transfers between these two combinations is never greater than 5 passengers per 1,000. Overall, the "D to Union Square, E to Medford" routing combination provides consistently high LOS in all phases, with ample flexibility.

Table B.2: Summary of GLX Routings by EWT, Unrestricted Solutions

Union Square Branch	Medford Branch	Minimum EWT			
		Phase I	Phase II	Phase III	Phase IV
D	E	2635	2635	2659	2476
B	E	2662	2662	2600	2503
C	E	2671	2671	--	2451
Govt Ctr	E	--	--	2609	--

Table B.3: Summary of GLX Routings by Transfers, Unrestricted Solutions

Union Square Branch	Medford Branch	Minimum Transfers			
		Phase I	Phase II	Phase III	Phase IV
D	E	45	45	40	45
B	E	40	50	40	41
C	E	39	48	--	33
Govt Ctr	E	--	--	55	--

As noted, there are a large number of solutions utilizing single-car trains. Table B.4 shows the breakdown of solutions in each phase by the number of single-car services proposed as well as the branches in which the single-car trains are used. For example, in Phase II, 71 of 100 solutions feature two single-car services, and the remaining 29 feature three single-car services. As the phases progress over time, the number of single-car services proposed decreases due to increased demand and increased resources; however, even under high-demand scenarios, solutions consisting entirely of two-car trains do not appear. Single-car trains are most commonly used on the C and E branches. In particular, Phase III always features single-car trains on the E branch; whereas Phase IV features single-car trains near-exclusively on the C branch. Note that some single-car services do not appear under the branch columns because they do not serve one of the western branches (e.g., a single-car service from Kenmore to Park Street).

Table B.4: Summary of Single-Car Train Use, Unrestricted Solutions

Phase	Number of Single-Car Services				Branches With Single-Car Services			
	0	1	2	3	B	C	D	E
I	0	0	0	100	99	99	5	97
II	0	0	71	29	72	72	3	82
III	0	64	36	0	0	19	0	100
IV	0	100	0	0	0	99	0	1

Table B.5: Unrestricted Solutions (Phase I Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.00	4.80	109	1942	2635	54
I	2	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.50	4.80	107	1902	2635	54
I	3	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.25	4.80	108	1922	2638	54
I	4	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.50	4.50	107	1912	2638	54
I	5	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.25	4.67	108	1927	2639	54
I	6	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	6.80	4.80	101	1784	2662	50
I	7	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.50	4.67	107	1907	2642	54
I	8	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.80	4.33	106	1897	2643	54
I	9	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.25	4.80	108	1928	2643	54
I	10	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.25	4.80	108	1928	2684	45
I	11	BC-PS	CC-PS	R-US	HS-MT	5.75	4.33	6.50	4.80	107	1913	2644	54
I	12	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.25	4.80	100	1815	2671	48
I	13	BC-PS	CC-PS	R-US	HS-MT	5.50	4.60	6.50	4.80	107	1908	2645	54
I	14	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.50	4.80	107	1913	2687	45
I	15	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.50	4.80	107	1908	2687	45
I	16	BC-US	CC-PS	R-GC	HS-MT	5.40	4.80	7.25	4.80	100	1765	2667	50
I	17	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.80	4.50	106	1893	2647	54
I	18	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.50	4.67	107	1913	2647	54
I	19	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.80	4.80	101	1829	2674	48
I	20	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	108	1980	2648	54
I	21	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	110	1956	2648	54
I	22	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.50	4.67	107	1913	2689	45
I	23	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.25	4.80	108	1916	2648	54
I	24	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.80	4.80	101	1818	2675	48
I	25	BC-GC	CC-PS	R-US	HS-MT	5.60	4.80	6.50	4.80	107	1902	2676	48
I	26	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.00	4.80	109	1942	2690	45
I	27	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.50	4.33	107	1912	2650	54
I	28	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.80	4.80	106	1888	2690	45
I	29	BC-PS	CC-GC	R-US	HS-MT	5.20	5.33	6.50	4.80	107	1902	2691	45
I	30	BC-PS	CC-US	R-GC	HS-MT	5.50	5.20	6.80	4.80	101	1823	2677	48
I	31	BC-PS	CC-PS	R-US	HS-MT	5.50	5.20	6.00	4.80	109	1936	2651	54
I	32	BC-PS	CC-PS	R-US	HS-MT	5.20	5.50	6.00	4.80	109	1931	2651	54
I	33	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.25	4.50	108	1926	2651	54
I	34	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	7.25	4.67	100	1770	2671	50
I	35	BC-PS	CC-US	R-GC	HS-MT	5.75	5.40	6.80	4.50	101	1828	2678	48
I	36	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.80	4.50	106	1898	2652	54
I	37	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	6.50	4.00	107	1910	2652	54
I	38	BC-PS	CC-GC	R-US	HS-MT	5.50	5.33	6.25	4.80	108	1922	2693	45
I	39	BC-PS	CC-PS	R-US	HS-MT	5.75	5.50	6.25	4.33	108	1926	2652	54
I	40	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	6.80	4.67	101	1828	2679	48
I	41	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.00	4.67	109	1941	2652	54
I	42	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.80	4.50	106	1898	2693	45
I	43	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.50	4.50	107	1912	2693	45
I	44	BC-PS	CC-US	R-GC	HS-MT	5.20	5.20	7.25	4.80	100	1804	2679	48
I	45	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.50	4.67	107	1902	2653	54
I	46	BC-PS	CC-PS	R-US	HS-MT	5.50	5.50	5.75	4.80	110	1950	2653	54
I	47	BC-PS	CC-PS	R-US	HS-MT	5.50	5.50	5.75	4.80	108	1975	2653	54
I	48	BC-US	CC-PS	R-NS	HS-MT	5.60	4.80	7.60	4.80	101	1784	2721	40
I	49	BC-PS	CC-PS	R-US	HS-MT	5.20	5.80	5.75	4.80	110	1945	2653	54
I	50	BC-PS	CC-PS	R-US	HS-MT	5.20	5.80	5.75	4.80	108	1969	2653	54

Table B.6: Unrestricted Solutions (Phase I Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	51	BC-PS	CC-PS	R-US	HS-MT	5.75	5.50	6.00	4.50	109	1940	2654	54
I	52	BC-PS	CC-US	R-NS	HS-MT	5.75	5.40	6.75	4.80	103	1857	2728	39
I	53	BC-PS	CC-PS	R-US	HS-MT	5.50	5.20	6.50	4.50	107	1907	2654	54
I	54	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.25	4.67	108	1927	2695	45
I	55	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	6.50	4.80	102	1843	2681	48
I	56	BC-PS	CC-PS	R-US	HS-MT	5.20	5.50	6.50	4.50	107	1901	2654	54
I	57	BC-US	CC-PS	R-GC	HS-MT	5.60	4.60	7.25	4.80	100	1770	2675	50
I	58	BC-PS	CC-GC	R-US	HS-MT	5.75	4.50	6.80	4.80	106	1899	2695	45
I	59	BC-PS	CC-US	R-GC	HS-MT	5.75	5.40	7.25	4.33	100	1813	2681	48
I	60	BC-PS	CC-GC	R-US	HS-MT	5.50	4.75	6.80	4.80	106	1894	2695	45
I	61	BC-US	CC-PS	R-GC	HS-MT	5.20	4.80	7.75	4.80	99	1745	2675	50
I	62	BC-US	CC-PS	R-GC	HS-MT	5.40	5.20	6.80	4.80	101	1779	2675	50
I	63	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	6.00	4.33	109	1940	2655	54
I	64	BC-PS	CC-US	R-GC	HS-MT	5.50	5.00	7.25	4.80	100	1809	2681	48
I	65	BC-PS	CC-PS	R-US	HS-MT	5.75	5.50	5.75	4.67	110	1955	2655	54
I	66	BC-US	CC-GC	R-GC	HS-MT	5.60	5.00	7.25	4.80	100	1770	2716	41
I	67	BC-PS	CC-PS	R-US	HS-MT	5.50	5.50	6.50	4.33	107	1906	2655	54
I	68	BC-PS	CC-PS	R-US	HS-MT	5.50	5.20	6.25	4.67	108	1921	2655	54
I	69	BC-PS	CC-GC	R-US	HS-MT	5.75	5.67	5.75	4.80	102	1774	2696	45
I	70	BC-PS	CC-GC	R-US	HS-MT	5.75	5.67	5.75	4.80	100	1833	2696	45
I	71	BC-PS	CC-GC	R-US	HS-MT	5.75	5.67	5.75	4.80	110	1956	2696	45
I	72	BC-PS	CC-PS	R-US	HS-MT	5.75	5.50	6.80	4.00	106	1896	2655	54
I	73	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	6.80	4.67	101	1823	2682	48
I	74	BC-PS	CC-PS	R-US	HS-MT	5.20	5.80	6.50	4.33	107	1900	2655	54
I	75	BC-GC	CC-PS	R-US	HS-MT	5.33	4.80	6.80	4.80	106	1883	2683	48
I	76	BC-PS	CC-PS	R-US	HS-MT	5.20	5.50	6.25	4.67	108	1916	2656	54
I	77	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	7.25	4.50	100	1814	2682	48
I	78	BC-PS	CC-US	R-GC	HS-MT	5.50	4.75	7.75	4.80	99	1795	2682	48
I	79	BC-PS	CC-GC	R-US	HS-MT	5.20	5.67	6.25	4.80	108	1916	2697	45
I	80	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	5.75	4.50	110	1955	2656	54
I	81	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.80	4.67	106	1899	2697	45
I	82	BC-PS	CC-PS	R-US	HS-MT	5.00	5.20	6.50	4.80	107	1897	2656	54
I	83	BC-US	CC-GC	R-GC	HS-MT	5.60	5.33	6.80	4.80	101	1784	2717	41
I	84	BC-PS	CC-PS	R-US	HS-MT	5.50	5.50	6.25	4.50	108	1921	2656	54
I	85	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	7.25	4.67	100	1814	2683	48
I	86	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.80	4.67	106	1893	2697	45
I	87	BC-PS	CC-PS	R-US	HS-MT	5.20	5.80	6.25	4.50	108	1915	2657	54
I	88	BC-PS	CC-GC	R-US	HS-MT	5.50	5.33	6.50	4.67	107	1907	2698	45
I	89	BC-PS	CC-PS	R-US	HS-MT	5.75	5.50	6.50	4.20	107	1911	2657	54
I	90	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.80	4.33	106	1897	2698	45
I	91	BC-US	CC-PS	R-GC	HS-MT	5.20	5.50	6.80	4.80	101	1773	2677	50
I	92	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	6.50	4.80	102	1837	2684	48
I	93	BC-PS	CC-GC	R-US	HS-MT	5.75	5.67	6.50	4.33	107	1912	2698	45
I	94	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.75	4.67	99	1800	2684	48
I	95	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.80	4.50	106	1887	2657	54
I	96	BC-PS	CC-PS	R-US	HS-MT	5.50	5.80	6.25	4.33	108	1920	2658	54
I	97	BC-PS	CC-PS	R-US	HS-MT	5.50	5.50	6.00	4.67	109	1935	2658	54
I	98	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	7.25	4.67	100	1803	2684	48
I	99	BC-PS	CC-US	R-NS	HS-MT	5.75	5.20	7.20	4.80	102	1843	2732	39
I	100	BC-PS	CC-PS	R-US	HS-MT	5.20	5.80	6.00	4.67	109	1930	2658	54

Table B.7: Unrestricted Solutions (Phase II Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	1	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.00	4.80	109	1942	2635	54
II	2	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.00	4.80	127	2207	2635	54
II	3	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.00	4.80	126	2287	2635	54
II	4	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.50	4.80	127	2197	2635	54
II	5	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.50	4.80	131	2374	2635	54
II	6	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.50	4.80	107	1902	2635	54
II	7	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.50	4.80	124	2247	2635	54
II	8	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.25	4.80	125	2267	2638	54
II	9	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.25	4.80	127	2202	2638	54
II	10	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.25	4.80	108	1922	2638	54
II	11	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.50	4.50	107	1912	2638	54
II	12	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.50	4.50	124	2257	2638	54
II	13	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.50	4.50	125	2178	2638	54
II	14	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.25	4.67	108	1927	2639	54
II	15	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.25	4.67	126	2192	2639	54
II	16	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.25	4.67	125	2272	2639	54
II	17	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	6.80	4.80	118	2129	2662	50
II	18	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	6.80	4.80	127	2168	2662	50
II	19	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	6.80	4.80	125	2256	2662	50
II	20	BC-US	CC-PS	R-GC	HS-MT	5.60	4.80	6.80	4.80	101	1784	2662	50
II	21	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.50	4.67	126	2187	2642	54
II	22	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.50	4.67	124	2252	2642	54
II	23	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.50	4.67	107	1907	2642	54
II	24	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.80	4.33	124	2163	2643	54
II	25	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.80	4.33	123	2242	2643	54
II	26	BC-PS	CC-PS	R-US	HS-MT	5.75	4.80	6.80	4.33	106	1897	2643	54
II	27	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.25	4.80	126	2193	2643	54
II	28	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.25	4.80	126	2293	2643	54
II	29	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.25	4.80	108	1928	2643	54
II	30	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.25	4.80	108	1928	2684	45
II	31	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.25	4.80	126	2293	2684	45
II	32	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.25	4.80	126	2193	2684	45
II	33	BC-PS	CC-PS	R-US	HS-MT	5.75	4.33	6.50	4.80	125	2179	2644	54
II	34	BC-PS	CC-PS	R-US	HS-MT	5.75	4.33	6.50	4.80	107	1913	2644	54
II	35	BC-PS	CC-PS	R-US	HS-MT	5.75	4.33	6.50	4.80	131	2385	2644	54
II	36	BC-PS	CC-PS	R-US	HS-MT	5.75	4.33	6.50	4.80	126	2299	2644	54
II	37	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.25	4.80	100	1815	2671	48
II	38	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.25	4.80	118	2080	2671	48
II	39	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.25	4.80	126	2342	2671	48
II	40	BC-PS	CC-US	R-GC	HS-MT	5.75	4.75	7.25	4.80	124	2286	2671	48
II	41	BC-PS	CC-PS	R-US	HS-MT	5.50	4.60	6.50	4.80	125	2273	2645	54
II	42	BC-PS	CC-PS	R-US	HS-MT	5.50	4.60	6.50	4.80	126	2188	2645	54
II	43	BC-PS	CC-PS	R-US	HS-MT	5.50	4.60	6.50	4.80	107	1908	2645	54
II	44	BC-PS	CC-PS	R-US	HS-MT	5.50	4.60	6.50	4.80	131	2380	2645	54
II	45	BC-PS	CC-PS	R-US	HS-MT	5.20	4.80	6.80	4.67	131	2379	2646	54
II	46	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.50	4.80	107	1913	2687	45
II	47	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.50	4.80	126	2299	2687	45
II	48	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.50	4.80	131	2385	2687	45
II	49	BC-PS	CC-GC	R-US	HS-MT	5.75	4.75	6.50	4.80	125	2179	2687	45
II	50	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.50	4.80	125	2273	2687	45

Table B.8: Unrestricted Solutions (Phase II Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.50	4.80	126	2188	2687	45
II	52	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.50	4.80	131	2380	2687	45
II	53	BC-PS	CC-GC	R-US	HS-MT	5.50	5.00	6.50	4.80	107	1908	2687	45
II	54	BC-US	CC-PS	R-GC	HS-MT	5.40	4.80	7.25	4.80	124	2236	2667	50
II	55	BC-US	CC-PS	R-GC	HS-MT	5.40	4.80	7.25	4.80	127	2163	2667	50
II	56	BC-US	CC-PS	R-GC	HS-MT	5.40	4.80	7.25	4.80	100	1765	2667	50
II	57	BC-US	CC-PS	R-GC	HS-MT	5.40	4.80	7.25	4.80	117	2110	2667	50
II	58	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.80	4.50	106	1893	2647	54
II	59	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.80	4.50	123	2237	2647	54
II	60	BC-PS	CC-PS	R-US	HS-MT	5.50	4.80	6.80	4.50	125	2173	2647	54
II	61	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.50	4.67	125	2178	2647	54
II	62	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.50	4.67	125	2278	2647	54
II	63	BC-PS	CC-PS	R-US	HS-MT	5.75	4.60	6.50	4.67	107	1913	2647	54
II	64	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.80	4.80	101	1829	2674	48
II	65	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.80	4.80	125	2301	2674	48
II	66	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.80	4.80	119	2094	2674	48
II	67	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.80	4.80	126	2336	2674	48
II	68	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	110	1956	2648	54
II	69	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	128	2221	2648	54
II	70	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	126	2280	2648	54
II	71	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	108	1980	2648	54
II	72	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	124	2305	2648	54
II	73	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	5.75	4.80	126	2246	2648	54
II	74	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.50	4.67	125	2178	2689	45
II	75	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.50	4.67	125	2278	2689	45
II	76	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	6.50	4.67	107	1913	2689	45
II	77	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.25	4.80	128	2211	2648	54
II	78	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.25	4.80	108	1916	2648	54
II	79	BC-PS	CC-PS	R-US	HS-MT	5.20	5.20	6.25	4.80	124	2241	2648	54
II	80	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.80	4.80	121	2113	2675	48
II	81	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.80	4.80	125	2289	2675	48
II	82	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.80	4.80	101	1818	2675	48
II	83	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.80	4.80	124	2284	2675	48
II	84	BC-GC	CC-PS	R-US	HS-MT	5.60	4.80	6.50	4.80	127	2197	2676	48
II	85	BC-GC	CC-PS	R-US	HS-MT	5.60	4.80	6.50	4.80	107	1902	2676	48
II	86	BC-GC	CC-PS	R-US	HS-MT	5.60	4.80	6.50	4.80	124	2247	2676	48
II	87	BC-GC	CC-PS	R-US	HS-MT	5.60	4.80	6.50	4.80	131	2374	2676	48
II	88	BC-PS	CC-PS	R-US	HS-MT	5.20	4.60	6.80	4.80	130	2360	2649	54
II	89	BC-PS	CC-PS	R-US	HS-MT	5.00	4.80	6.80	4.80	130	2354	2649	54
II	90	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.00	4.80	109	1942	2690	45
II	91	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.00	4.80	127	2207	2690	45
II	92	BC-PS	CC-GC	R-US	HS-MT	5.75	5.33	6.00	4.80	126	2287	2690	45
II	93	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.50	4.33	125	2177	2650	54
II	94	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.50	4.33	123	2236	2650	54
II	95	BC-PS	CC-PS	R-US	HS-MT	5.75	5.20	6.50	4.33	107	1912	2650	54
II	96	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.80	4.80	106	1888	2690	45
II	97	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.80	4.80	126	2183	2690	45
II	98	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.80	4.80	124	2254	2690	45
II	99	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.80	4.80	130	2360	2690	45
II	100	BC-PS	CC-GC	R-US	HS-MT	5.20	5.33	6.50	4.80	107	1902	2691	45

Table B.9: Unrestricted Solutions (Phase III Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-US	CC-PS	R-GC	HS-MT		5.33	5.67	7.20	4.00		154	2677	2600	50
III	2	BC-US	CC-PS	R-GC	HS-MT		5.20	5.67	7.60	4.00		154	2672	2610	50
III	3	BC-US	CC-PS	R-GC	HS-MT		5.50	5.33	7.60	4.00		152	2654	2619	50
III	4	BC-US	CC-PS	R-GC	HS-MT		5.75	5.00	7.60	4.00		152	2665	2620	50
III	5	BC-US	CC-PS	R-GC	HS-MT		5.50	6.20	6.40	4.00		154	2676	2620	50
III	6	BC-US	CC-PS	R-GC	HS-MT		6.20	5.00	6.75	4.00		152	2675	2622	50
III	7	BC-US	CC-PS	R-GC	HS-MT		5.33	6.20	6.75	4.00		154	2671	2622	50
III	8	BC-US	CC-PS	R-GC	HS-MT		5.50	5.67	7.20	4.00		152	2648	2624	50
III	9	BC-US	CC-PS	R-GC	HS-MT		5.75	5.33	7.20	4.00		152	2659	2625	50
III	10	BC-US	CC-PS	R-GC	HS-MT		6.00	5.00	7.20	4.00		152	2670	2626	50
III	11	BC-US	CC-PS	R-GC	HS-MT		5.75	5.67	6.75	4.00		152	2653	2626	50
III	12	BC-US	CC-PS	R-GC	HS-MT		6.00	5.33	6.75	4.00		152	2664	2628	50
III	13	BC-US	CC-PS	R-GC	HS-MT		5.33	5.67	7.60	4.00		152	2643	2629	50
III	14	BC-US	CC-PS	R-GC	HS-MT		6.00	4.75	7.60	4.00		152	2676	2630	50
III	15	BC-US	CC-PS	R-GC	HS-MT		6.20	5.33	6.40	4.00		152	2669	2630	50
III	16	BC-US	CC-PS	R-GC	HS-MT		5.20	6.20	7.20	4.00		154	2666	2636	50
III	17	BC-US	CC-PS	R-GC	HS-MT		6.00	5.67	6.40	4.00		152	2657	2636	50
III	18	BC-US	CC-PS	R-NS	HS-MT		6.20	5.00	7.60	4.00		152	2675	2684	40
III	19	BC-US	CC-PS	R-GC	HS-MT		5.00	6.20	7.60	4.00		154	2661	2637	50
III	20	BC-US	CC-PS	R-GC	HS-MT		5.33	6.60	6.40	4.00		154	2665	2638	50
III	21	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.20	5.80	7.60	4.00	5.00	151	2678	2616	55
III	22	BC-PS	CC-GC	R-US	HS-MT		5.75	5.80	6.60	4.00		150	2664	2664	45
III	23	BC-PS	CC-GC	R-US	HS-MT		5.20	6.67	6.33	4.00		152	2676	2666	45
III	24	BC-US	CC-PS	R-GC	HS-MT		5.50	6.60	6.20	4.00		154	2670	2647	50
III	25	BC-GC	CC-PS	R-NS	HS-MT	US-GC	5.60	5.33	7.60	4.00	5.00	151	2678	2609	57
III	26	BC-PS	CC-GC	R-US	HS-MT		5.75	5.20	7.20	4.00		150	2676	2670	45
III	27	BC-US	CC-PS	R-GC	HS-MT		6.20	5.67	6.20	4.00		152	2662	2650	50
III	28	BC-PS	CC-GC	R-US	HS-MT		4.75	6.20	7.20	4.00		152	2672	2671	45
III	29	BC-GC	CC-PS	R-NS	HS-MT	US-GC	6.20	5.00	7.60	4.00	4.40	150	2677	2611	57
III	30	BC-GC	CC-PS	R-US	HS-MT		5.60	6.20	6.33	4.00		152	2676	2659	48
III	31	BC-GC	CC-PS	R-US	HS-MT		5.40	5.67	7.00	4.00		152	2677	2660	48
III	32	BC-GC	CC-PS	R-NS	HS-MT	US-GC	5.60	5.67	7.20	4.00	5.00	151	2671	2614	57
III	33	BC-US	CC-PS	R-GC	HS-MT		5.75	6.60	5.80	4.00		154	2675	2653	50
III	34	BC-PS	CC-GC	R-US	HS-MT		5.00	6.20	7.00	4.00		152	2677	2674	45
III	35	BC-GC	CC-PS	R-US	HS-MT		6.20	5.33	6.60	4.00		150	2664	2661	48
III	36	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.20	5.33	6.60	4.00	6.80	146	2554	2661	48
III	37	BC-PS	CC-GC	R-US	HS-MT		5.75	6.20	6.33	4.00		150	2657	2675	45
III	38	BC-GC	CC-PS	R-US	HS-MT		5.20	5.67	7.20	4.00		152	2672	2662	48
III	39	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.20	6.20	7.20	4.00	5.00	151	2671	2628	55
III	40	BC-US	CC-PS	R-GC	HS-MT		5.75	5.33	7.60	4.00		150	2624	2654	50
III	41	BC-US	CC-PS	R-GC	HS-MT	K-PS	5.75	5.33	7.60	4.00	6.80	146	2515	2654	50
III	42	BC-US	CC-PS	R-GC	HS-MT		6.20	5.00	7.20	4.00		150	2640	2655	50
III	43	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.20	5.00	7.20	4.00	6.80	145	2511	2655	50
III	44	BC-PS	CC-GC	R-US	HS-MT		5.50	5.50	7.20	4.00		150	2665	2675	45
III	45	BC-PS	CC-GC	R-US	HS-MT		5.20	5.80	7.20	4.00		150	2654	2676	45
III	46	BC-US	CC-PS	R-GC	HS-MT		6.00	5.00	7.60	4.00		150	2635	2656	50
III	47	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.00	5.00	7.60	4.00	6.80	145	2506	2656	50
III	48	BC-PS	CC-GC	R-US	HS-MT		5.00	6.67	6.60	4.00		152	2671	2676	45
III	49	BC-US	CC-PS	R-GC	HS-MT		6.20	5.33	6.75	4.00		150	2634	2656	50
III	50	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.20	5.33	6.75	4.00	6.80	146	2525	2656	50

Table B.10: Unrestricted Solutions (Phase III Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-PS	CC-GC	R-US	HS-MT		5.75	5.50	7.00	4.00		150	2670	2678	45
III	52	BC-GC	CC-PS	R-US	HS-MT		6.20	5.67	6.33	4.00		150	2657	2665	48
III	53	BC-PS	CC-GC	R-US	HS-MT		5.50	5.20	7.50	4.00		150	2671	2679	45
III	54	BC-PS	CC-GC	R-US	HS-MT		6.20	5.50	6.60	4.00		150	2675	2679	45
III	55	BC-PS	CC-GC	R-US	HS-MT		5.20	5.50	7.50	4.00		150	2660	2679	45
III	56	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.20	4.75	7.60	4.00	6.80	144	2497	2658	50
III	57	BC-US	CC-PS	R-GC	HS-MT		6.20	4.75	7.60	4.00		150	2647	2658	50
III	58	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.75	5.50	7.20	4.00	5.50	150	2676	2632	55
III	59	BC-US	CC-PS	R-GC	HS-MT		6.50	5.33	6.20	4.00		152	2673	2659	50
III	60	BC-PS	CC-GC	R-US	HS-MT		5.50	6.20	6.60	4.00		150	2653	2679	45
III	61	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.75	5.80	6.80	4.00	5.50	150	2670	2634	55
III	62	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.60	5.00	6.60	4.00	6.80	145	2545	2668	48
III	63	BC-GC	CC-PS	R-US	HS-MT		6.60	5.00	6.60	4.00		150	2675	2668	48
III	64	BC-GC	CC-PS	R-US	HS-MT		5.60	5.00	7.50	4.00		150	2660	2668	48
III	65	BC-GC	CC-PS	R-US	HS-MT	K-PS	5.60	5.00	7.50	4.00	6.80	145	2530	2668	48
III	66	BC-GC	CC-PS	R-US	HS-MT		5.60	5.33	7.20	4.00		150	2654	2668	48
III	67	BC-GC	CC-PS	R-US	HS-MT	K-PS	5.60	5.33	7.20	4.00	6.80	146	2544	2668	48
III	68	BC-US	CC-PS	R-GC	HS-MT		6.00	5.33	7.20	4.00		150	2629	2661	50
III	69	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.00	5.33	7.20	4.00	6.80	146	2520	2661	50
III	70	BC-GC	CC-PS	R-US	HS-MT		5.40	6.20	6.60	4.00		152	2671	2669	48
III	71	BC-PS	CC-GC	R-NS	HS-MT	US-GC	4.75	6.67	7.60	4.00	4.40	152	2673	2635	55
III	72	BC-GC	CC-PS	R-US	HS-MT		6.20	4.75	7.20	4.00		150	2676	2669	48
III	73	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.20	4.75	7.20	4.00	6.80	144	2526	2669	48
III	74	BC-GC	CC-PS	R-NS	HS-MT	US-GC	5.40	5.67	7.60	4.00	5.00	151	2667	2623	57
III	75	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.50	5.50	7.60	4.00	5.50	150	2671	2636	55
III	76	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.20	5.80	7.60	4.00	5.50	150	2660	2636	55
III	77	BC-PS	CC-GC	R-US	HS-MT		5.50	5.80	7.00	4.00		150	2659	2684	45
III	78	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.00	6.20	7.60	4.00	5.00	151	2667	2637	55
III	79	BC-US	CC-PS	R-GC	HS-MT		6.50	5.67	5.80	4.00		152	2667	2664	50
III	80	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.50	5.80	7.20	4.00	5.50	150	2665	2637	55
III	81	BC-US	CC-GC	R-GC	HS-MT	K-PS	6.20	5.20	7.60	4.00	6.80	144	2497	2705	41
III	82	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.60	5.33	6.33	4.00	6.80	146	2559	2672	48
III	83	BC-GC	CC-PS	R-US	HS-MT		6.60	5.33	6.33	4.00		150	2669	2672	48
III	84	BC-US	CC-PS	R-GC	HS-MT		6.50	5.00	6.75	4.00		150	2645	2665	50
III	85	BC-US	CC-PS	R-GC	HS-MT	K-PS	6.50	5.00	6.75	4.00	6.80	145	2516	2665	50
III	86	BC-GC	CC-PS	R-US	HS-MT		6.20	5.00	7.00	4.00		150	2670	2673	48
III	87	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.20	5.00	7.00	4.00	6.80	145	2540	2673	48
III	88	BC-US	CC-PS	R-GC	HS-MT		6.20	5.67	6.40	4.00		150	2628	2665	50
III	89	BC-NS	CC-PS	R-GC	HS-MT	US-GC	6.33	5.33	6.75	4.00	5.00	151	2678	2621	58
III	90	BC-GC	CC-PS	R-NS	HS-MT	US-GC	6.20	5.00	7.20	4.00	5.50	150	2676	2626	57
III	91	BC-US	CC-GC	R-GC	HS-MT	K-PS	6.20	5.50	7.20	4.00	6.80	145	2511	2707	41
III	92	BC-US	CC-GC	R-GC	HS-MT	K-PS	6.00	5.50	7.60	4.00	6.80	145	2506	2708	41
III	93	BC-US	CC-GC	R-PS	HS-MT		5.33	6.20	6.67	4.00		154	2677	2616	60
III	94	BC-PS	CC-GC	R-NS	HS-MT	US-GC	5.20	5.80	7.20	4.00	6.33	151	2676	2641	55
III	95	BC-GC	CC-PS	R-US	HS-MT		6.00	5.00	7.20	4.00		150	2665	2675	48
III	96	BC-GC	CC-PS	R-US	HS-MT	K-PS	6.00	5.00	7.20	4.00	6.80	145	2535	2675	48
III	97	BC-GC	CC-GC	R-US	HS-MT		6.20	5.20	7.20	4.00		150	2676	2716	40
III	98	BC-GC	CC-GC	R-US	HS-MT	K-PS	6.20	5.20	7.20	4.00	6.80	144	2526	2716	40
III	99	BC-GC	CC-PS	R-US	HS-MT		6.00	5.67	6.60	4.00		150	2653	2675	48
III	100	BC-NS	CC-PS	R-GC	HS-MT	US-GC	5.75	5.33	7.60	4.00	5.00	151	2668	2624	58

Table B.11: Unrestricted Solutions (Phase IV Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	6.40	4.20	167	2999	2451	48
IV	2	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	6.40	4.33	167	2990	2455	48
IV	3	BC-PS	CC-US	R-GC	HS-MT	4.75	4.80	6.75	4.33	167	2985	2455	48
IV	4	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	6.40	4.33	166	2980	2456	48
IV	5	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	6.75	4.20	167	2995	2457	48
IV	6	BC-PS	CC-US	R-NS	HS-MT	5.20	4.80	6.80	4.33	167	2995	2505	39
IV	7	BC-PS	CC-US	R-GC	HS-MT	5.20	4.50	6.75	4.33	165	2966	2458	48
IV	8	BC-PS	CC-US	R-GC	HS-MT	4.75	5.00	6.40	4.33	168	2999	2458	48
IV	9	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	6.75	4.20	166	2985	2458	48
IV	10	BC-PS	CC-US	R-GC	HS-MT	4.75	4.80	6.40	4.50	167	2980	2459	48
IV	11	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	6.40	4.20	168	3009	2460	48
IV	12	BC-PS	CC-US	R-GC	HS-MT	4.75	5.00	6.75	4.20	168	3004	2460	48
IV	13	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	5.80	4.33	168	3009	2460	48
IV	14	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	6.20	4.33	167	2995	2461	48
IV	15	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	5.80	4.50	167	2990	2461	48
IV	16	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	6.75	4.33	166	2976	2461	48
IV	17	BC-PS	CC-GC	R-US	HS-MT	5.20	4.25	6.33	4.33	172	3065	2476	45
IV	18	BC-PS	CC-US	R-GC	HS-MT	5.50	4.80	5.80	4.33	167	2999	2462	48
IV	19	BC-PS	CC-US	R-NS	HS-MT	5.20	5.00	6.80	4.20	168	3014	2510	39
IV	20	BC-PS	CC-US	R-GC	HS-MT	5.20	4.50	6.40	4.50	165	2961	2462	48
IV	21	BC-PS	CC-US	R-NS	HS-MT	5.20	4.80	7.20	4.20	167	2999	2510	39
IV	22	BC-PS	CC-US	R-GC	HS-MT	5.50	4.50	6.40	4.33	165	2971	2463	48
IV	23	BC-PS	CC-US	R-GC	HS-MT	4.75	5.20	6.40	4.20	169	3018	2463	48
IV	24	BC-PS	CC-US	R-GC	HS-MT	5.50	4.67	6.40	4.20	166	2990	2463	48
IV	25	BC-PS	CC-GC	R-US	HS-MT	5.20	4.50	6.33	4.20	173	3084	2478	45
IV	26	BC-PS	CC-US	R-GC	HS-MT	5.75	4.80	5.80	4.20	167	3009	2464	48
IV	27	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	6.75	4.50	164	2947	2464	48
IV	28	BC-PS	CC-US	R-NS	HS-MT	5.20	5.00	6.50	4.33	168	3009	2512	39
IV	29	BC-PS	CC-US	R-NS	HS-MT	5.50	4.80	6.80	4.20	167	3004	2512	39
IV	30	BC-PS	CC-US	R-GC	HS-MT	4.75	4.80	7.20	4.20	167	2990	2464	48
IV	31	BC-PS	CC-US	R-GC	HS-MT	5.50	4.33	6.75	4.33	164	2957	2465	48
IV	32	BC-PS	CC-US	R-GC	HS-MT	5.75	4.33	6.40	4.33	164	2962	2465	48
IV	33	BC-PS	CC-US	R-GC	HS-MT	5.75	4.50	6.40	4.20	165	2981	2465	48
IV	34	BC-GC	CC-US	R-GC	HS-MT	5.60	4.80	6.40	4.20	167	2999	2493	43
IV	35	BC-PS	CC-US	R-NS	HS-MT	5.20	4.80	6.50	4.50	167	2990	2513	39
IV	36	BC-PS	CC-US	R-GC	HS-MT	5.50	4.50	6.75	4.20	165	2976	2465	48
IV	37	BC-PS	CC-US	R-GC	HS-MT	5.20	5.20	5.80	4.20	169	3028	2465	48
IV	38	BC-PS	CC-US	R-NS	HS-MT	5.00	5.00	6.80	4.33	168	3004	2513	39
IV	39	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	6.40	4.50	166	2971	2466	48
IV	40	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.20	4.20	168	3014	2466	48
IV	41	BC-PS	CC-US	R-GC	HS-MT	4.75	4.67	6.75	4.50	166	2966	2466	48
IV	42	BC-PS	CC-US	R-NS	HS-MT	5.50	4.80	6.50	4.33	167	2999	2514	39
IV	43	BC-PS	CC-US	R-NS	HS-MT	5.00	4.80	7.20	4.33	167	2990	2514	39
IV	44	BC-PS	CC-US	R-GC	HS-MT	5.75	4.33	6.75	4.20	164	2967	2466	48
IV	45	BC-PS	CC-US	R-NS	HS-MT	5.00	4.80	6.80	4.50	167	2985	2514	39
IV	46	BC-PS	CC-US	R-GC	HS-MT	5.50	5.00	5.80	4.20	168	3018	2467	48
IV	47	BC-PS	CC-GC	R-US	HS-MT	5.00	4.50	6.33	4.33	173	3074	2481	45
IV	48	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	7.20	4.33	164	2952	2467	48
IV	49	BC-PS	CC-US	R-GC	HS-MT	5.20	4.50	7.20	4.20	165	2971	2467	48
IV	50	BC-PS	CC-US	R-NS	HS-MT	5.20	4.67	7.20	4.33	166	2980	2515	39

Table B.12: Unrestricted Solutions (Phase IV Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-PS	CC-US	R-GC	HS-MT	5.00	4.50	6.75	4.50	165	2957	2467	48
IV	52	BC-PS	CC-US	R-GC	HS-MT	5.50	4.80	6.20	4.20	167	3004	2468	48
IV	53	BC-PS	CC-US	R-NS	HS-MT	5.75	4.80	6.50	4.20	167	3009	2515	39
IV	54	BC-PS	CC-GC	R-US	HS-MT	5.75	4.50	5.67	4.33	173	3089	2482	45
IV	55	BC-PS	CC-US	R-NS	HS-MT	5.20	4.67	6.80	4.50	166	2976	2516	39
IV	56	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	6.40	4.67	164	2942	2468	48
IV	57	BC-GC	CC-US	R-GC	HS-MT	5.40	4.80	6.40	4.33	167	2990	2496	43
IV	58	BC-PS	CC-GC	R-US	HS-MT	5.20	4.25	6.60	4.20	172	3070	2482	45
IV	59	BC-PS	CC-US	R-GC	HS-MT	5.75	4.67	5.80	4.33	166	2990	2468	48
IV	60	BC-PS	CC-GC	R-US	HS-MT	5.50	4.25	6.33	4.20	172	3075	2483	45
IV	61	BC-PS	CC-US	R-GC	HS-MT	5.00	5.20	5.80	4.33	169	3018	2468	48
IV	62	BC-PS	CC-US	R-GC	HS-MT	4.60	5.00	6.75	4.33	168	2994	2468	48
IV	63	BC-PS	CC-US	R-NS	HS-MT	4.75	5.20	6.80	4.33	169	3013	2516	39
IV	64	BC-PS	CC-US	R-NS	HS-MT	5.50	4.67	6.80	4.33	166	2985	2516	39
IV	65	BC-PS	CC-US	R-GC	HS-MT	4.75	4.67	7.20	4.33	166	2971	2469	48
IV	66	BC-PS	CC-US	R-GC	HS-MT	5.50	4.33	6.40	4.50	164	2952	2469	48
IV	67	BC-PS	CC-US	R-NS	HS-MT	5.20	5.20	6.50	4.20	169	3028	2517	39
IV	68	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	6.20	4.33	168	3004	2469	48
IV	69	BC-US	CC-GC	R-GC	HS-MT	5.50	4.50	6.40	4.33	173	3045	2503	41
IV	70	BC-US	CC-GC	R-GC	HS-MT	5.50	4.25	6.75	4.33	172	3031	2503	41
IV	71	BC-PS	CC-US	R-NS	HS-MT	4.75	5.00	7.20	4.33	168	2999	2517	39
IV	72	BC-GC	CC-US	R-GC	HS-MT	5.60	4.67	6.40	4.33	166	2980	2497	43
IV	73	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	5.80	4.50	168	2999	2469	48
IV	74	BC-PS	CC-US	R-NS	HS-MT	5.75	4.80	6.20	4.33	167	3004	2517	39
IV	75	BC-PS	CC-US	R-GC	HS-MT	4.60	4.80	6.75	4.50	167	2975	2469	48
IV	76	BC-PS	CC-US	R-NS	HS-MT	4.75	5.00	6.80	4.50	168	2994	2517	39
IV	77	BC-PS	CC-US	R-GC	HS-MT	4.75	4.67	6.40	4.67	166	2961	2470	48
IV	78	BC-GC	CC-US	R-GC	HS-MT	5.40	4.80	6.75	4.20	167	2995	2498	43
IV	79	BC-PS	CC-US	R-NS	HS-MT	4.75	4.80	7.60	4.33	167	2985	2518	39
IV	80	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	6.20	4.50	167	2985	2470	48
IV	81	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.75	4.00	168	3023	2470	48
IV	82	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.75	4.00	162	2922	2470	48
IV	83	BC-GC	CC-US	R-NS	HS-MT	5.60	4.80	6.80	4.33	167	2995	2546	33
IV	84	BC-PS	CC-US	R-NS	HS-MT	4.75	4.80	7.20	4.50	167	2980	2518	39
IV	85	BC-PS	CC-US	R-NS	HS-MT	5.75	4.50	6.80	4.33	165	2976	2518	39
IV	86	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	5.80	4.67	167	2980	2470	48
IV	87	BC-PS	CC-US	R-NS	HS-MT	5.00	5.20	6.80	4.20	169	3023	2518	39
IV	88	BC-PS	CC-US	R-NS	HS-MT	5.75	4.67	6.80	4.20	166	2995	2518	39
IV	89	BC-PS	CC-US	R-GC	HS-MT	5.00	4.50	7.20	4.33	165	2961	2471	48
IV	90	BC-PS	CC-US	R-NS	HS-MT	5.20	5.20	6.20	4.33	169	3023	2518	39
IV	91	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	7.20	4.20	166	2980	2471	48
IV	92	BC-PS	CC-US	R-NS	HS-MT	4.75	4.80	6.80	4.67	167	2975	2518	39
IV	93	BC-PS	CC-US	R-NS	HS-MT	5.50	5.00	6.50	4.20	168	3018	2519	39
IV	94	BC-PS	CC-GC	R-US	HS-MT	5.00	4.25	6.33	4.50	172	3055	2485	45
IV	95	BC-US	CC-GC	R-GC	HS-MT	5.50	4.50	6.75	4.20	173	3050	2505	41
IV	96	BC-PS	CC-GC	R-US	HS-MT	5.20	4.50	5.67	4.67	173	3069	2485	45
IV	97	BC-US	CC-GC	R-GC	HS-MT	5.33	4.50	6.75	4.33	173	3040	2505	41
IV	98	BC-PS	CC-US	R-NS	HS-MT	5.00	5.00	7.20	4.20	168	3009	2519	39
IV	99	BC-GC	CC-US	R-GC	HS-MT	5.60	4.50	6.75	4.33	165	2966	2499	43
IV	100	BC-PS	CC-US	R-GC	HS-MT	5.75	4.20	6.75	4.33	163	2948	2471	48

B.3 Partial Restrictions on Single-Car Trains

Solutions in this section have additional constraints added to limit (but not entirely prohibit) the use of single-car trains. The constraints are specific to each phase based on the results generated without any restrictions on the use of single-car trains:

- In phases I and II, unrestricted solutions typically include two to three service patterns using single-car trains. A new restriction is applied to the solutions below that limits these solutions to no more than one single-car service in phases I and II.

- In Phase III, unrestricted solutions universally propose single-car trains on the E branch. A new restriction is applied to the solutions below that prohibits single-car trains on the E branch in Phase III.

- In Phase IV, unrestricted solutions near-universally propose single-car trains on the C branch. A new restriction is applied to the solutions below that prohibits single-car trains on the C branch in Phase IV.

Table B.13 shows the number of solutions in each phase that are assigned a particular GLX branch routing combination. Similarly to the unrestricted solutions, the "D to Union Square, E to Medford/Tufts" routing combination and the "B to Union Square, E to Medford/Tufts" routing combination have the overall largest presence among the solutions. However, in Phase III (where single-car trains are not permitted on the E branch), neither of these solutions appear in the 100 most optimal solutions. Therefore, preservation of the D/E or B/E routing combination across all four scenarios requires single-car trains on the E branch to avoid sub-optimal solutions. On the other hand, preventing single-car trains on the C branch (Phase IV) does not limit the effectiveness of either routing combination.

Table B.13: Summary of GLX Routings by Occurrence, Partially Restricted Solutions

Union Square Branch	Medford Branch	Number of Occurrences			
		Phase I	Phase II	Phase III	Phase IV
D	E	11	22	0	29
B	E	49	60	0	31
C	E	0	0	43	40
E	B	40	18	0	0
E	C	0	0	53	0
B	C	0	0	4	0

Table B.14 and Table B.15 show the minimum EWT and minimum transfers attained, respectively, by each of the GLX routing combinations. In phases I, III, and IV, the range of the minimum wait times is under 100 minutes of wait time per 1,000 passengers. However, in Phase II, the B/E routing combination includes a solution with a decrease of 200 minutes of wait time per 1,000 relative to other GLX routings; that solution short-turns C branch trains at Kenmore and also results in an increase in transfers to 105 transfers per 1,000.

Table B.14: Summary of GLX Routings by EWT, Partially Restricted Solutions

Union Square Branch	Medford Branch	Minimum EWT			
		Phase I	Phase II	Phase III	Phase IV
D	E	2975	2733	--	2483
B	E	2897	2510	--	2470
C	E	--	--	2721	2470
E	B	2879	2729	--	--
E	C	--	--	2648	--
B	C	--	--	2625	--

Table B.15: Summary of GLX Routings by Transfers, Partially Restricted Solutions

Union Square Branch	Medford Branch	Minimum Transfers			
		Phase I	Phase II	Phase III	Phase IV
D	E	45	45	--	40
B	E	41	40	--	32
C	E	--	--	48	39
E	B	46	46	--	--
E	C	--	--	55	--
B	C	--	--	74	--

Table B.16 shows the breakdown of solutions in each phase by the number of single-car services proposed as well as the branches in which the single-car trains are used. Despite the partial restrictions on the use of single-car trains, every solution generated includes one single-car service. Use of single-car trains is most frequently on the E branch, except in Phase III where single-car trains are explicitly prohibited from serving the E branch.

Table B.16: Summary of Single-Car Train Use, Partially Restricted Solutions

Phase	Number of Single-Car Services				Branches With Single-Car Services			
	0	1	2	3	B	C	D	E
I	0	100	0	0	40	0	0	60
II	0	100	0	0	18	0	0	82
III	0	100	0	0	0	100	0	0
IV	0	100	0	0	0	0	0	100

Table B.17: Solutions Limited to One Single-Car Service (Phase I Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-US	CC-K	R-GC	HS-MT	6.33	6.60	7.75	4.33	119	2049	2940	105
I	2	BC-MT	CC-PS	R-GC	HS-US	5.00	6.80	7.75	7.20	115	2049	3191	55
I	3	BC-MT	CC-PS	R-GC	HS-US	4.67	7.40	7.75	7.20	115	2038	3191	55
I	4	BC-MT	CC-PS	R-GC	HS-US	5.00	7.40	7.75	6.75	115	2048	3191	55
I	5	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	7.75	5.25	118	2043	3226	50
I	6	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.75	4.67	117	2043	3226	50
I	7	BC-US	CC-PS	R-PS	HS-MT	6.60	7.40	7.67	4.80	118	2048	3139	68
I	8	BC-MT	CC-PS	R-GC	HS-US	4.67	6.80	7.75	7.75	115	2040	3204	55
I	9	BC-MT	CC-PS	R-GC	HS-US	4.33	7.40	7.75	7.75	116	2043	3204	55
I	10	BC-US	CC-PS	R-GC	HS-MT	7.67	6.80	7.75	4.80	116	2035	3236	50
I	11	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.25	4.67	117	2048	3237	50
I	12	BC-MT	CC-PS	R-GC	HS-US	5.00	6.25	7.75	7.75	115	2051	3209	55
I	13	BC-US	CC-K	R-GC	HS-MT	6.33	6.60	7.25	4.67	119	2044	2963	105
I	14	BC-US	CC-K	R-GC	HS-MT	6.60	6.60	6.80	4.67	119	2049	2968	105
I	15	BC-MT	CC-PS	R-PS	HS-US	4.67	7.40	7.67	6.75	115	2043	3123	74
I	16	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.75	4.50	116	2033	3244	50
I	17	BC-MT	CC-PS	R-GC	HS-US	4.80	7.40	7.75	7.20	114	2023	3216	55
I	18	BC-MT	CC-PS	R-GC	HS-US	5.00	7.40	7.25	7.20	115	2043	3216	55
I	19	BC-MT	CC-PS	R-GC	HS-US	4.40	7.40	7.75	7.75	115	2028	3217	55
I	20	BC-MT	CC-PS	R-GC	HS-US	4.60	7.40	7.25	7.75	116	2048	3217	55
I	21	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.25	5.25	118	2048	3246	50
I	22	BC-GC	CC-PS	R-US	HS-MT	7.50	7.40	7.50	4.80	116	2048	3255	48
I	23	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.75	4.80	116	2023	3250	50
I	24	BC-MT	CC-PS	R-GC	HS-US	5.50	6.80	7.75	6.75	114	2044	3222	55
I	25	BC-MT	CC-GC	R-GC	HS-US	5.00	7.50	7.75	7.20	115	2049	3263	47
I	26	BC-MT	CC-PS	R-GC	HS-US	5.50	6.25	7.75	7.20	114	2046	3226	55
I	27	BC-MT	CC-PS	R-GC	HS-US	5.50	7.40	7.75	6.33	114	2043	3227	55
I	28	BC-US	CC-PS	R-GC	HS-MT	7.33	6.25	7.75	5.50	117	2046	3256	50
I	29	BC-MT	CC-PS	R-GC	HS-US	5.20	6.80	7.75	7.20	114	2035	3228	55
I	30	BC-MT	CC-PS	R-GC	HS-US	5.20	7.40	7.75	6.75	114	2033	3228	55
I	31	BC-MT	CC-PS	R-GC	HS-US	4.80	6.80	7.75	7.75	114	2025	3229	55
I	32	BC-MT	CC-PS	R-GC	HS-US	5.00	6.80	7.25	7.75	115	2044	3229	55
I	33	BC-MT	CC-PS	R-GC	HS-US	4.67	7.40	7.25	7.75	115	2033	3229	55
I	34	BC-US	CC-K	R-GC	HS-MT	6.33	7.60	7.75	4.00	119	2048	2984	105
I	35	BC-US	CC-PS	R-GC	HS-MT	7.67	6.25	7.75	5.25	116	2036	3259	50
I	36	BC-US	CC-PS	R-GC	HS-MT	7.33	6.80	7.75	5.20	117	2044	3260	50
I	37	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.25	4.80	116	2028	3261	50
I	38	BC-US	CC-PS	R-GC	HS-MT	6.60	6.80	7.75	5.80	118	2044	3262	50
I	39	BC-US	CC-K	R-PS	HS-MT	6.33	6.00	7.20	4.67	119	2050	2897	123
I	40	BC-US	CC-K	R-GC	HS-MT	7.33	6.60	6.80	4.20	118	2049	2989	105
I	41	BC-MT	CC-GC	R-GC	HS-US	4.67	7.50	7.75	7.75	115	2040	3276	47
I	42	BC-US	CC-PS	R-GC	HS-MT	7.00	6.80	7.75	5.50	117	2035	3266	50
I	43	BC-US	CC-K	R-PS	HS-MT	6.33	6.60	7.20	4.33	119	2049	2900	123
I	44	BC-GC	CC-PS	R-US	HS-MT	7.50	6.80	7.50	5.25	116	2049	3274	48
I	45	BC-US	CC-K	R-GC	HS-MT	6.60	6.60	6.80	4.80	118	2029	2992	105
I	46	BC-US	CC-PS	R-GC	HS-MT	7.67	6.25	7.25	5.50	117	2051	3267	50
I	47	BC-US	CC-GC	R-GC	HS-MT	7.67	7.50	7.75	4.80	116	2035	3308	41
I	48	BC-US	CC-PS	R-GC	HS-MT	7.33	6.80	7.75	5.25	116	2025	3269	50
I	49	BC-PS	CC-K	R-US	HS-MT	7.40	6.60	6.80	4.20	116	2044	2975	109
I	50	BC-US	CC-PS	R-GC	HS-MT	7.67	6.80	7.25	5.20	117	2049	3270	50

Table B.18: Solutions Limited to One Single-Car Service (Phase I Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	51	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	7.75	5.50	117	2023	3271	50
I	52	BC-GC	CC-K	R-US	HS-MT	6.20	6.60	7.20	4.80	118	2049	3005	103
I	53	BC-US	CC-K	R-PS	HS-MT	6.60	6.00	7.20	4.50	118	2041	2905	123
I	54	BC-PS	CC-K	R-US	HS-MT	7.00	6.60	7.50	4.00	115	2025	2978	109
I	55	BC-MT	CC-PS	R-GC	HS-US	5.33	7.40	6.80	7.20	115	2048	3245	55
I	56	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.75	4.67	115	2014	3274	50
I	57	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.75	5.20	117	2033	3274	50
I	58	BC-US	CC-K	R-GC	HS-MT	5.60	6.60	7.75	5.25	120	2039	2999	105
I	59	BC-MT	CC-K	R-PS	HS-US	4.20	6.00	6.67	7.20	117	2050	2879	129
I	60	BC-MT	CC-GC	R-GC	HS-US	5.00	7.00	7.75	7.75	115	2051	3287	47
I	61	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.25	116	2049	3295	45
I	62	BC-MT	CC-PS	R-GC	HS-US	5.20	6.25	7.75	7.75	114	2036	3246	55
I	63	BC-MT	CC-GC	R-PS	HS-US	4.67	7.50	7.67	7.20	115	2044	3195	66
I	64	BC-MT	CC-K	R-PS	HS-US	4.20	6.60	6.67	6.75	117	2049	2880	129
I	65	BC-MT	CC-PS	R-GC	HS-US	5.50	6.80	7.25	7.20	114	2040	3247	55
I	66	BC-MT	CC-PS	R-GC	HS-US	5.50	7.40	7.25	6.75	114	2038	3247	55
I	67	BC-US	CC-K	R-GC	HS-MT	7.67	6.60	6.80	4.00	117	2039	3001	105
I	68	BC-US	CC-PS	R-GC	HS-MT	7.33	6.80	7.25	5.50	117	2040	3276	50
I	69	BC-US	CC-K	R-PS	HS-MT	6.33	6.60	7.67	4.20	118	2034	2910	123
I	70	BC-GC	CC-PS	R-US	HS-MT	7.00	7.40	7.50	5.25	116	2038	3285	48
I	71	BC-PS	CC-K	R-US	HS-MT	7.00	6.60	6.50	4.67	117	2049	2983	109
I	72	BC-US	CC-K	R-PS	HS-MT	6.60	6.60	7.67	4.00	117	2025	2912	123
I	73	BC-US	CC-K	R-PS	HS-MT	5.60	6.60	7.67	4.80	120	2044	2913	123
I	74	BC-US	CC-PS	R-GC	HS-MT	7.67	6.80	7.25	5.25	116	2030	3279	50
I	75	BC-US	CC-K	R-PS	HS-MT	6.60	6.60	7.20	4.20	118	2039	2914	123
I	76	BC-GC	CC-PS	R-US	HS-MT	6.60	7.40	7.50	5.50	117	2048	3289	48
I	77	BC-US	CC-GC	R-PS	HS-MT	6.60	7.50	7.67	5.25	118	2049	3230	60
I	78	BC-MT	CC-PS	R-GC	HS-US	5.33	6.80	7.75	7.20	113	2020	3252	55
I	79	BC-US	CC-GC	R-PS	HS-MT	7.33	7.50	7.67	4.67	117	2049	3230	60
I	80	BC-US	CC-K	R-PS	HS-MT	6.20	6.60	7.67	4.33	119	2044	2915	123
I	81	BC-MT	CC-PS	R-GC	HS-US	5.00	7.40	7.75	7.20	113	2009	3253	55
I	82	BC-US	CC-K	R-GC	HS-MT	6.33	7.60	7.25	4.33	119	2043	3007	105
I	83	BC-MT	CC-PS	R-GC	HS-US	5.20	7.40	7.25	7.20	114	2028	3253	55
I	84	BC-MT	CC-PS	R-GC	HS-US	5.33	7.40	7.75	6.75	113	2019	3253	55
I	85	BC-GC	CC-K	R-US	HS-MT	6.20	6.60	7.50	4.67	117	2034	3015	103
I	86	BC-MT	CC-GC	R-GC	HS-US	5.50	7.50	7.75	6.75	114	2044	3294	47
I	87	BC-US	CC-PS	R-GC	HS-MT	7.00	6.80	7.25	5.80	118	2049	3283	50
I	88	BC-MT	CC-PS	R-GC	HS-US	4.60	7.40	7.75	7.75	114	2014	3254	55
I	89	BC-MT	CC-PS	R-GC	HS-US	4.80	7.40	7.25	7.75	114	2019	3254	55
I	90	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.75	5.25	116	2014	3283	50
I	91	BC-MT	CC-PS	R-GC	HS-US	5.50	5.80	7.75	7.75	114	2047	3255	55
I	92	BC-MT	CC-PS	R-NS	HS-US	5.33	7.40	7.60	7.20	115	2048	3304	46
I	93	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.25	5.20	117	2038	3285	50
I	94	BC-GC	CC-K	R-US	HS-MT	6.00	6.60	7.50	4.80	118	2044	3019	103
I	95	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	7.75	5.80	118	2033	3286	50
I	96	BC-MT	CC-PS	R-GC	HS-US	5.33	6.80	6.80	7.75	115	2049	3258	55
I	97	BC-US	CC-K	R-PS	HS-MT	6.60	6.00	6.67	4.80	118	2036	2920	123
I	98	BC-US	CC-K	R-PS	HS-MT	6.33	6.60	6.67	4.67	119	2044	2920	123
I	99	BC-US	CC-K	R-GC	HS-MT	6.60	7.60	6.80	4.33	119	2048	3012	105
I	100	BC-MT	CC-PS	R-GC	HS-US	5.00	7.40	6.80	7.75	115	2038	3258	55

Table B.19: Solutions Limited to One Single-Car Service (Phase II Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	1	BC-US	CC-PS	R-GC	HS-MT	5.60	6.25	7.75	4.00	137	2380	2739	50
II	2	BC-US	CC-PS	R-GC	HS-MT	5.60	5.80	7.75	4.33	137	2381	2752	50
II	3	BC-PS	CC-PS	R-US	HS-MT	5.75	6.25	6.80	4.00	135	2385	2733	54
II	4	BC-MT	CC-PS	R-GC	HS-US	4.40	5.80	7.25	5.67	133	2381	2729	55
II	5	BC-MT	CC-PS	R-GC	HS-US	4.40	5.80	7.75	5.40	133	2386	2729	55
II	6	BC-US	CC-PS	R-GC	HS-MT	5.60	6.80	7.25	4.00	137	2374	2759	50
II	7	BC-US	CC-PS	R-GC	HS-MT	6.00	6.25	7.25	4.00	137	2385	2759	50
II	8	BC-US	CC-PS	R-GC	HS-MT	6.33	5.80	7.25	4.00	135	2366	2761	50
II	9	BC-PS	CC-PS	R-US	HS-MT	5.50	5.80	7.50	4.00	135	2386	2741	54
II	10	BC-US	CC-PS	R-GC	HS-MT	5.60	6.25	7.25	4.33	137	2375	2762	50
II	11	BC-US	CC-PS	R-GC	HS-MT	5.40	6.25	7.25	4.50	138	2385	2763	50
II	12	BC-US	CC-PS	R-GC	HS-MT	6.33	5.80	6.80	4.20	136	2381	2763	50
II	13	BC-US	CC-PS	R-GC	HS-MT	6.60	5.80	6.80	4.00	135	2371	2766	50
II	14	BC-US	CC-PS	R-GC	HS-MT	6.33	5.50	7.75	4.00	135	2373	2766	50
II	15	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	7.25	4.20	138	2383	2766	50
II	16	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	6.80	4.33	135	2386	2746	54
II	17	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	7.75	4.00	137	2369	2767	50
II	18	BC-US	CC-PS	R-GC	HS-MT	6.60	5.50	7.25	4.00	135	2377	2768	50
II	19	BC-MT	CC-PS	R-GC	HS-US	4.40	6.25	7.25	5.40	133	2380	2739	55
II	20	BC-MT	CC-PS	R-GC	HS-US	4.40	5.80	6.80	6.00	133	2376	2741	55
II	21	BC-US	CC-PS	R-GC	HS-MT	5.40	6.25	7.75	4.33	137	2370	2770	50
II	22	BC-US	CC-PS	R-GC	HS-MT	5.40	5.80	7.25	4.80	138	2386	2770	50
II	23	BC-MT	CC-PS	R-GC	HS-US	4.40	6.25	6.80	5.67	133	2375	2742	55
II	24	BC-US	CC-PS	R-GC	HS-MT	5.20	6.25	7.75	4.50	138	2380	2771	50
II	25	BC-GC	CC-PS	R-US	HS-MT	6.20	6.25	6.80	4.00	135	2385	2779	48
II	26	BC-MT	CC-PS	R-GC	HS-US	4.40	5.50	7.25	6.00	133	2382	2743	55
II	27	BC-US	CC-PS	R-GC	HS-MT	6.00	5.80	7.25	4.33	137	2386	2773	50
II	28	BC-PS	CC-PS	R-US	HS-MT	5.50	6.25	7.20	4.00	135	2380	2753	54
II	29	BC-US	CC-PS	R-GC	HS-MT	6.60	5.20	7.75	4.00	135	2384	2773	50
II	30	BC-MT	CC-PS	R-GC	HS-US	4.67	5.80	6.80	5.67	133	2386	2745	55
II	31	BC-US	CC-PS	R-GC	HS-MT	6.33	6.25	6.80	4.00	135	2360	2774	50
II	32	BC-US	CC-PS	R-NS	HS-MT	6.33	5.80	7.60	4.20	136	2381	2822	40
II	33	BC-US	CC-PS	R-GC	HS-MT	5.20	6.80	7.75	4.20	138	2379	2775	50
II	34	BC-US	CC-PS	R-GC	HS-MT	5.60	6.25	7.75	4.20	136	2360	2775	50
II	35	BC-US	CC-PS	R-GC	HS-MT	5.60	5.80	7.25	4.67	137	2376	2775	50
II	36	BC-US	CC-GC	R-GC	HS-MT	5.60	7.00	7.75	4.00	137	2380	2817	41
II	37	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	6.50	4.00	135	2379	2756	54
II	38	BC-US	CC-PS	R-NS	HS-MT	6.60	5.80	7.60	4.00	135	2371	2825	40
II	39	BC-PS	CC-PS	R-US	HS-MT	5.20	6.25	7.50	4.00	135	2375	2757	54
II	40	BC-MT	CC-PS	R-GC	HS-US	4.40	6.25	7.75	5.20	133	2385	2748	55
II	41	BC-US	CC-PS	R-GC	HS-MT	6.20	5.80	7.25	4.20	136	2376	2777	50
II	42	BC-US	CC-GC	R-GC	HS-MT	6.33	6.00	7.75	4.00	135	2373	2818	41
II	43	BC-US	CC-PS	R-PS	HS-MT	5.60	5.80	7.67	4.00	137	2386	2686	68
II	44	BC-US	CC-PS	R-GC	HS-MT	6.20	5.80	7.75	4.00	135	2361	2778	50
II	45	BC-US	CC-PS	R-GC	HS-MT	5.20	5.80	7.75	4.80	138	2381	2779	50
II	46	BC-US	CC-GC	R-GC	HS-MT	6.60	6.00	7.25	4.00	135	2377	2820	41
II	47	BC-PS	CC-PS	R-US	HS-MT	5.75	6.25	6.50	4.33	135	2380	2759	54
II	48	BC-US	CC-PS	R-GC	HS-MT	6.60	5.80	6.50	4.20	136	2386	2779	50
II	49	BC-US	CC-PS	R-GC	HS-MT	5.60	5.50	7.75	4.67	137	2382	2781	50
II	50	BC-US	CC-GC	R-GC	HS-MT	6.60	5.67	7.75	4.00	135	2384	2822	41

Table B.20: Solutions Limited to One Single-Car Service (Phase II Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-MT	CC-PS	R-NS	HS-US	4.40	5.80	7.60	6.00	133	2376	2800	46
II	52	BC-MT	CC-PS	R-GC	HS-US	4.33	5.80	7.75	5.67	132	2361	2753	55
II	53	BC-US	CC-PS	R-GC	HS-MT	5.60	5.80	7.75	4.50	136	2361	2782	50
II	54	BC-MT	CC-PS	R-NS	HS-US	4.40	6.25	7.60	5.67	133	2375	2801	46
II	55	BC-US	CC-PS	R-GC	HS-MT	6.20	5.50	7.75	4.20	136	2382	2783	50
II	56	BC-MT	CC-GC	R-GC	HS-US	4.40	6.00	7.25	6.00	133	2382	2795	47
II	57	BC-US	CC-PS	R-NS	HS-MT	6.60	5.80	7.20	4.20	136	2386	2831	40
II	58	BC-US	CC-PS	R-GC	HS-MT	5.40	5.80	7.75	4.67	137	2371	2783	50
II	59	BC-US	CC-PS	R-GC	HS-MT	6.00	6.80	6.80	4.00	137	2379	2783	50
II	60	BC-PS	CC-PS	R-US	HS-MT	6.50	5.80	6.80	4.00	133	2366	2763	54
II	61	BC-US	CC-PS	R-GC	HS-MT	5.40	6.25	6.80	4.80	138	2380	2784	50
II	62	BC-US	CC-GC	R-GC	HS-MT	5.60	6.50	7.75	4.33	137	2381	2825	41
II	63	BC-MT	CC-PS	R-GC	HS-US	4.67	6.25	6.80	5.40	133	2385	2755	55
II	64	BC-GC	CC-PS	R-US	HS-MT	6.00	5.80	7.50	4.00	135	2386	2792	48
II	65	BC-MT	CC-PS	R-GC	HS-US	4.40	5.50	6.80	6.33	133	2377	2756	55
II	66	BC-PS	CC-PS	R-US	HS-MT	5.50	6.80	6.80	4.00	135	2374	2764	54
II	67	BC-GC	CC-PS	R-US	HS-MT	6.20	5.80	6.80	4.33	135	2386	2792	48
II	68	BC-MT	CC-PS	R-NS	HS-US	4.67	5.80	7.60	5.67	133	2386	2804	46
II	69	BC-US	CC-K	R-GC	HS-MT	5.60	4.40	7.25	4.00	137	2374	2510	105
II	70	BC-PS	CC-PS	R-US	HS-MT	6.50	5.80	6.50	4.20	134	2381	2765	54
II	71	BC-US	CC-PS	R-NS	HS-MT	6.33	6.25	7.60	4.00	135	2360	2833	40
II	72	BC-US	CC-PS	R-GC	HS-MT	6.00	5.80	7.75	4.20	136	2371	2786	50
II	73	BC-US	CC-PS	R-GC	HS-MT	5.60	6.80	6.80	4.33	137	2369	2786	50
II	74	BC-US	CC-PS	R-GC	HS-MT	6.33	5.50	6.80	4.50	136	2382	2786	50
II	75	BC-US	CC-PS	R-GC	HS-MT	6.00	6.25	6.80	4.33	137	2380	2786	50
II	76	BC-PS	CC-PS	R-US	HS-MT	5.20	6.25	6.80	4.50	136	2385	2766	54
II	77	BC-MT	CC-PS	R-GC	HS-US	4.40	5.20	7.25	6.33	133	2384	2758	55
II	78	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	7.50	4.00	133	2356	2766	54
II	79	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	6.80	4.50	138	2379	2787	50
II	80	BC-US	CC-PS	R-GC	HS-MT	6.33	5.80	6.80	4.33	135	2361	2787	50
II	81	BC-PS	CC-PS	R-US	HS-MT	5.50	6.25	6.80	4.33	135	2375	2767	54
II	82	BC-US	CC-PS	R-GC	HS-MT	6.33	6.25	6.50	4.20	136	2375	2788	50
II	83	BC-US	CC-PS	R-GC	HS-MT	6.20	6.25	7.25	4.00	135	2355	2788	50
II	84	BC-US	CC-PS	R-GC	HS-MT	5.60	7.40	6.80	4.00	137	2367	2788	50
II	85	BC-PS	CC-PS	R-US	HS-MT	5.75	5.80	7.20	4.20	134	2371	2768	54
II	86	BC-US	CC-PS	R-GC	HS-MT	5.20	6.25	7.25	4.80	138	2375	2788	50
II	87	BC-US	CC-PS	R-GC	HS-MT	5.60	6.25	6.80	4.67	137	2370	2789	50
II	88	BC-PS	CC-PS	R-US	HS-MT	6.20	5.80	6.80	4.20	134	2376	2768	54
II	89	BC-PS	CC-PS	R-US	HS-MT	5.75	6.25	6.80	4.20	134	2365	2769	54
II	90	BC-US	CC-PS	R-GC	HS-MT	6.33	5.50	7.25	4.33	135	2368	2789	50
II	91	BC-MT	CC-GC	R-GC	HS-US	4.40	6.50	7.25	5.67	133	2381	2801	47
II	92	BC-MT	CC-GC	R-GC	HS-US	4.40	6.50	7.75	5.40	133	2386	2802	47
II	93	BC-PS	CC-PS	R-US	HS-MT	5.20	6.80	6.80	4.20	136	2383	2769	54
II	94	BC-US	CC-PS	R-GC	HS-MT	6.20	6.80	6.50	4.00	137	2383	2790	50
II	95	BC-GC	CC-PS	R-US	HS-MT	5.60	6.25	7.50	4.00	135	2375	2798	48
II	96	BC-US	CC-PS	R-GC	HS-MT	6.60	6.25	6.50	4.00	135	2365	2790	50
II	97	BC-US	CC-PS	R-GC	HS-MT	5.60	6.25	6.50	4.80	138	2385	2790	50
II	98	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	7.25	4.33	137	2364	2790	50
II	99	BC-US	CC-PS	R-PS	HS-MT	5.60	6.25	7.20	4.00	137	2380	2698	68
II	100	BC-PS	CC-GC	R-US	HS-MT	5.75	7.00	6.80	4.00	135	2385	2811	45

Table B.21: Solutions With Single-Car Trains Prohibited on E Branch (Phase III Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-PS	CC-MT	R-GC	HS-US	5.75	4.20	6.75	5.67	149	2674	2648	55
III	2	BC-PS	CC-MT	R-GC	HS-US	5.50	4.20	7.60	5.40	149	2674	2648	55
III	3	BC-PS	CC-MT	R-GC	HS-US	5.20	4.20	7.60	5.67	149	2664	2654	55
III	4	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	7.60	5.67	150	2673	2659	55
III	5	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	6.75	6.00	150	2673	2662	55
III	6	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	6.40	6.25	150	2669	2670	55
III	7	BC-PS	CC-MT	R-GC	HS-US	5.20	4.20	6.75	6.25	149	2654	2671	55
III	8	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	7.60	6.25	151	2674	2672	55
III	9	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.75	6.60	151	2674	2673	55
III	10	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	7.20	6.00	150	2669	2675	55
III	11	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	6.75	6.25	150	2664	2676	55
III	12	BC-PS	CC-MT	R-GC	HS-US	5.50	4.20	6.40	6.25	149	2659	2676	55
III	13	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	7.60	6.00	150	2664	2678	55
III	14	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	7.60	6.00	149	2654	2679	55
III	15	BC-PS	CC-MT	R-GC	HS-US	4.60	4.00	7.60	6.60	151	2675	2683	55
III	16	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	7.20	6.25	150	2659	2683	55
III	17	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	7.20	6.25	149	2650	2684	55
III	18	BC-PS	CC-MT	R-GC	HS-US	5.50	4.33	6.20	6.25	150	2673	2686	55
III	19	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	7.20	5.75	150	2677	2721	48
III	20	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	7.60	6.25	149	2645	2688	55
III	21	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	6.75	7.00	151	2675	2690	55
III	22	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	7.20	5.50	150	2676	2724	48
III	23	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	7.20	6.60	151	2669	2691	55
III	24	BC-PS	CC-MT	R-GC	HS-US	5.20	4.20	6.40	6.60	149	2650	2693	55
III	25	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	7.20	5.25	150	2675	2728	48
III	26	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	7.60	5.25	149	2660	2728	48
III	27	BC-PS	CC-US	R-GC	HS-MT	5.00	4.33	7.60	5.75	150	2672	2730	48
III	28	BC-PS	CC-MT	R-GC	HS-US	4.60	4.33	7.60	6.25	150	2654	2697	55
III	29	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	6.40	6.60	150	2659	2698	55
III	30	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	6.75	6.60	150	2654	2698	55
III	31	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	7.60	6.60	149	2646	2698	55
III	32	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	6.75	6.60	149	2645	2699	55
III	33	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	6.75	6.00	150	2672	2733	48
III	34	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	7.60	5.50	150	2671	2733	48
III	35	BC-PS	CC-MT	R-GC	HS-US	4.40	4.20	7.60	6.60	151	2664	2700	55
III	36	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.40	7.00	151	2669	2702	55
III	37	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	6.75	5.75	150	2671	2736	48
III	38	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	7.60	5.25	150	2670	2737	48
III	39	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	6.20	6.60	150	2664	2704	55
III	40	BC-PS	CC-MT	R-GC	HS-US	4.20	4.33	7.60	6.60	152	2673	2704	55
III	41	BC-PS	CC-US	R-GC	HS-MT	5.50	4.33	6.40	6.00	150	2677	2738	48
III	42	BC-PS	CC-MT	R-GC	HS-US	5.50	4.33	5.80	6.60	150	2669	2705	55
III	43	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.75	5.50	150	2670	2739	48
III	44	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	7.20	6.60	149	2640	2706	55
III	45	BC-PS	CC-US	R-GC	HS-MT	5.50	4.67	6.40	5.75	150	2676	2741	48
III	46	BC-PS	CC-MT	R-GC	HS-US	4.60	4.00	7.20	7.00	151	2670	2708	55
III	47	BC-PS	CC-US	R-GC	HS-MT	4.75	4.80	7.20	5.75	151	2675	2742	48
III	48	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	7.20	5.50	149	2656	2744	48
III	49	BC-PS	CC-US	R-GC	HS-MT	4.75	4.50	7.20	6.00	151	2676	2744	48
III	50	BC-PS	CC-US	R-GC	HS-MT	5.50	5.00	6.40	5.50	150	2675	2744	48

Table B.22: Solutions With Single-Car Trains Prohibited on E Branch (Phase III Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-PS	CC-US	R-GC	HS-MT	5.00	4.33	7.20	6.00	150	2667	2745	48
III	52	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	6.75	7.00	151	2664	2712	55
III	53	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	7.60	6.25	148	2624	2713	55
III	54	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	6.20	7.00	151	2674	2713	55
III	55	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	7.20	5.75	150	2666	2749	48
III	56	BC-PS	CC-US	R-GC	HS-MT	4.75	4.33	7.60	6.00	150	2662	2749	48
III	57	BC-PS	CC-MT	R-GC	HS-US	4.60	4.33	7.20	6.60	150	2649	2716	55
III	58	BC-PS	CC-MT	R-GC	HS-US	5.75	4.33	5.60	6.60	150	2673	2716	55
III	59	BC-PS	CC-MT	R-GC	HS-US	4.40	4.33	6.75	7.00	152	2673	2717	55
III	60	BC-PS	CC-MT	R-GC	HS-US	4.40	4.00	7.60	7.00	151	2666	2717	55
III	61	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	7.20	5.50	150	2665	2752	48
III	62	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.75	5.25	150	2668	2752	48
III	63	BC-PS	CC-US	R-GC	HS-MT	4.75	4.67	7.60	5.75	150	2661	2752	48
III	64	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	7.60	5.50	149	2651	2753	48
III	65	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	6.40	7.40	151	2670	2719	55
III	66	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	6.40	6.00	151	2675	2754	48
III	67	BC-PS	CC-US	R-GC	HS-MT	4.75	4.80	6.75	6.00	151	2670	2754	48
III	68	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	7.60	6.60	149	2635	2720	55
III	69	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	6.40	6.00	150	2666	2755	48
III	70	BC-PS	CC-US	R-GC	HS-MT	4.75	5.20	7.20	5.50	151	2674	2755	48
III	71	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	6.75	5.75	149	2651	2755	48
III	72	BC-US	CC-MT	R-GC	HS-GC	5.50	4.00	7.60	5.50	153	2675	2625	74
III	73	BC-PS	CC-US	R-GC	HS-MT	5.00	4.20	7.60	6.00	149	2653	2756	48
III	74	BC-PS	CC-US	R-GC	HS-MT	4.75	5.00	7.60	5.50	150	2660	2756	48
III	75	BC-PS	CC-US	R-GC	HS-MT	4.60	4.80	7.60	5.75	151	2670	2756	48
III	76	BC-PS	CC-US	R-GC	HS-MT	5.20	5.20	7.20	5.25	149	2654	2756	48
III	77	BC-PS	CC-US	R-GC	HS-MT	5.20	4.50	6.75	6.00	149	2652	2757	48
III	78	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	6.40	5.25	150	2673	2757	48
III	79	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	7.20	7.00	149	2641	2724	55
III	80	BC-PS	CC-US	R-GC	HS-MT	4.60	4.50	7.60	6.00	151	2672	2758	48
III	81	BC-PS	CC-MT	R-GC	HS-US	4.40	4.33	7.60	6.60	150	2644	2725	55
III	82	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.40	5.75	150	2665	2758	48
III	83	BC-PS	CC-MT	R-GC	HS-US	4.40	4.20	7.20	7.00	151	2659	2725	55
III	84	BC-PS	CC-US	R-GC	HS-MT	4.75	4.20	7.20	6.33	151	2678	2760	48
III	85	BC-PS	CC-US	R-GC	HS-MT	5.00	4.67	6.75	6.00	150	2661	2760	48
III	86	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	6.40	7.00	150	2649	2727	55
III	87	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	6.40	7.00	149	2640	2728	55
III	88	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.75	7.00	149	2635	2728	55
III	89	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	5.80	7.00	150	2659	2729	55
III	90	BC-PS	CC-MT	R-GC	HS-US	4.20	4.33	7.20	7.00	152	2669	2729	55
III	91	BC-PS	CC-MT	R-GC	HS-US	4.60	4.00	6.75	7.40	151	2666	2730	55
III	92	BC-US	CC-MT	R-GC	HS-GC	5.50	4.20	7.20	5.50	153	2669	2633	74
III	93	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	6.75	5.75	150	2660	2764	48
III	94	BC-PS	CC-MT	R-GC	HS-US	5.00	4.00	6.20	7.40	151	2675	2730	55
III	95	BC-US	CC-MT	R-GC	HS-GC	5.50	4.20	7.60	5.20	153	2674	2633	74
III	96	BC-PS	CC-US	R-GC	HS-MT	5.00	5.40	7.20	5.25	150	2663	2765	48
III	97	BC-PS	CC-US	R-GC	HS-MT	5.00	5.20	7.60	5.25	149	2649	2765	48
III	98	BC-US	CC-MT	R-GC	HS-GC	5.75	4.20	6.75	5.50	153	2674	2635	74
III	99	BC-PS	CC-US	R-GC	HS-MT	5.00	5.20	6.40	5.75	151	2674	2767	48
III	100	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	6.40	6.33	150	2667	2767	48

Table B.23: Solutions With Single-Car Trains Prohibited on C Branch (Phase IV Solutions 1 through 50, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-US	R-GC	HS-MT	5.20	5.00	6.75	4.00	162	2922	2470	48
IV	2	BC-PS	CC-US	R-GC	HS-MT	5.75	4.80	6.40	4.00	162	2938	2472	48
IV	3	BC-PS	CC-US	R-GC	HS-MT	5.50	4.80	6.75	4.00	162	2933	2472	48
IV	4	BC-PS	CC-US	R-GC	HS-MT	5.20	5.20	6.40	4.00	162	2916	2473	48
IV	5	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	7.20	4.00	162	2928	2475	48
IV	6	BC-PS	CC-GC	R-US	HS-MT	5.20	4.67	6.60	4.00	162	2885	2490	45
IV	7	BC-PS	CC-US	R-GC	HS-MT	5.50	5.00	6.40	4.00	162	2927	2475	48
IV	8	BC-PS	CC-GC	R-US	HS-MT	5.50	4.67	6.33	4.00	162	2890	2490	45
IV	9	BC-US	CC-PS	R-GC	HS-MT	5.50	4.75	6.40	4.00	162	2838	2470	50
IV	10	BC-US	CC-PS	R-GC	HS-MT	5.50	4.50	6.75	4.00	162	2844	2470	50
IV	11	BC-US	CC-PS	R-GC	HS-MT	5.33	4.75	6.75	4.00	162	2833	2472	50
IV	12	BC-US	CC-PS	R-GC	HS-MT	5.33	5.00	6.40	4.00	162	2827	2472	50
IV	13	BC-PS	CC-US	R-GC	HS-MT	5.00	5.20	6.75	4.00	162	2911	2479	48
IV	14	BC-PS	CC-US	R-GC	HS-MT	5.75	4.67	6.75	4.00	162	2944	2479	48
IV	15	BC-PS	CC-GC	R-US	HS-MT	5.20	5.00	6.33	4.00	162	2879	2494	45
IV	16	BC-PS	CC-GC	R-US	HS-MT	5.00	5.20	6.33	4.00	162	2868	2494	45
IV	17	BC-PS	CC-GC	R-US	HS-MT	5.75	5.20	5.67	4.00	162	2882	2495	45
IV	18	BC-GC	CC-PS	R-US	HS-MT	5.60	4.50	6.33	4.00	162	2879	2483	48
IV	19	BC-PS	CC-US	R-GC	HS-MT	5.00	5.40	6.40	4.00	162	2905	2482	48
IV	20	BC-PS	CC-US	R-GC	HS-MT	4.75	5.40	6.75	4.00	162	2900	2482	48
IV	21	BC-US	CC-GC	R-GC	HS-MT	5.50	5.20	6.40	4.00	162	2838	2516	41
IV	22	BC-PS	CC-US	R-NS	HS-MT	5.75	5.00	6.80	4.00	162	2932	2530	39
IV	23	BC-PS	CC-US	R-GC	HS-MT	5.00	5.00	7.20	4.00	162	2917	2483	48
IV	24	BC-US	CC-PS	R-GC	HS-MT	5.50	4.25	7.20	4.00	162	2851	2477	50
IV	25	BC-PS	CC-US	R-NS	HS-MT	5.75	4.80	7.20	4.00	162	2938	2531	39
IV	26	BC-GC	CC-US	R-GC	HS-MT	5.60	5.00	6.75	4.00	162	2922	2511	43
IV	27	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	7.60	4.00	162	2923	2484	48
IV	28	BC-US	CC-PS	R-NS	HS-MT	5.50	5.00	6.80	4.00	162	2832	2525	40
IV	29	BC-US	CC-GC	R-GC	HS-MT	5.33	5.20	6.75	4.00	162	2833	2518	41
IV	30	BC-PS	CC-US	R-NS	HS-MT	5.20	5.40	6.80	4.00	162	2910	2532	39
IV	31	BC-PS	CC-GC	R-US	HS-MT	5.75	4.50	6.33	4.00	162	2901	2498	45
IV	32	BC-PS	CC-GC	R-US	HS-MT	4.75	5.20	6.60	4.00	162	2863	2499	45
IV	33	BC-PS	CC-US	R-NS	HS-MT	5.20	5.20	7.20	4.00	162	2916	2532	39
IV	34	BC-US	CC-PS	R-GC	HS-MT	5.20	5.00	6.75	4.00	162	2822	2478	50
IV	35	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	7.60	4.00	162	2934	2485	48
IV	36	BC-PS	CC-GC	R-US	HS-MT	5.20	5.20	6.20	4.00	162	2873	2499	45
IV	37	BC-PS	CC-GC	R-US	HS-MT	4.75	5.50	6.33	4.00	162	2857	2499	45
IV	38	BC-PS	CC-US	R-NS	HS-MT	5.20	5.00	7.60	4.00	162	2922	2533	39
IV	39	BC-US	CC-PS	R-GC	HS-MT	5.33	4.50	7.20	4.00	162	2839	2479	50
IV	40	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	5.80	4.00	162	2926	2486	48
IV	41	BC-US	CC-GC	R-GC	HS-MT	5.50	4.67	7.20	4.00	162	2851	2520	41
IV	42	BC-US	CC-PS	R-GC	HS-MT	5.75	4.25	6.75	4.00	162	2855	2479	50
IV	43	BC-US	CC-PS	R-GC	HS-MT	5.75	4.50	6.40	4.00	162	2849	2480	50
IV	44	BC-PS	CC-US	R-NS	HS-MT	5.50	5.20	6.80	4.00	162	2921	2534	39
IV	45	BC-PS	CC-GC	R-US	HS-MT	5.50	5.50	5.67	4.00	162	2871	2500	45
IV	46	BC-PS	CC-US	R-GC	HS-MT	4.75	5.20	7.20	4.00	162	2906	2486	48
IV	47	BC-GC	CC-PS	R-US	HS-MT	5.60	4.25	6.60	4.00	162	2885	2487	48
IV	48	BC-PS	CC-US	R-GC	HS-MT	5.50	4.67	7.20	4.00	162	2939	2486	48
IV	49	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	6.20	4.00	162	2932	2486	48
IV	50	BC-PS	CC-GC	R-US	HS-MT	5.75	4.67	6.20	4.00	162	2895	2500	45

Table B.24: Solutions With Single-Car Trains Prohibited on C Branch (Phase IV Solutions 51 through 100, Single-Car Services Highlighted)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	4.00	162	2860	2500	45
IV	52	BC-GC	CC-US	R-GC	HS-MT	5.60	5.20	6.40	4.00	162	2916	2514	43
IV	53	BC-PS	CC-US	R-NS	HS-MT	5.50	5.00	7.20	4.00	162	2927	2534	39
IV	54	BC-PS	CC-US	R-GC	HS-MT	4.75	5.00	7.60	4.00	162	2912	2487	48
IV	55	BC-US	CC-GC	R-GC	HS-MT	5.50	5.00	6.75	4.00	162	2844	2521	41
IV	56	BC-GC	CC-PS	R-US	HS-MT	5.40	4.75	6.33	4.00	162	2868	2488	48
IV	57	BC-US	CC-PS	R-GC	HS-MT	5.50	5.00	6.20	4.00	162	2832	2481	50
IV	58	BC-PS	CC-US	R-NS	HS-MT	5.50	4.80	7.60	4.00	162	2933	2535	39
IV	59	BC-US	CC-PS	R-NS	HS-MT	5.50	4.75	7.20	4.00	162	2838	2529	40
IV	60	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	6.20	4.00	162	2910	2487	48
IV	61	BC-GC	CC-US	R-GC	HS-MT	5.60	4.80	7.20	4.00	162	2928	2516	43
IV	62	BC-PS	CC-US	R-GC	HS-MT	5.75	4.50	7.20	4.00	162	2950	2488	48
IV	63	BC-US	CC-GC	R-GC	HS-MT	5.75	4.67	6.75	4.00	162	2855	2523	41
IV	64	BC-GC	CC-GC	R-US	HS-MT	5.60	4.67	6.60	4.00	162	2885	2531	40
IV	65	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	5.80	4.00	162	2915	2489	48
IV	66	BC-PS	CC-GC	R-US	HS-MT	5.75	4.25	6.60	4.00	162	2907	2503	45
IV	67	BC-US	CC-PS	R-GC	HS-MT	5.33	4.25	7.60	4.00	162	2846	2482	50
IV	68	BC-PS	CC-GC	R-US	HS-MT	5.50	4.50	6.60	4.00	162	2896	2503	45
IV	69	BC-US	CC-GC	R-GC	HS-MT	5.33	5.50	6.40	4.00	162	2827	2524	41
IV	70	BC-US	CC-PS	R-GC	HS-MT	5.00	5.00	7.20	4.00	162	2817	2483	50
IV	71	BC-US	CC-PS	R-NS	HS-MT	5.33	5.00	7.20	4.00	162	2827	2531	40
IV	72	BC-PS	CC-US	R-GC	HS-MT	5.50	5.20	6.20	4.00	162	2921	2489	48
IV	73	BC-PS	CC-US	R-NS	HS-MT	5.75	5.20	6.50	4.00	162	2926	2537	39
IV	74	BC-PS	CC-GC	R-US	HS-MT	5.00	5.00	6.60	4.00	162	2874	2504	45
IV	75	BC-GC	CC-US	R-GC	HS-MT	6.20	4.80	6.40	4.00	162	2938	2518	43
IV	76	BC-US	CC-PS	R-GC	HS-MT	5.00	5.33	6.75	4.00	162	2811	2484	50
IV	77	BC-US	CC-PS	R-NS	HS-MT	5.50	4.50	7.60	4.00	162	2844	2532	40
IV	78	BC-US	CC-GC	R-GC	HS-MT	5.33	4.67	7.60	4.00	162	2846	2526	41
IV	79	BC-GC	CC-PS	R-US	HS-MT	5.40	4.50	6.60	4.00	162	2874	2493	48
IV	80	BC-PS	CC-US	R-GC	HS-MT	5.50	4.50	7.60	4.00	162	2946	2492	48
IV	81	BC-GC	CC-US	R-GC	HS-MT	5.40	5.20	6.75	4.00	162	2911	2520	43
IV	82	BC-GC	CC-PS	R-US	HS-MT	5.60	5.33	5.67	4.00	162	2860	2493	48
IV	83	BC-US	CC-PS	R-GC	HS-MT	5.20	4.75	7.20	4.00	162	2828	2486	50
IV	84	BC-US	CC-PS	R-GC	HS-MT	5.50	5.33	5.80	4.00	162	2826	2486	50
IV	85	BC-GC	CC-PS	R-US	HS-MT	5.60	4.75	6.20	4.00	162	2873	2494	48
IV	86	BC-GC	CC-PS	R-US	HS-MT	5.20	5.00	6.33	4.00	162	2857	2494	48
IV	87	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	5.50	4.00	162	2876	2507	45
IV	88	BC-PS	CC-US	R-NS	HS-MT	5.50	5.40	6.50	4.00	162	2915	2540	39
IV	89	BC-GC	CC-GC	R-US	HS-MT	5.60	5.00	6.33	4.00	162	2879	2535	40
IV	90	BC-US	CC-PS	R-GC	HS-MT	5.00	4.75	7.60	4.00	162	2823	2487	50
IV	91	BC-GC	CC-GC	R-US	HS-MT	5.40	5.20	6.33	4.00	162	2868	2535	40
IV	92	BC-US	CC-PS	R-NS	HS-MT	5.33	4.75	7.60	4.00	162	2833	2534	40
IV	93	BC-PS	CC-US	R-NS	HS-MT	5.00	5.40	7.20	4.00	162	2905	2541	39
IV	94	BC-GC	CC-PS	R-US	HS-MT	6.20	4.75	5.67	4.00	162	2882	2494	48
IV	95	BC-PS	CC-GC	R-US	HS-MT	5.50	5.20	6.00	4.00	162	2877	2507	45
IV	96	BC-US	CC-GC	R-NS	HS-MT	5.50	5.20	7.20	4.00	162	2838	2575	32
IV	97	BC-PS	CC-GC	R-US	HS-MT	5.20	5.50	6.00	4.00	162	2866	2507	45
IV	98	BC-PS	CC-US	R-GC	HS-MT	5.75	4.33	7.60	4.00	162	2957	2493	48
IV	99	BC-US	CC-PS	R-GC	HS-MT	5.75	5.00	5.80	4.00	162	2837	2487	50
IV	100	BC-US	CC-PS	R-GC	HS-MT	5.20	5.33	6.40	4.00	162	2816	2487	50

B.4 Strict Prohibition of Single-Car Trains

Solutions in this section are constrained to prohibit single-car operations anywhere on the Green Line. Note that all solutions in Phase I and some solutions in Phase II feature two-car trains on the C branch short-turning at Kenmore, rather than currently planned service which preserves C branch operations through the Central Subway. This is due to the lack of headways above 8 minutes in the service pattern inputs, which are required to run all four services into the Central Subway with the given operator hours (2,052 hours in Phase I).

Table B.25 shows the number of solutions in each phase that are assigned a particular GLX branch routing combination. Similarly to the unrestricted solutions, the "D to Union Square, E to Medford/Tufts" routing combination and the "B to Union Square, E to Medford/Tufts" routing combination provide solutions in all phases. Of these, the D/E combination is more numerous in Phase IV and the B/E combination is more numerous in phases I through III.

Table B.25: Summary of GLX Routings by Occurrence, Solutions Prohibiting Single-Car Trains

Union Square Branch	Medford Branch	Number of Occurrences			
		Phase I	Phase II	Phase III	Phase IV
D	E	12	21	19	48
B	E	23	46	41	24
C	E	0	0	0	28
E	B	32	33	40	0
E	D	12	0	0	0
D	B	12	0	0	0
B	D	9	0	0	0

Table B.26 and Table B.27 show the minimum EWT and minimum transfers attained, respectively, by each of the GLX routing combinations. In phases II, III, and IV, the ranges in the minimum wait times are small, with no range greater than 58 minutes of wait time per 1,000. In Phase I, the inclusion of 3 additional routing combinations in the 100 most optimal solutions widens the range to 148 minutes of wait time per 1,000. Phase I is also unique from a transfer perspective: the low resources combined with the two-car train requirement necessitate that C branch trains be turned at Kenmore (current plans for post-GLX operation, which also use two-car trains exclusively on all branches but do not require short-turns at Kenmore, propose headways that are higher than the input headways).

Table B.26: Summary of GLX Routings by EWT, Solutions Prohibiting Single-Car Trains

Union Square Branch	Medford Branch	Minimum EWT			
		Phase I	Phase II	Phase III	Phase IV
D	E	3650	3084	3209	2781
B	E	3585	3072	3179	2773
C	E	--	--	--	2767
E	B	3535	3059	3151	--
E	D	3605	--	--	--
D	B	3502	--	--	--
B	D	3528	--	--	--

Table B.27: Summary of GLX Routings by Transfers, Solutions Prohibiting Single-Car Trains

Union Square Branch	Medford Branch	Minimum Transfers			
		Phase I	Phase II	Phase III	Phase IV
D	E	103	48	45	40
B	E	105	50	50	41
C	E	--	--	--	43
E	B	110	47	55	--
E	D	108	--	--	--
D	B	134	--	--	--
B	D	133	--	--	--

Table B.28: Solutions Prohibiting Single-Car Trains (Phase I Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-PS	CC-K	R-MT	HS-US	7.40	6.60	7.50	7.20	116	2049	3605	114
I	2	BC-US	CC-K	R-GC	HS-MT	7.00	7.60	7.75	7.20	118	2048	3653	105
I	3	BC-MT	CC-K	R-PS	HS-US	7.00	6.60	7.67	7.20	118	2044	3535	129
I	4	BC-MT	CC-K	R-PS	HS-US	7.00	6.00	7.67	7.75	118	2045	3548	129
I	5	BC-MT	CC-K	R-PS	HS-US	6.67	6.60	7.67	7.75	118	2034	3548	129
I	6	BC-MT	CC-K	R-GC	HS-US	7.33	6.60	7.25	7.75	118	2044	3642	110
I	7	BC-PS	CC-K	R-US	HS-MT	7.00	6.60	7.50	7.75	116	2044	3650	109
I	8	BC-MT	CC-K	R-GC	HS-US	7.00	7.60	7.75	7.20	118	2038	3645	110
I	9	BC-PS	CC-K	R-US	HS-MT	7.00	7.60	7.50	7.20	116	2043	3655	109
I	10	BC-US	CC-K	R-PS	HS-MT	6.60	6.60	7.67	7.75	118	2044	3585	123
I	11	BC-PS	CC-K	R-US	HS-MT	7.40	6.60	7.20	7.75	116	2049	3657	109
I	12	BC-PS	CC-K	R-MT	HS-US	7.40	6.60	7.20	7.75	116	2044	3634	114
I	13	BC-US	CC-K	R-PS	HS-MT	6.60	7.60	7.67	7.20	118	2043	3590	123
I	14	BC-PS	CC-K	R-US	HS-MT	7.40	7.60	7.20	7.20	116	2048	3662	109
I	15	BC-MT	CC-K	R-PS	HS-US	7.33	6.60	7.20	7.20	118	2049	3563	129
I	16	BC-PS	CC-K	R-MT	HS-US	7.00	6.60	7.50	7.75	116	2039	3640	114
I	17	BC-MT	CC-K	R-GC	HS-US	6.67	7.60	7.75	7.75	118	2028	3658	110
I	18	BC-PS	CC-K	R-MT	HS-US	7.40	7.60	7.50	6.75	116	2048	3647	114
I	19	BC-US	CC-K	R-GC	HS-MT	6.60	7.60	7.75	7.75	118	2038	3695	105
I	20	BC-MT	CC-K	R-PS	HS-US	7.33	6.00	7.20	7.75	118	2050	3576	129
I	21	BC-US	CC-K	R-PS	HS-MT	7.67	6.60	7.20	7.20	116	2029	3605	123
I	22	BC-MT	CC-K	R-PS	HS-US	7.00	6.60	7.20	7.75	118	2039	3576	129
I	23	BC-MT	CC-K	R-PS	HS-US	6.67	7.60	7.67	7.20	118	2033	3577	129
I	24	BC-MT	CC-K	R-PS	HS-US	7.00	7.60	7.67	6.75	118	2043	3577	129
I	25	BC-MT	CC-K	R-GC	HS-US	7.33	7.60	7.25	7.20	118	2043	3670	110
I	26	BC-MT	CC-K	R-GC	HS-US	7.67	6.60	6.80	7.75	118	2049	3670	110
I	27	BC-US	CC-K	R-PS	HS-MT	7.00	6.60	7.20	7.75	118	2049	3608	123
I	28	BC-US	CC-K	R-PS	HS-MT	7.00	7.60	7.20	7.20	118	2048	3613	123
I	29	BC-MT	CC-K	R-US	HS-PS	6.67	6.60	7.50	7.50	120	2044	3502	146
I	30	BC-PS	CC-K	R-MT	HS-US	7.40	7.60	7.20	7.20	116	2043	3662	114
I	31	BC-US	CC-K	R-GC	HS-MT	7.67	7.60	7.25	7.20	116	2023	3712	105
I	32	BC-MT	CC-K	R-GC	HS-US	7.00	7.60	7.25	7.75	118	2033	3683	110
I	33	BC-PS	CC-K	R-MT	HS-US	7.00	7.60	7.50	7.20	116	2038	3668	114
I	34	BC-US	CC-K	R-GC	HS-MT	7.00	7.60	7.25	7.75	118	2043	3715	105
I	35	BC-PS	CC-K	R-US	HS-MT	7.40	7.60	7.50	7.20	114	2013	3696	109
I	36	BC-MT	CC-K	R-PS	HS-US	7.33	6.60	6.67	7.75	118	2044	3598	129
I	37	BC-PS	CC-K	R-US	HS-MT	6.50	7.60	7.50	7.75	116	2033	3703	109
I	38	BC-MT	CC-K	R-PS	HS-US	6.40	7.60	7.67	7.75	118	2023	3603	129
I	39	BC-MT	CC-K	R-PS	HS-US	7.00	7.60	7.20	7.20	118	2038	3604	129
I	40	BC-MT	CC-K	R-PS	HS-US	7.33	7.60	7.20	6.75	118	2048	3605	129
I	41	BC-MT	CC-K	R-GC	HS-US	7.67	7.60	6.80	7.20	118	2048	3699	110
I	42	BC-US	CC-K	R-PS	HS-MT	7.67	7.60	7.20	6.80	116	2028	3637	123
I	43	BC-US	CC-K	R-GC	HS-MT	7.33	7.60	6.80	7.75	118	2048	3730	105
I	44	BC-MT	CC-K	R-PS	HS-US	7.00	6.60	7.67	7.75	116	2005	3610	129
I	45	BC-US	CC-K	R-MT	HS-PS	6.60	6.60	7.50	7.50	120	2049	3528	145
I	46	BC-US	CC-K	R-PS	HS-MT	7.00	6.60	7.67	7.75	116	2015	3642	123
I	47	BC-PS	CC-K	R-US	HS-MT	7.40	7.60	6.80	7.75	116	2043	3715	109
I	48	BC-MT	CC-K	R-US	HS-PS	7.00	6.60	7.20	7.50	120	2049	3530	146
I	49	BC-MT	CC-K	R-PS	HS-US	6.67	7.60	7.20	7.75	118	2028	3618	129
I	50	BC-PS	CC-K	R-MT	HS-US	6.50	7.60	7.50	7.75	116	2028	3692	114

Table B.29: Solutions Prohibiting Single-Car Trains (Phase I Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	51	BC-US	CC-K	R-PS	HS-MT	7.00	7.60	7.67	7.20	116	2013	3647	123
I	52	BC-MT	CC-K	R-US	HS-PS	6.67	7.60	7.50	6.75	120	2043	3533	146
I	53	BC-PS	CC-K	R-US	HS-MT	7.00	7.60	7.20	7.75	116	2038	3720	109
I	54	BC-MT	CC-K	R-GC	HS-US	7.33	7.60	6.80	7.75	118	2038	3712	110
I	55	BC-US	CC-K	R-PS	HS-MT	6.33	7.60	7.67	7.75	118	2033	3650	123
I	56	BC-PS	CC-K	R-MT	HS-US	7.00	7.60	7.20	7.75	116	2033	3696	114
I	57	BC-MT	CC-K	R-PS	HS-US	7.67	6.60	7.20	7.20	116	2020	3624	129
I	58	BC-US	CC-K	R-PS	HS-MT	6.60	7.60	7.20	7.75	118	2038	3654	123
I	59	BC-GC	CC-K	R-US	HS-MT	7.00	7.60	7.50	7.75	116	2033	3754	103
I	60	BC-US	CC-K	R-PS	HS-MT	7.33	6.60	7.20	7.75	116	2020	3656	123
I	61	BC-MT	CC-K	R-PS	HS-US	7.33	7.60	6.67	7.20	118	2043	3627	129
I	62	BC-MT	CC-K	R-US	HS-GC	6.67	7.60	7.50	7.50	120	2043	3606	134
I	63	BC-US	CC-K	R-PS	HS-MT	7.33	7.60	7.20	7.20	116	2018	3661	123
I	64	BC-PS	CC-K	R-MT	HS-US	7.40	7.60	7.00	7.75	116	2038	3706	114
I	65	BC-US	CC-K	R-PS	HS-MT	7.67	6.60	6.67	7.75	116	2025	3664	123
I	66	BC-PS	CC-K	R-MT	HS-US	7.40	7.60	7.50	7.20	114	2009	3709	114
I	67	BC-MT	CC-K	R-PS	HS-US	7.67	6.60	6.33	7.75	118	2049	3636	129
I	68	BC-MT	CC-K	R-PS	HS-US	7.33	6.60	7.20	7.75	116	2010	3638	129
I	69	BC-MT	CC-K	R-US	HS-PS	7.33	6.60	7.50	6.75	118	2025	3554	146
I	70	BC-MT	CC-K	R-PS	HS-US	7.00	7.60	7.67	7.20	116	2004	3639	129
I	71	BC-MT	CC-K	R-GC	HS-US	7.67	7.60	7.25	7.20	116	2013	3732	110
I	72	BC-US	CC-K	R-PS	HS-MT	7.67	7.60	6.67	7.20	116	2023	3669	123
I	73	BC-MT	CC-K	R-PS	HS-US	7.00	7.60	6.67	7.75	118	2033	3640	129
I	74	BC-MT	CC-K	R-US	HS-PS	6.40	7.60	7.50	7.50	120	2033	3556	146
I	75	BC-GC	CC-K	R-MT	HS-US	7.00	7.60	7.50	7.75	116	2028	3743	108
I	76	BC-US	CC-K	R-MT	HS-PS	6.60	7.60	7.50	6.75	120	2048	3559	145
I	77	BC-US	CC-K	R-GC	HS-MT	7.33	7.60	7.25	7.75	116	2013	3763	105
I	78	BC-GC	CC-K	R-US	HS-MT	7.50	7.60	7.20	7.75	116	2038	3771	103
I	79	BC-US	CC-K	R-PS	HS-MT	7.00	7.60	6.67	7.75	118	2043	3672	123
I	80	BC-US	CC-K	R-MT	HS-PS	7.33	6.60	7.50	6.75	118	2029	3561	145
I	81	BC-US	CC-K	R-MT	HS-PS	7.67	6.60	7.20	6.75	118	2034	3561	145
I	82	BC-GC	CC-K	R-MT	HS-US	7.50	7.60	7.20	7.75	116	2033	3748	108
I	83	BC-MT	CC-K	R-US	HS-PS	7.00	7.60	7.20	6.75	120	2048	3561	146
I	84	BC-MT	CC-K	R-US	HS-PS	7.33	6.00	7.50	7.50	118	2026	3564	146
I	85	BC-MT	CC-K	R-US	HS-PS	7.00	6.60	7.50	7.50	118	2015	3564	146
I	86	BC-MT	CC-K	R-US	HS-GC	7.33	6.60	7.50	7.50	118	2025	3626	134
I	87	BC-MT	CC-K	R-PS	HS-US	6.67	7.60	7.67	7.75	116	1994	3652	129
I	88	BC-MT	CC-K	R-GC	HS-US	7.33	7.60	7.25	7.75	116	2004	3745	110
I	89	BC-US	CC-K	R-MT	HS-PS	7.33	6.00	7.50	7.50	118	2031	3571	145
I	90	BC-PS	CC-K	R-US	HS-MT	7.00	7.60	7.50	7.75	114	2004	3754	109
I	91	BC-US	CC-K	R-MT	HS-PS	7.67	6.00	7.20	7.50	118	2036	3571	145
I	92	BC-US	CC-K	R-MT	HS-GC	6.60	7.60	7.50	7.50	120	2048	3631	133
I	93	BC-US	CC-K	R-MT	HS-GC	7.33	6.60	7.50	7.50	118	2029	3633	133
I	94	BC-MT	CC-K	R-US	HS-PS	6.67	7.60	7.20	7.50	120	2038	3571	146
I	95	BC-US	CC-K	R-GC	HS-MT	7.67	7.60	6.80	7.75	116	2018	3777	105
I	96	BC-US	CC-K	R-MT	HS-GC	7.67	6.60	7.20	7.50	118	2034	3634	133
I	97	BC-MT	CC-K	R-US	HS-GC	7.00	7.60	7.20	7.50	120	2048	3633	134
I	98	BC-US	CC-K	R-PS	HS-MT	6.60	7.60	7.67	7.75	116	2004	3689	123
I	99	BC-MT	CC-K	R-GC	HS-US	7.67	7.60	6.50	7.75	118	2043	3752	110
I	100	BC-PS	CC-K	R-US	HS-MT	7.40	7.60	7.20	7.75	114	2009	3761	109

Table B.30: Solutions Prohibiting Single-Car Trains (Phase II Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	1	BC-US	CC-K	R-GC	HS-MT	6.33	5.33	7.75	5.80	136	2386	3072	105
II	2	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	7.25	6.40	136	2382	3357	50
II	3	BC-MT	CC-PS	R-GC	HS-US	6.40	6.80	7.75	6.33	136	2379	3332	55
II	4	BC-MT	CC-PS	R-GC	HS-US	6.40	6.25	7.75	6.75	136	2380	3332	55
II	5	BC-US	CC-K	R-GC	HS-MT	6.33	6.00	7.75	5.50	136	2384	3087	105
II	6	BC-US	CC-K	R-GC	HS-MT	6.33	4.80	7.25	6.40	136	2382	3087	105
II	7	BC-MT	CC-K	R-GC	HS-US	5.75	5.33	7.75	6.33	138	2386	3059	110
II	8	BC-US	CC-PS	R-GC	HS-MT	6.33	6.80	7.25	6.80	136	2383	3366	50
II	9	BC-PS	CC-PS	R-US	HS-MT	6.20	6.80	7.50	6.40	134	2383	3347	54
II	10	BC-US	CC-PS	R-GC	HS-MT	7.33	6.80	7.75	5.80	134	2379	3367	50
II	11	BC-US	CC-PS	R-GC	HS-MT	6.60	6.80	7.75	6.40	134	2359	3370	50
II	12	BC-US	CC-PS	R-GC	HS-MT	7.00	6.25	7.75	6.40	134	2370	3370	50
II	13	BC-US	CC-PS	R-GC	HS-MT	7.33	5.80	7.75	6.40	134	2381	3371	50
II	14	BC-MT	CC-K	R-GC	HS-US	5.50	5.33	7.75	6.75	138	2376	3070	110
II	15	BC-MT	CC-PS	R-GC	HS-US	6.67	6.80	7.25	6.33	136	2383	3345	55
II	16	BC-MT	CC-PS	R-GC	HS-US	6.67	6.25	7.25	6.75	136	2385	3345	55
II	17	BC-MT	CC-PS	R-GC	HS-US	5.50	7.40	7.75	7.20	138	2377	3346	55
II	18	BC-US	CC-PS	R-GC	HS-MT	6.20	7.40	7.75	6.40	136	2377	3375	50
II	19	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.75	5.50	134	2377	3376	50
II	20	BC-MT	CC-PS	R-GC	HS-US	6.40	5.80	7.75	7.20	136	2381	3347	55
II	21	BC-MT	CC-PS	R-GC	HS-US	6.40	7.40	7.75	6.00	136	2377	3348	55
II	22	BC-US	CC-PS	R-GC	HS-MT	7.67	6.80	7.25	5.80	134	2383	3378	50
II	23	BC-PS	CC-K	R-US	HS-MT	6.50	5.33	7.20	5.80	134	2386	3084	109
II	24	BC-US	CC-K	R-GC	HS-MT	6.33	6.00	7.25	5.80	136	2380	3104	105
II	25	BC-US	CC-K	R-GC	HS-MT	6.33	6.60	7.75	5.25	136	2383	3105	105
II	26	BC-MT	CC-K	R-GC	HS-US	5.50	4.80	7.75	7.20	138	2377	3076	110
II	27	BC-US	CC-K	R-GC	HS-MT	6.20	4.80	7.75	6.40	136	2377	3105	105
II	28	BC-PS	CC-PS	R-US	HS-MT	6.50	7.40	6.80	6.40	134	2382	3360	54
II	29	BC-GC	CC-PS	R-US	HS-MT	6.60	6.80	7.50	6.40	134	2383	3388	48
II	30	BC-MT	CC-PS	R-GC	HS-US	6.20	6.80	7.75	6.75	136	2369	3352	55
II	31	BC-US	CC-PS	R-GC	HS-MT	7.33	6.25	7.25	6.40	134	2375	3381	50
II	32	BC-MT	CC-PS	R-GC	HS-US	6.40	6.80	7.25	6.75	136	2374	3352	55
II	33	BC-US	CC-PS	R-GC	HS-MT	6.33	6.25	7.25	7.20	136	2385	3381	50
II	34	BC-US	CC-K	R-GC	HS-MT	6.33	5.33	7.25	6.20	136	2381	3107	105
II	35	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.75	5.80	134	2367	3382	50
II	36	BC-PS	CC-PS	R-US	HS-MT	6.20	6.25	7.50	6.80	134	2385	3361	54
II	37	BC-US	CC-PS	R-GC	HS-MT	7.33	6.25	7.75	6.20	134	2380	3382	50
II	38	BC-US	CC-PS	R-GC	HS-MT	7.67	5.80	7.25	6.40	134	2386	3382	50
II	39	BC-PS	CC-K	R-US	HS-MT	6.20	5.33	7.50	5.80	134	2381	3087	109
II	40	BC-MT	CC-K	R-GC	HS-US	6.40	4.80	7.75	6.00	136	2377	3079	110
II	41	BC-PS	CC-PS	R-US	HS-MT	7.40	6.80	7.50	5.80	132	2374	3362	54
II	42	BC-MT	CC-K	R-GC	HS-US	5.75	5.33	7.25	6.75	138	2381	3079	110
II	43	BC-PS	CC-PS	R-US	HS-MT	5.75	7.40	7.50	6.40	134	2372	3363	54
II	44	BC-US	CC-K	R-GC	HS-MT	6.60	6.00	6.80	5.80	136	2384	3109	105
II	45	BC-MT	CC-PS	R-GC	HS-US	5.75	7.40	7.25	7.20	138	2382	3355	55
II	46	BC-US	CC-PS	R-GC	HS-MT	6.20	6.80	7.75	6.80	136	2379	3384	50
II	47	BC-US	CC-K	R-GC	HS-MT	6.33	5.33	6.80	6.40	136	2376	3109	105
II	48	BC-US	CC-PS	R-GC	HS-MT	6.60	6.25	7.75	6.80	134	2360	3384	50
II	49	BC-US	CC-K	R-GC	HS-MT	6.60	5.33	7.75	5.80	134	2356	3110	105
II	50	BC-PS	CC-K	R-US	HS-MT	6.50	4.80	6.80	6.40	134	2382	3090	109

Table B.31: Solutions Prohibiting Single-Car Trains (Phase II Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-MT	CC-PS	R-GC	HS-US	6.20	6.25	7.75	7.20	136	2370	3356	55
II	52	BC-MT	CC-K	R-GC	HS-US	5.50	6.00	7.75	6.33	138	2375	3082	110
II	53	BC-MT	CC-PS	R-GC	HS-US	6.40	6.25	7.25	7.20	136	2375	3357	55
II	54	BC-MT	CC-PS	R-GC	HS-US	6.20	7.40	7.75	6.33	136	2367	3357	55
II	55	BC-MT	CC-PS	R-GC	HS-US	6.40	7.40	7.25	6.33	136	2372	3357	55
II	56	BC-MT	CC-K	R-GC	HS-US	5.75	6.00	7.75	6.00	138	2384	3083	110
II	57	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.25	5.50	134	2382	3386	50
II	58	BC-US	CC-K	R-GC	HS-MT	6.60	5.33	6.80	6.20	136	2386	3112	105
II	59	BC-PS	CC-PS	R-US	HS-MT	7.40	5.80	7.50	6.40	132	2376	3366	54
II	60	BC-MT	CC-K	R-GC	HS-US	6.40	4.40	7.75	6.33	136	2379	3083	110
II	61	BC-US	CC-K	R-GC	HS-MT	7.00	4.80	7.75	5.80	134	2367	3112	105
II	62	BC-US	CC-K	R-GC	HS-MT	6.33	6.60	7.25	5.50	136	2378	3112	105
II	63	BC-MT	CC-PS	R-GC	HS-US	5.50	6.80	7.75	7.75	138	2379	3359	55
II	64	BC-PS	CC-K	R-US	HS-MT	5.75	4.80	7.50	6.40	134	2372	3093	109
II	65	BC-US	CC-K	R-GC	HS-MT	7.00	5.33	7.75	5.50	134	2366	3114	105
II	66	BC-MT	CC-PS	R-GC	HS-US	6.67	5.80	7.25	7.20	136	2386	3359	55
II	67	BC-MT	CC-K	R-GC	HS-US	5.75	4.80	7.25	7.20	138	2382	3086	110
II	68	BC-MT	CC-PS	R-PS	HS-US	6.40	6.25	7.67	6.33	136	2385	3269	74
II	69	BC-PS	CC-PS	R-US	HS-MT	6.50	6.80	6.80	6.80	134	2383	3369	54
II	70	BC-US	CC-K	R-GC	HS-MT	5.40	6.00	7.75	6.40	138	2384	3115	105
II	71	BC-MT	CC-PS	R-GC	HS-US	6.67	7.40	7.25	6.00	136	2382	3361	55
II	72	BC-US	CC-PS	R-GC	HS-MT	7.00	6.80	7.25	6.40	134	2364	3390	50
II	73	BC-PS	CC-PS	R-US	HS-MT	7.40	7.40	7.50	5.50	132	2372	3371	54
II	74	BC-MT	CC-K	R-GC	HS-US	6.20	4.80	7.75	6.33	136	2367	3087	110
II	75	BC-US	CC-PS	R-GC	HS-MT	7.00	6.80	7.75	6.20	134	2369	3391	50
II	76	BC-MT	CC-K	R-GC	HS-US	6.40	4.80	7.25	6.33	136	2372	3088	110
II	77	BC-US	CC-K	R-GC	HS-MT	7.67	4.80	7.25	5.50	134	2382	3117	105
II	78	BC-PS	CC-PS	R-US	HS-MT	7.00	6.25	7.50	6.40	132	2365	3372	54
II	79	BC-US	CC-K	R-GC	HS-MT	5.40	5.33	7.75	6.80	138	2386	3117	105
II	80	BC-MT	CC-K	R-GC	HS-US	6.40	5.33	7.75	5.67	136	2376	3089	110
II	81	BC-US	CC-K	R-GC	HS-MT	6.60	6.60	6.80	5.50	136	2383	3117	105
II	82	BC-US	CC-K	R-GC	HS-MT	6.33	4.40	7.25	6.80	136	2383	3118	105
II	83	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.25	5.80	134	2372	3392	50
II	84	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	7.50	6.80	134	2374	3372	54
II	85	BC-MT	CC-GC	R-GC	HS-US	6.40	7.50	7.75	6.33	136	2379	3404	47
II	86	BC-US	CC-PS	R-GC	HS-MT	7.67	6.25	7.25	6.20	134	2385	3393	50
II	87	BC-PS	CC-K	R-US	HS-MT	6.20	4.40	7.50	6.40	134	2383	3098	109
II	88	BC-PS	CC-PS	R-US	HS-MT	6.20	7.40	7.50	6.20	134	2382	3373	54
II	89	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	7.75	6.40	134	2348	3394	50
II	90	BC-PS	CC-K	R-US	HS-MT	6.50	6.00	7.20	5.50	134	2384	3099	109
II	91	BC-GC	CC-PS	R-US	HS-MT	6.60	6.25	7.50	6.80	134	2385	3402	48
II	92	BC-PS	CC-PS	R-US	HS-MT	6.20	7.40	7.20	6.40	134	2377	3375	54
II	93	BC-MT	CC-K	R-GC	HS-US	5.75	6.00	7.25	6.33	138	2380	3091	110
II	94	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	7.25	6.40	134	2353	3395	50
II	95	BC-US	CC-PS	R-GC	HS-MT	7.00	5.80	7.75	6.80	134	2371	3395	50
II	96	BC-US	CC-K	R-NS	HS-MT	6.60	6.00	7.60	5.80	136	2384	3168	95
II	97	BC-MT	CC-K	R-GC	HS-US	6.67	4.80	7.25	6.00	136	2382	3092	110
II	98	BC-GC	CC-K	R-US	HS-MT	6.60	5.33	7.50	5.80	134	2381	3128	103
II	99	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	6.80	6.80	136	2377	3395	50
II	100	BC-US	CC-PS	R-GC	HS-MT	7.67	6.25	6.80	6.40	134	2380	3395	50

Table B.32: Solutions Prohibiting Single-Car Trains (Phase III Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-US	CC-PS	R-GC	HS-MT	6.20	6.60	7.20	6.00	152	2675	3179	50
III	2	BC-MT	CC-PS	R-GC	HS-US	5.40	6.60	7.60	6.60	154	2670	3151	55
III	3	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	7.60	5.75	150	2672	3182	50
III	4	BC-MT	CC-PS	R-GC	HS-US	5.60	6.60	7.20	6.60	154	2675	3159	55
III	5	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	7.20	6.60	152	2677	3190	50
III	6	BC-US	CC-PS	R-GC	HS-MT	6.75	5.67	7.60	6.00	150	2662	3191	50
III	7	BC-US	CC-PS	R-GC	HS-MT	6.00	5.67	7.60	6.60	152	2672	3191	50
III	8	BC-US	CC-PS	R-GC	HS-MT	7.00	5.33	7.60	6.00	150	2673	3192	50
III	9	BC-US	CC-PS	R-GC	HS-MT	7.00	6.20	7.60	5.50	150	2671	3192	50
III	10	BC-MT	CC-PS	R-GC	HS-US	5.40	5.67	7.60	7.40	154	2672	3164	55
III	11	BC-MT	CC-PS	R-GC	HS-US	6.25	5.67	7.60	6.25	152	2672	3164	55
III	12	BC-MT	CC-PS	R-GC	HS-US	5.40	6.20	7.60	7.00	154	2671	3164	55
III	13	BC-MT	CC-PS	R-GC	HS-US	6.00	5.67	7.60	6.60	152	2662	3166	55
III	14	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	7.50	6.00	150	2676	3215	45
III	15	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	7.20	6.00	150	2667	3197	50
III	16	BC-US	CC-PS	R-GC	HS-MT	6.20	6.20	7.20	6.33	152	2676	3198	50
III	17	BC-US	CC-PS	R-GC	HS-MT	6.00	6.20	7.60	6.33	152	2671	3199	50
III	18	BC-MT	CC-PS	R-GC	HS-US	5.60	5.67	7.20	7.40	154	2677	3171	55
III	19	BC-US	CC-PS	R-GC	HS-MT	7.33	5.67	7.20	5.75	150	2677	3200	50
III	20	BC-MT	CC-PS	R-GC	HS-US	5.60	6.20	7.20	7.00	154	2676	3172	55
III	21	BC-GC	CC-PS	R-US	HS-MT	6.20	6.60	7.50	5.75	150	2675	3209	48
III	22	BC-MT	CC-PS	R-GC	HS-US	6.00	6.20	7.60	6.25	152	2661	3173	55
III	23	BC-PS	CC-GC	R-US	HS-MT	5.75	7.20	7.50	5.75	150	2675	3225	45
III	24	BC-MT	CC-PS	R-GC	HS-US	5.40	6.60	7.20	7.00	154	2665	3176	55
III	25	BC-GC	CC-PS	R-US	HS-MT	6.20	6.20	7.50	6.00	150	2676	3213	48
III	26	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	7.50	6.33	150	2677	3226	45
III	27	BC-US	CC-PS	R-GC	HS-MT	6.20	6.60	6.75	6.33	152	2670	3206	50
III	28	BC-MT	CC-PS	R-GC	HS-US	6.25	5.33	7.60	6.60	152	2673	3177	55
III	29	BC-US	CC-PS	R-GC	HS-MT	7.33	6.60	7.20	5.25	150	2675	3207	50
III	30	BC-MT	CC-PS	R-GC	HS-US	5.60	6.60	6.75	7.00	154	2670	3180	55
III	31	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	7.50	6.33	150	2677	3217	48
III	32	BC-MT	CC-PS	R-GC	HS-US	6.50	5.67	7.20	6.25	152	2677	3181	55
III	33	BC-MT	CC-PS	R-GC	HS-US	6.25	6.60	7.60	5.67	152	2670	3181	55
III	34	BC-US	CC-PS	R-GC	HS-MT	5.75	6.20	7.60	6.60	152	2661	3211	50
III	35	BC-US	CC-PS	R-GC	HS-MT	7.33	6.20	7.20	5.50	150	2676	3211	50
III	36	BC-MT	CC-PS	R-GC	HS-US	6.25	5.67	7.20	6.60	152	2667	3182	55
III	37	BC-US	CC-PS	R-GC	HS-MT	7.33	5.67	6.75	6.00	150	2672	3212	50
III	38	BC-MT	CC-PS	R-GC	HS-US	5.80	5.67	7.60	7.00	152	2653	3183	55
III	39	BC-GC	CC-PS	R-US	HS-MT	6.20	6.60	7.20	6.00	150	2670	3220	48
III	40	BC-US	CC-PS	R-GC	HS-MT	6.20	6.20	6.75	6.60	152	2671	3212	50
III	41	BC-MT	CC-PS	R-GC	HS-US	6.25	6.20	7.60	6.00	152	2671	3185	55
III	42	BC-MT	CC-PS	R-GC	HS-US	6.00	5.33	7.60	7.00	152	2664	3186	55
III	43	BC-US	CC-PS	R-GC	HS-MT	6.50	5.67	7.60	6.33	150	2653	3215	50
III	44	BC-PS	CC-GC	R-US	HS-MT	5.75	7.20	7.20	6.00	150	2670	3236	45
III	45	BC-US	CC-PS	R-GC	HS-MT	6.75	5.33	7.60	6.33	150	2664	3216	50
III	46	BC-MT	CC-PS	R-GC	HS-US	5.60	7.20	6.75	6.60	154	2668	3188	55
III	47	BC-US	CC-PS	R-GC	HS-MT	6.00	6.20	7.20	6.60	152	2666	3217	50
III	48	BC-PS	CC-GC	R-US	HS-MT	5.75	7.75	7.50	5.50	150	2673	3238	45
III	49	BC-US	CC-PS	R-GC	HS-MT	7.00	5.00	7.60	6.33	150	2675	3217	50
III	50	BC-MT	CC-PS	R-GC	HS-US	5.40	6.20	7.20	7.40	154	2666	3189	55

Table B.33: Solutions Prohibiting Single-Car Trains (Phase III Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-MT	CC-PS	R-GC	HS-US	6.25	6.20	7.20	6.25	152	2666	3190	55
III	52	BC-US	CC-PS	R-GC	HS-MT	7.33	6.60	6.75	5.50	150	2670	3219	50
III	53	BC-US	CC-PS	R-GC	HS-MT	7.00	6.20	6.75	6.00	150	2661	3219	50
III	54	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	7.20	6.60	150	2672	3240	45
III	55	BC-MT	CC-PS	R-GC	HS-US	6.00	5.67	7.20	7.00	152	2657	3191	55
III	56	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	7.60	6.60	150	2643	3220	50
III	57	BC-MT	CC-PS	R-GC	HS-US	5.25	6.20	7.60	7.40	154	2661	3191	55
III	58	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	7.20	6.33	150	2671	3240	45
III	59	BC-MT	CC-PS	R-GC	HS-US	6.00	6.20	7.20	6.60	152	2656	3191	55
III	60	BC-MT	CC-PS	R-GC	HS-US	5.80	6.60	6.40	7.00	154	2675	3191	55
III	61	BC-US	CC-PS	R-GC	HS-MT	6.75	5.67	7.20	6.33	150	2657	3221	50
III	62	BC-MT	CC-PS	R-GC	HS-US	5.60	6.20	6.75	7.40	154	2671	3193	55
III	63	BC-US	CC-PS	R-GC	HS-MT	7.33	6.20	6.75	5.75	150	2671	3222	50
III	64	BC-US	CC-PS	R-GC	HS-MT	7.00	5.33	7.20	6.33	150	2669	3222	50
III	65	BC-US	CC-PS	R-GC	HS-MT	6.50	6.60	6.40	6.33	152	2675	3223	50
III	66	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	7.20	6.60	150	2672	3231	48
III	67	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	6.75	6.33	150	2662	3224	50
III	68	BC-PS	CC-GC	R-US	HS-MT	5.50	7.20	7.50	6.00	150	2665	3245	45
III	69	BC-MT	CC-PS	R-GC	HS-US	6.50	5.67	6.75	6.60	152	2672	3196	55
III	70	BC-US	CC-PS	R-GC	HS-MT	6.00	6.60	6.75	6.60	152	2660	3225	50
III	71	BC-GC	CC-PS	R-US	HS-MT	6.00	6.60	7.50	6.00	150	2665	3234	48
III	72	BC-MT	CC-PS	R-GC	HS-US	6.25	5.00	7.60	7.00	152	2675	3198	55
III	73	BC-MT	CC-PS	R-GC	HS-US	5.40	6.60	6.75	7.40	154	2660	3198	55
III	74	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	7.60	6.00	148	2633	3227	50
III	75	BC-MT	CC-PS	R-GC	HS-US	6.50	6.60	7.20	5.67	152	2675	3198	55
III	76	BC-US	CC-PS	R-GC	HS-MT	5.75	5.67	7.60	7.00	152	2662	3227	50
III	77	BC-MT	CC-PS	R-GC	HS-US	6.25	6.60	6.75	6.25	152	2660	3198	55
III	78	BC-MT	CC-PS	R-GC	HS-US	5.80	7.20	6.40	6.60	154	2673	3199	55
III	79	BC-US	CC-PS	R-GC	HS-MT	6.20	6.60	6.40	6.60	152	2665	3228	50
III	80	BC-PS	CC-GC	R-US	HS-MT	5.50	6.20	7.50	6.60	150	2667	3248	45
III	81	BC-US	CC-PS	R-GC	HS-MT	6.50	5.33	7.60	6.60	150	2654	3228	50
III	82	BC-US	CC-PS	R-GC	HS-MT	6.00	5.33	7.60	7.00	152	2673	3228	50
III	83	BC-GC	CC-PS	R-US	HS-MT	7.40	5.67	7.50	5.75	148	2667	3236	48
III	84	BC-MT	CC-PS	R-GC	HS-US	6.00	6.60	6.75	6.60	152	2650	3200	55
III	85	BC-PS	CC-GC	R-US	HS-MT	5.50	6.67	7.50	6.33	150	2666	3249	45
III	86	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	6.75	7.00	152	2672	3229	50
III	87	BC-US	CC-PS	R-GC	HS-MT	6.75	5.00	7.60	6.60	150	2665	3229	50
III	88	BC-US	CC-PS	R-GC	HS-MT	6.50	6.20	6.40	6.60	152	2676	3229	50
III	89	BC-MT	CC-PS	R-GC	HS-US	5.60	5.67	7.60	7.40	152	2643	3201	55
III	90	BC-US	CC-PS	R-GC	HS-MT	7.33	5.67	7.60	5.75	148	2643	3230	50
III	91	BC-GC	CC-PS	R-US	HS-MT	6.20	6.20	7.20	6.33	150	2671	3238	48
III	92	BC-MT	CC-PS	R-GC	HS-US	6.50	6.20	7.20	6.00	152	2676	3202	55
III	93	BC-MT	CC-PS	R-GC	HS-US	6.25	5.33	7.20	7.00	152	2669	3203	55
III	94	BC-MT	CC-PS	R-GC	HS-US	6.50	6.20	6.75	6.25	152	2671	3203	55
III	95	BC-GC	CC-PS	R-US	HS-MT	7.00	5.67	7.50	6.00	148	2657	3240	48
III	96	BC-MT	CC-PS	R-GC	HS-US	5.80	5.33	7.60	7.40	152	2654	3203	55
III	97	BC-MT	CC-PS	R-GC	HS-US	6.25	5.67	6.75	7.00	152	2662	3204	55
III	98	BC-US	CC-PS	R-GC	HS-MT	6.50	5.67	7.20	6.60	150	2648	3233	50
III	99	BC-US	CC-PS	R-GC	HS-MT	6.00	5.67	7.20	7.00	152	2667	3233	50
III	100	BC-MT	CC-PS	R-GC	HS-US	6.25	6.20	6.75	6.60	152	2661	3205	55

Table B.34: Solutions Prohibiting Single-Car Trains (Phase IV Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-US	R-GC	HS-MT	5.75	5.40	7.60	4.67	172	3146	2767	48
IV	2	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	6.60	4.67	172	3096	2783	45
IV	3	BC-PS	CC-US	R-GC	HS-MT	5.75	5.67	7.60	4.50	172	3144	2775	48
IV	4	BC-PS	CC-GC	R-US	HS-MT	5.75	5.20	7.20	4.67	172	3108	2789	45
IV	5	BC-PS	CC-US	R-GC	HS-MT	5.75	5.67	7.20	4.67	172	3139	2776	48
IV	6	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	7.20	4.50	172	3107	2791	45
IV	7	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	7.20	4.33	172	3106	2792	45
IV	8	BC-US	CC-PS	R-GC	HS-MT	5.50	5.67	7.60	4.67	172	3046	2773	50
IV	9	BC-PS	CC-US	R-GC	HS-MT	5.50	5.67	7.60	4.67	172	3134	2779	48
IV	10	BC-GC	CC-PS	R-US	HS-MT	6.20	5.33	6.60	4.67	172	3096	2781	48
IV	11	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	6.75	5.25	172	3137	2780	48
IV	12	BC-PS	CC-GC	R-US	HS-MT	5.75	5.20	7.50	4.50	172	3113	2794	45
IV	13	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	6.33	4.67	172	3090	2794	45
IV	14	BC-US	CC-PS	R-GC	HS-MT	5.75	5.33	7.60	4.67	172	3057	2774	50
IV	15	BC-US	CC-PS	R-GC	HS-MT	6.20	5.00	7.60	4.50	172	3078	2774	50
IV	16	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	6.60	4.50	172	3095	2795	45
IV	17	BC-US	CC-PS	R-GC	HS-MT	6.20	5.00	7.20	4.67	172	3073	2774	50
IV	18	BC-PS	CC-GC	R-US	HS-MT	5.50	5.50	7.20	4.67	172	3097	2795	45
IV	19	BC-PS	CC-GC	R-US	HS-MT	5.75	5.20	6.33	5.25	172	3094	2795	45
IV	20	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	7.50	4.33	172	3112	2795	45
IV	21	BC-PS	CC-US	R-GC	HS-MT	6.50	5.40	6.75	4.67	172	3155	2781	48
IV	22	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	7.20	4.67	172	3086	2795	45
IV	23	BC-US	CC-PS	R-GC	HS-MT	6.00	5.00	7.60	4.67	172	3068	2775	50
IV	24	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	7.20	4.50	172	3096	2796	45
IV	25	BC-US	CC-PS	R-GC	HS-MT	6.20	5.33	6.75	4.67	172	3067	2776	50
IV	26	BC-PS	CC-US	R-GC	HS-MT	5.75	5.40	6.40	5.25	172	3131	2783	48
IV	27	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	6.75	5.25	172	3126	2783	48
IV	28	BC-PS	CC-US	R-GC	HS-MT	6.20	5.40	7.60	4.50	172	3155	2783	48
IV	29	BC-PS	CC-US	R-GC	HS-MT	6.20	5.40	7.20	4.67	172	3150	2783	48
IV	30	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	7.00	4.67	172	3102	2798	45
IV	31	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	6.33	4.67	172	3090	2785	48
IV	32	BC-PS	CC-GC	R-US	HS-MT	6.50	5.20	6.60	4.67	172	3118	2798	45
IV	33	BC-GC	CC-PS	R-US	HS-MT	6.20	5.00	7.20	4.50	172	3107	2785	48
IV	34	BC-PS	CC-US	R-GC	HS-MT	6.50	5.40	7.60	4.33	172	3165	2784	48
IV	35	BC-PS	CC-GC	R-US	HS-MT	5.50	5.20	7.50	4.67	172	3103	2798	45
IV	36	BC-PS	CC-US	R-GC	HS-MT	6.20	5.20	7.60	4.67	172	3157	2784	48
IV	37	BC-PS	CC-GC	R-US	HS-MT	6.20	5.50	6.60	4.67	172	3107	2798	45
IV	38	BC-PS	CC-US	R-GC	HS-MT	5.75	5.00	7.20	5.25	172	3143	2784	48
IV	39	BC-PS	CC-GC	R-US	HS-MT	5.20	5.50	7.50	4.67	172	3092	2798	45
IV	40	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	6.60	4.50	172	3095	2786	48
IV	41	BC-PS	CC-US	R-GC	HS-MT	6.50	5.40	7.20	4.50	172	3160	2784	48
IV	42	BC-US	CC-PS	R-GC	HS-MT	6.20	4.75	7.60	4.67	172	3079	2778	50
IV	43	BC-PS	CC-GC	R-US	HS-MT	6.50	5.50	6.33	4.67	172	3112	2799	45
IV	44	BC-PS	CC-GC	R-US	HS-MT	6.20	5.80	6.33	4.67	172	3101	2799	45
IV	45	BC-PS	CC-US	R-GC	HS-MT	5.75	4.80	7.60	5.25	172	3149	2785	48
IV	46	BC-PS	CC-GC	R-US	HS-MT	5.50	6.20	6.60	4.67	172	3085	2799	45
IV	47	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	7.00	4.50	172	3101	2799	45
IV	48	BC-PS	CC-US	R-GC	HS-MT	6.50	5.20	7.60	4.50	172	3166	2785	48
IV	49	BC-GC	CC-US	R-GC	HS-MT	6.20	5.40	7.60	4.67	172	3146	2813	43
IV	50	BC-PS	CC-GC	R-US	HS-MT	6.50	5.50	6.60	4.50	172	3117	2799	45

Table B.35: Solutions Prohibiting Single-Car Trains (Phase IV Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-US	CC-PS	R-GC	HS-MT	5.75	5.67	7.60	4.50	172	3055	2779	50
IV	52	BC-US	CC-PS	R-GC	HS-MT	6.20	5.33	7.60	4.33	172	3076	2779	50
IV	53	BC-US	CC-PS	R-GC	HS-MT	5.50	5.00	7.20	5.25	172	3043	2779	50
IV	54	BC-PS	CC-GC	R-US	HS-MT	5.50	5.50	7.50	4.50	172	3102	2799	45
IV	55	BC-PS	CC-GC	R-US	HS-MT	6.20	5.80	6.60	4.50	172	3106	2799	45
IV	56	BC-PS	CC-US	R-GC	HS-MT	5.20	5.40	7.20	5.25	172	3121	2785	48
IV	57	BC-PS	CC-US	R-GC	HS-MT	6.50	5.20	7.20	4.67	172	3162	2785	48
IV	58	BC-US	CC-PS	R-GC	HS-MT	5.75	5.67	7.20	4.67	172	3051	2779	50
IV	59	BC-US	CC-PS	R-GC	HS-MT	6.20	5.33	7.20	4.50	172	3071	2779	50
IV	60	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	7.50	4.50	172	3091	2800	45
IV	61	BC-PS	CC-GC	R-US	HS-MT	6.50	5.80	6.33	4.50	172	3111	2800	45
IV	62	BC-PS	CC-GC	R-US	HS-MT	5.50	5.20	6.60	5.25	172	3089	2800	45
IV	63	BC-PS	CC-US	R-GC	HS-MT	5.20	5.20	7.60	5.25	172	3127	2786	48
IV	64	BC-PS	CC-GC	R-US	HS-MT	5.20	5.50	6.60	5.25	172	3078	2800	45
IV	65	BC-PS	CC-US	R-GC	HS-MT	6.50	5.00	7.60	4.67	172	3168	2786	48
IV	66	BC-GC	CC-PS	R-US	HS-MT	6.60	5.00	6.60	4.67	172	3107	2787	48
IV	67	BC-PS	CC-GC	R-US	HS-MT	6.50	5.80	6.60	4.33	172	3116	2800	45
IV	68	BC-US	CC-PS	R-GC	HS-MT	6.00	5.33	7.60	4.50	172	3067	2780	50
IV	69	BC-PS	CC-GC	R-US	HS-MT	5.50	5.50	6.33	5.25	172	3083	2800	45
IV	70	BC-GC	CC-PS	R-US	HS-MT	5.60	5.00	7.50	4.67	172	3092	2788	48
IV	71	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	7.50	4.33	172	3101	2801	45
IV	72	BC-US	CC-PS	R-GC	HS-MT	5.50	5.33	6.75	5.25	172	3037	2780	50
IV	73	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	6.33	5.25	172	3071	2801	45
IV	74	BC-GC	CC-PS	R-US	HS-MT	5.60	5.33	7.20	4.67	172	3086	2788	48
IV	75	BC-US	CC-PS	R-GC	HS-MT	6.00	5.33	7.20	4.67	172	3062	2780	50
IV	76	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	6.75	4.50	172	3065	2780	50
IV	77	BC-GC	CC-GC	R-US	HS-MT	6.20	5.80	6.60	4.67	172	3096	2829	40
IV	78	BC-PS	CC-US	R-GC	HS-MT	5.50	5.20	7.20	5.25	172	3132	2787	48
IV	79	BC-US	CC-PS	R-GC	HS-MT	5.75	5.00	6.75	5.25	172	3048	2781	50
IV	80	BC-GC	CC-PS	R-US	HS-MT	6.20	4.75	7.20	4.67	172	3108	2789	48
IV	81	BC-PS	CC-US	R-GC	HS-MT	5.50	5.00	7.60	5.25	172	3138	2788	48
IV	82	BC-US	CC-GC	R-GC	HS-MT	5.75	5.80	7.60	4.67	172	3057	2822	41
IV	83	BC-US	CC-PS	R-GC	HS-MT	6.00	5.67	6.75	4.67	172	3055	2782	50
IV	84	BC-GC	CC-PS	R-US	HS-MT	5.60	5.00	6.60	5.25	172	3078	2789	48
IV	85	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	7.50	4.20	172	3111	2802	45
IV	86	BC-GC	CC-PS	R-US	HS-MT	6.20	5.00	7.50	4.33	172	3112	2789	48
IV	87	BC-GC	CC-PS	R-US	HS-MT	6.20	5.33	7.20	4.33	172	3106	2790	48
IV	88	BC-US	CC-PS	R-GC	HS-MT	5.50	4.75	7.60	5.25	172	3049	2782	50
IV	89	BC-PS	CC-US	R-GC	HS-MT	6.20	5.67	6.75	4.67	172	3144	2789	48
IV	90	BC-PS	CC-GC	R-US	HS-MT	5.75	5.00	7.50	4.67	172	3115	2803	45
IV	91	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	7.00	4.67	172	3091	2803	45
IV	92	BC-PS	CC-US	R-GC	HS-MT	5.75	6.20	6.75	4.50	172	3132	2790	48
IV	93	BC-PS	CC-US	R-GC	HS-MT	6.50	5.67	6.75	4.50	172	3154	2790	48
IV	94	BC-US	CC-GC	R-GC	HS-MT	6.20	5.80	6.75	4.67	172	3067	2824	41
IV	95	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	7.20	4.33	172	3070	2784	50
IV	96	BC-US	CC-GC	R-GC	HS-MT	6.20	5.20	7.60	4.67	172	3079	2825	41
IV	97	BC-GC	CC-PS	R-US	HS-MT	6.60	5.33	6.33	4.67	172	3101	2792	48
IV	98	BC-US	CC-PS	R-GC	HS-MT	6.50	5.00	6.75	4.67	172	3078	2784	50
IV	99	BC-PS	CC-US	R-GC	HS-MT	5.75	6.00	6.75	4.67	172	3133	2791	48
IV	100	BC-PS	CC-US	R-GC	HS-MT	5.20	5.67	6.75	5.25	172	3115	2791	48

B.5 Comparison of Restrictions on Single-Car Trains

As discussed in more detail in Chapter 5, widespread peak-period use of single-car trains in the Central Subway is potentially risky, even if they are scheduled to accommodate demand levels. Therefore, despite the low wait times enabled by two or more single-car services on the Green Line network, it is operationally desirable to limit the use of single-car trains. However, such limits should be balanced with LOS considerations.

Table B.36 compares the effects of restrictions on the use of single-car trains. For each phase and level of restrictions, the average wait time and average number of transfers across the twenty most optimal solutions is shown. Averages are taken because the wait time and transfers of specific solutions may vary depending on the routing combination, and there is no routing combination that appears in every phase and every restriction level.

Table B.36: Comparison of Solutions with Varying Restrictions on Single-Car Trains

Phase	Single-Car Trains	Average EWT of 20 Most Optimal Solutions		Average Transfers of 20 Most Optimal Solutions	
		(min/1000)	% Increase from Unrestricted	(per 1000)	% Increase from Unrestricted
I	Unrestricted	2654	--	51	--
	Partially Restricted	3168	19.4%	63	22.1%
	Prohibited	3619	36.4%	116	125.3%
II	Unrestricted	2642	--	53	--
	Partially Restricted	2752	4.2%	51	-2.8%
	Prohibited	3286	24.4%	66	24.6%
III	Unrestricted	2628	--	49	--
	Partially Restricted	2674	1.8%	55	11.4%
	Prohibited	3182	21.1%	52	5.3%
IV	Unrestricted	2464	--	47	--
	Partially Restricted	2479	0.6%	48	1.3%
	Prohibited	2784	13.0%	47	-0.2%

In all four phases, the partial restrictions on single-car trains have a lower impact on wait times than a full prohibition. In Phases I, cutting back from two or three single-car services to just one single-car service increases wait time up to 20% on average, but this increase is moderate compared to the 36% average wait time increase that occurs with two-car trains only. The discrepancy is greater in Phase

II, where a prohibition on single-car services result in a wait time increase six times greater than that of partial restrictions. In Phases III and IV, the wait time impacts of systemwide two-car trains is an order of magnitude higher than shifting the location of the single-car trains, even when shifting the single-car trains away from dominant routes. For example, despite 99% of the unrestricted Phase IV solutions proposing single-car trains on the C branch, assigning all single-car trains to the E branch instead only results in an average wait time increase of 0.6%.

The effect of single-car service restrictions on transfers, however, is inconsistent. Although a prohibition on two-car trains results in a large increase in transfers of 125% relative to unrestricted solutions in Phase I, there are some instances in which additional restrictions result in a lower number of transfers overall compared to restricted solutions. This can be explained partially by the choice of turnaround locations, which is influenced not only by the number of resulting transfers, but also use of agency resources (due to the integrality of the fleet requirement, the use of some turnaround locations may result in inefficient cycle times).

Generally speaking, situations in which agency resources are limited (Phase I, and to a lesser degree Phase II) result in the highest increases in transfers; with single-car trains prohibited in Phase I, for example, the input headways only allow for solutions that short-turn the C branch at Kenmore, a major source of transfers.

Overall, the comparisons suggest that it is possible to limit single-car trains in an operationally desirable way (i.e., specifying both the number of single-car services and/or the location) without long-term impacts to passenger LOS. From a LOS perspective, these partial restrictions on single-car trains are favorable to a full prohibition, which result in higher wait times (in all cases) and more transfers (when resources are low).

B.6 Current Path

Current Path solutions, as discussed in Chapter 5, adhere strictly to current operating practices. The solutions below include the following constraints in addition to the core constraints:

- Single-car services are prohibited everywhere on the Green Line.
- No more than 4 service patterns may be proposed.
- The headway of the D branch service must be lower than or equal to the headway of the C branch service.
- The headway of the D branch service must be lower than or equal to the headway of the E branch service.

Note that Phase I has only one solution, which is the service currently planned for the beginning of post-GLX operations.

Table B.37: Current Path Solutions (Phase I, Phase II Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-GC	CC-GC	R-US	HS-MT	7.50	9.00	8.00	8.50	116	2051	3897	40
II	1	BC-PS	CC-PS	R-US	HS-MT	6.50	6.80	6.80	6.80	134	2383	3369	54
II	2	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	6.80	6.80	136	2377	3395	50
II	3	BC-US	CC-PS	R-GC	HS-MT	6.33	6.80	6.80	7.20	136	2379	3405	50
II	4	BC-MT	CC-PS	R-GC	HS-US	6.40	6.80	6.80	7.20	136	2369	3380	55
II	5	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	6.50	6.80	136	2382	3411	50
II	6	BC-MT	CC-PS	R-GC	HS-US	5.50	7.40	7.25	7.75	138	2372	3384	55
II	7	BC-GC	CC-PS	R-US	HS-MT	7.00	6.80	6.80	6.80	134	2383	3421	48
II	8	BC-US	CC-PS	R-PS	HS-MT	6.33	6.80	6.67	6.80	136	2383	3323	68
II	9	BC-PS	CC-PS	R-US	HS-MT	6.50	7.40	6.50	6.80	134	2377	3397	54
II	10	BC-PS	CC-PS	R-US	HS-MT	6.20	7.40	6.80	6.80	134	2372	3401	54
II	11	BC-US	CC-PS	R-GC	HS-MT	6.60	6.80	6.50	7.20	136	2383	3421	50
II	12	BC-PS	CC-GC	R-US	HS-MT	6.50	7.50	6.80	6.80	134	2383	3442	45
II	13	BC-MT	CC-PS	R-PS	HS-US	5.50	7.40	7.20	7.20	138	2377	3305	74
II	14	BC-MT	CC-PS	R-GC	HS-US	5.75	7.40	6.80	7.75	138	2377	3397	55
II	15	BC-PS	CC-PS	R-US	HS-MT	6.50	6.80	6.50	7.20	134	2379	3407	54
II	16	BC-US	CC-PS	R-GC	HS-MT	7.00	6.80	6.80	6.80	134	2359	3429	50
II	17	BC-MT	CC-GC	R-GC	HS-US	5.75	7.50	7.25	7.75	138	2383	3441	47
II	18	BC-PS	CC-PS	R-MT	HS-US	7.00	6.80	6.60	6.75	134	2383	3382	59
II	19	BC-MT	CC-PS	R-PS	HS-US	6.40	6.80	6.67	6.75	136	2374	3309	74
II	20	BC-PS	CC-PS	R-US	HS-MT	6.20	6.80	6.80	7.20	134	2374	3410	54
II	21	BC-MT	CC-PS	R-PS	HS-US	5.75	7.40	6.67	7.20	138	2382	3312	74
II	22	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	6.80	6.80	134	2348	3434	50
II	23	BC-GC	CC-PS	R-US	HS-MT	6.60	7.40	6.80	6.80	134	2372	3442	48
II	24	BC-MT	CC-PS	R-GC	HS-US	6.20	7.40	6.80	7.20	136	2358	3406	55
II	25	BC-US	CC-GC	R-GC	HS-MT	6.33	7.50	6.80	7.20	136	2379	3477	41
II	26	BC-MT	CC-PS	R-GC	HS-US	6.67	6.80	6.50	7.20	136	2374	3408	55
II	27	BC-MT	CC-PS	R-GC	HS-US	7.00	6.80	6.50	6.75	136	2383	3408	55
II	28	BC-MT	CC-PS	R-GC	HS-US	6.67	7.40	6.50	6.75	136	2372	3408	55
II	29	BC-MT	CC-GC	R-GC	HS-US	6.67	7.00	6.80	7.20	136	2380	3451	47
II	30	BC-PS	CC-PS	R-MT	HS-US	6.50	6.80	6.60	7.20	134	2374	3393	59
II	31	BC-PS	CC-PS	R-MT	HS-US	6.50	7.40	6.60	6.75	134	2372	3393	59
II	32	BC-PS	CC-PS	R-US	HS-MT	7.00	7.40	6.25	6.80	134	2382	3420	54
II	33	BC-GC	CC-PS	R-US	HS-MT	7.00	7.40	6.50	6.80	134	2377	3448	48
II	34	BC-PS	CC-PS	R-US	HS-MT	7.00	6.80	6.80	6.80	132	2354	3421	54
II	35	BC-MT	CC-GC	R-GC	HS-US	6.40	7.50	6.80	7.20	136	2369	3453	47
II	36	BC-PS	CC-GC	R-US	HS-MT	6.50	7.00	6.80	7.20	134	2385	3462	45
II	37	BC-US	CC-PS	R-GC	HS-MT	6.60	6.80	6.80	7.20	134	2349	3443	50
II	38	BC-GC	CC-PS	R-US	HS-MT	6.60	6.80	6.80	7.20	134	2374	3451	48
II	39	BC-GC	CC-GC	R-US	HS-MT	7.00	7.50	6.80	6.80	134	2383	3493	40
II	40	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	6.50	7.20	136	2372	3445	50
II	41	BC-MT	CC-PS	R-PS	HS-US	5.75	6.80	6.67	7.75	138	2383	3325	74
II	42	BC-PS	CC-PS	R-US	HS-MT	5.75	7.40	6.80	7.20	134	2362	3426	54
II	43	BC-NS	CC-PS	R-US	HS-MT	7.75	6.80	6.80	6.80	134	2383	3498	39
II	44	BC-US	CC-GC	R-PS	HS-MT	6.33	7.50	6.67	6.80	136	2383	3396	60
II	45	BC-MT	CC-PS	R-GC	HS-US	6.20	6.80	6.80	7.75	136	2359	3419	55
II	46	BC-PS	CC-PS	R-US	HS-MT	7.40	6.80	6.50	6.80	132	2359	3427	54
II	47	BC-US	CC-PS	R-GC	HS-MT	6.20	7.40	6.80	7.20	136	2367	3448	50
II	48	BC-US	CC-PS	R-NS	HS-MT	6.33	7.40	7.20	7.20	136	2372	3497	40
II	49	BC-PS	CC-PS	R-MT	HS-US	7.00	6.80	6.33	7.20	134	2379	3402	59
II	50	BC-MT	CC-PS	R-GC	HS-US	6.40	7.40	6.50	7.20	136	2362	3421	55

Table B.38: Current Path Solutions (Phase II Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-PS	CC-PS	R-MT	HS-US	7.00	7.40	6.33	6.75	134	2377	3403	59
II	52	BC-PS	CC-PS	R-US	HS-MT	7.00	6.80	6.25	7.20	134	2383	3429	54
II	53	BC-GC	CC-PS	R-US	HS-MT	7.00	6.80	6.50	7.20	134	2379	3458	48
II	54	BC-MT	CC-PS	R-GC	HS-US	6.00	7.40	6.50	7.75	138	2382	3422	55
II	55	BC-PS	CC-PS	R-US	HS-MT	6.50	7.40	6.80	6.80	132	2343	3431	54
II	56	BC-GC	CC-PS	R-MT	HS-US	7.50	6.80	6.60	6.75	134	2383	3434	53
II	57	BC-US	CC-GC	R-GC	HS-MT	6.60	7.50	6.50	7.20	136	2383	3494	41
II	58	BC-US	CC-PS	R-PS	HS-MT	6.33	7.40	6.33	6.80	136	2377	3361	68
II	59	BC-MT	CC-PS	R-NS	HS-US	6.40	7.40	7.20	7.20	136	2362	3472	46
II	60	BC-US	CC-PS	R-PS	HS-MT	6.60	6.80	6.67	6.80	134	2354	3362	68
II	61	BC-US	CC-PS	R-NS	HS-MT	6.60	7.40	6.75	7.20	136	2377	3502	40
II	62	BC-MT	CC-PS	R-PS	HS-US	6.20	6.80	6.67	7.20	136	2364	3333	74
II	63	BC-MT	CC-PS	R-NS	HS-US	6.00	7.40	7.20	7.75	138	2382	3473	46
II	64	BC-US	CC-PS	R-GC	HS-MT	7.33	6.80	6.50	6.80	134	2364	3454	50
II	65	BC-MT	CC-PS	R-PS	HS-US	6.67	6.80	6.33	6.75	136	2379	3334	74
II	66	BC-MT	CC-PS	R-PS	HS-US	6.20	7.40	6.67	6.75	136	2362	3334	74
II	67	BC-PS	CC-K	R-MT	HS-US	5.75	6.60	6.33	6.33	136	2383	3134	114
II	68	BC-US	CC-GC	R-GC	HS-MT	7.33	7.00	6.80	6.80	134	2370	3497	41
II	69	BC-US	CC-GC	R-NS	HS-MT	6.60	7.50	7.20	7.20	136	2383	3545	32
II	70	BC-US	CC-PS	R-PS	HS-MT	6.20	7.40	6.67	6.80	136	2372	3366	68
II	71	BC-PS	CC-PS	R-US	HS-MT	6.20	7.40	6.50	7.20	134	2367	3438	54
II	72	BC-PS	CC-GC	R-US	HS-MT	6.50	7.50	6.50	7.20	134	2379	3479	45
II	73	BC-MT	CC-PS	R-GC	HS-US	6.67	6.80	6.80	7.20	134	2339	3430	55
II	74	BC-MT	CC-K	R-GC	HS-US	5.75	6.60	6.50	6.75	138	2368	3155	110
II	75	BC-MT	CC-GC	R-PS	HS-US	6.67	7.00	6.67	6.75	136	2385	3379	66
II	76	BC-MT	CC-PS	R-GC	HS-US	5.75	7.40	7.25	7.75	136	2343	3430	55
II	77	BC-PS	CC-PS	R-MT	HS-US	6.50	7.40	6.33	7.20	134	2367	3413	59
II	78	BC-MT	CC-PS	R-PS	HS-US	6.67	7.40	6.33	6.33	136	2377	3339	74
II	79	BC-US	CC-K	R-GC	HS-MT	5.60	6.60	6.50	6.80	138	2378	3185	105
II	80	BC-US	CC-GC	R-GC	HS-MT	7.00	7.50	6.80	6.80	134	2359	3501	41
II	81	BC-PS	CC-PS	R-US	HS-MT	6.50	7.40	6.25	7.20	134	2372	3440	54
II	82	BC-PS	CC-GC	R-MT	HS-US	7.00	7.50	6.60	6.75	134	2383	3455	51
II	83	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	6.20	7.20	136	2377	3461	50
II	84	BC-PS	CC-PS	R-US	HS-MT	6.50	6.80	6.80	7.20	132	2344	3441	54
II	85	BC-MT	CC-GC	R-PS	HS-US	6.40	7.50	6.67	6.75	136	2374	3382	66
II	86	BC-MT	CC-PS	R-PS	HS-US	5.50	7.40	6.67	7.75	138	2372	3341	74
II	87	BC-PS	CC-GC	R-US	HS-MT	5.75	7.50	7.20	7.20	134	2369	3482	45
II	88	BC-MT	CC-PS	R-US	HS-NS	6.40	7.40	6.80	7.25	138	2382	3431	56
II	89	BC-PS	CC-GC	R-US	HS-MT	7.40	7.00	6.80	6.80	132	2365	3482	45
II	90	BC-US	CC-PS	R-PS	HS-MT	7.33	6.80	6.33	6.40	134	2369	3370	68
II	91	BC-PS	CC-PS	R-MT	HS-US	5.20	7.40	7.20	7.20	136	2382	3415	59
II	92	BC-PS	CC-GC	R-US	HS-MT	6.20	7.50	6.80	7.20	134	2374	3483	45
II	93	BC-US	CC-PS	R-PS	HS-MT	6.33	6.80	6.33	7.20	136	2379	3370	68
II	94	BC-MT	CC-PS	R-GC	HS-US	6.40	6.80	6.50	7.75	136	2364	3434	55
II	95	BC-GC	CC-PS	R-MT	HS-US	7.00	6.80	6.60	7.20	134	2374	3444	53
II	96	BC-MT	CC-K	R-GC	HS-US	6.20	6.60	6.20	6.33	138	2383	3160	110
II	97	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	6.60	6.75	134	2372	3445	53
II	98	BC-GC	CC-PS	R-US	HS-MT	7.50	7.40	6.25	6.80	134	2382	3471	48
II	99	BC-GC	CC-PS	R-US	HS-MT	7.50	6.80	6.80	6.80	132	2354	3472	48
II	100	BC-MT	CC-GC	R-GC	HS-US	6.40	7.00	6.80	7.75	136	2370	3476	47

Table B.39: Current Path Solutions (Phase III Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-MT	CC-PS	R-GC	HS-US	5.80	6.60	6.40	7.00	154	2675	3191	55
III	2	BC-MT	CC-PS	R-GC	HS-US	5.80	7.20	6.40	6.60	154	2673	3199	55
III	3	BC-US	CC-PS	R-GC	HS-MT	6.20	6.60	6.40	6.60	152	2665	3228	50
III	4	BC-MT	CC-PS	R-GC	HS-US	5.60	6.60	6.40	7.40	154	2665	3209	55
III	5	BC-US	CC-PS	R-GC	HS-MT	5.50	7.75	6.40	6.60	154	2672	3247	50
III	6	BC-MT	CC-PS	R-GC	HS-US	6.25	6.60	6.40	6.60	152	2655	3220	55
III	7	BC-US	CC-PS	R-GC	HS-MT	6.50	6.60	6.20	6.60	152	2670	3256	50
III	8	BC-MT	CC-PS	R-GC	HS-US	6.00	6.60	6.40	7.00	152	2645	3229	55
III	9	BC-MT	CC-PS	R-GC	HS-US	5.80	6.60	6.20	7.40	154	2670	3231	55
III	10	BC-MT	CC-GC	R-PS	HS-US	5.60	6.67	6.67	7.00	154	2676	3181	66
III	11	BC-US	CC-PS	R-GC	HS-MT	5.50	7.20	6.40	7.00	154	2673	3262	50
III	12	BC-US	CC-PS	R-GC	HS-MT	6.75	6.60	5.80	6.60	152	2675	3262	50
III	13	BC-US	CC-PS	R-GC	HS-MT	5.33	7.20	6.75	7.00	154	2668	3264	50
III	14	BC-MT	CC-PS	R-GC	HS-US	6.00	6.60	5.80	7.40	154	2675	3239	55
III	15	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	6.60	7.00	150	2661	3291	45
III	16	BC-GC	CC-PS	R-MT	HS-US	5.60	6.60	6.60	7.00	152	2675	3252	53
III	17	BC-US	CC-PS	R-GC	HS-MT	6.00	6.60	6.40	7.00	152	2655	3271	50
III	18	BC-US	CC-PS	R-GC	HS-MT	5.50	6.60	6.40	7.40	154	2675	3271	50
III	19	BC-MT	CC-PS	R-GC	HS-US	6.00	7.20	5.80	7.00	154	2673	3247	55
III	20	BC-US	CC-PS	R-GC	HS-MT	6.75	7.20	5.80	6.33	152	2673	3277	50
III	21	BC-MT	CC-PS	R-GC	HS-US	6.00	7.75	5.80	6.60	154	2672	3249	55
III	22	BC-MT	CC-GC	R-PS	HS-US	5.40	6.67	6.67	7.40	154	2666	3198	66
III	23	BC-GC	CC-PS	R-MT	HS-US	5.60	7.20	6.60	6.60	152	2673	3260	53
III	24	BC-PS	CC-GC	R-MT	HS-US	5.20	6.67	6.60	7.40	152	2676	3273	51
III	25	BC-PS	CC-GC	R-MT	HS-US	5.20	7.20	6.60	7.00	152	2675	3273	51
III	26	BC-MT	CC-PS	R-GC	HS-US	6.75	6.60	6.20	6.25	152	2670	3250	55
III	27	BC-PS	CC-GC	R-MT	HS-US	5.75	6.67	6.60	7.00	150	2656	3274	51
III	28	BC-MT	CC-PS	R-GC	HS-US	6.50	6.60	6.20	6.60	152	2660	3252	55
III	29	BC-US	CC-GC	R-PS	HS-MT	6.20	6.67	6.33	6.60	152	2671	3230	60
III	30	BC-PS	CC-GC	R-MT	HS-US	5.20	7.75	6.60	6.60	152	2673	3275	51
III	31	BC-MT	CC-PS	R-GC	HS-US	6.75	6.20	6.20	6.60	152	2671	3257	55
III	32	BC-US	CC-PS	R-GC	HS-MT	6.50	6.20	6.20	7.00	152	2671	3286	50
III	33	BC-GC	CC-PS	R-US	HS-MT	5.40	7.75	6.60	6.60	152	2667	3296	48
III	34	BC-MT	CC-GC	R-PS	HS-US	5.60	6.67	6.33	7.40	154	2671	3211	66
III	35	BC-MT	CC-GC	R-PS	HS-US	5.60	7.20	6.33	7.00	154	2670	3212	66
III	36	BC-US	CC-PS	R-GC	HS-MT	6.75	6.20	5.80	7.00	152	2676	3293	50
III	37	BC-MT	CC-PS	R-GC	HS-US	5.80	7.20	5.80	7.40	154	2663	3264	55
III	38	BC-GC	CC-PS	R-US	HS-MT	5.60	7.20	6.33	7.00	152	2673	3301	48
III	39	BC-MT	CC-PS	R-GC	HS-US	6.50	6.20	6.20	7.00	152	2661	3265	55
III	40	BC-GC	CC-PS	R-MT	HS-US	5.60	6.60	6.40	7.40	152	2670	3275	53
III	41	BC-PS	CC-GC	R-US	HS-MT	5.00	7.20	7.00	7.00	152	2675	3315	45
III	42	BC-US	CC-PS	R-GC	HS-MT	7.00	7.75	5.60	6.00	152	2677	3295	50
III	43	BC-PS	CC-GC	R-US	HS-MT	5.20	7.75	6.33	7.00	152	2673	3317	45
III	44	BC-MT	CC-PS	R-GC	HS-US	6.75	6.60	5.80	6.60	152	2665	3269	55
III	45	BC-US	CC-PS	R-GC	HS-MT	7.75	6.60	5.80	6.00	150	2665	3298	50
III	46	BC-US	CC-PS	R-GC	HS-MT	7.33	6.60	5.80	6.33	150	2655	3298	50
III	47	BC-US	CC-PS	R-GC	HS-MT	7.00	6.60	5.80	6.60	150	2645	3298	50
III	48	BC-US	CC-PS	R-GC	HS-MT	6.50	6.60	5.80	7.00	152	2665	3298	50
III	49	BC-US	CC-GC	R-PS	HS-MT	6.50	6.67	6.00	6.60	152	2676	3248	60
III	50	BC-PS	CC-GC	R-MT	HS-US	5.50	7.20	6.20	7.40	152	2675	3296	51

Table B.40: Current Path Solutions (Phase III Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-MT	CC-GC	R-PS	HS-US	6.25	6.67	6.33	6.60	152	2661	3222	66
III	52	BC-MT	CC-PS	R-GC	HS-US	6.25	6.20	6.20	7.40	152	2651	3274	55
III	53	BC-PS	CC-GC	R-MT	HS-US	5.20	7.20	6.40	7.40	152	2670	3297	51
III	54	BC-GC	CC-PS	R-US	HS-MT	5.60	6.60	6.33	7.40	152	2675	3310	48
III	55	BC-GC	CC-PS	R-US	HS-MT	5.40	7.20	6.60	7.00	152	2668	3311	48
III	56	BC-MT	CC-GC	R-PS	HS-US	5.80	6.67	6.00	7.40	154	2676	3224	66
III	57	BC-MT	CC-GC	R-PS	HS-US	5.80	7.20	6.00	7.00	154	2675	3224	66
III	58	BC-US	CC-PS	R-GC	HS-MT	7.33	6.20	5.80	6.60	150	2656	3305	50
III	59	BC-PS	CC-GC	R-MT	HS-US	5.20	7.75	6.40	7.00	152	2668	3299	51
III	60	BC-GC	CC-PS	R-MT	HS-US	5.40	6.60	6.60	7.40	152	2665	3286	53
III	61	BC-MT	CC-PS	R-GC	HS-US	6.50	6.60	5.80	7.00	152	2655	3277	55
III	62	BC-PS	CC-GC	R-US	HS-MT	5.00	7.75	6.60	7.00	152	2668	3327	45
III	63	BC-MT	CC-GC	R-PS	HS-US	5.80	7.75	6.00	6.60	154	2673	3226	66
III	64	BC-US	CC-GC	R-PS	HS-MT	6.50	7.20	6.00	6.33	152	2675	3256	60
III	65	BC-US	CC-GC	R-PS	HS-MT	5.33	7.20	6.67	7.00	154	2675	3257	60
III	66	BC-MT	CC-GC	R-PS	HS-US	5.40	7.20	6.33	7.40	154	2660	3229	66
III	67	BC-MT	CC-PS	R-GC	HS-US	6.25	7.75	5.60	6.60	154	2677	3280	55
III	68	BC-US	CC-PS	R-GC	HS-MT	5.33	7.20	6.40	7.40	154	2663	3309	50
III	69	BC-PS	CC-GC	R-MT	HS-US	5.50	6.67	6.60	7.40	150	2646	3303	51
III	70	BC-US	CC-PS	R-GC	HS-MT	6.75	7.20	5.60	6.60	152	2668	3310	50
III	71	BC-MT	CC-PS	R-US	HS-GC	5.40	6.60	6.60	7.50	156	2670	3164	79
III	72	BC-US	CC-PS	R-GC	HS-MT	5.75	7.75	5.80	7.00	154	2672	3310	50
III	73	BC-MT	CC-GC	R-PS	HS-US	6.00	6.67	6.33	7.00	152	2651	3231	66
III	74	BC-PS	CC-GC	R-US	HS-MT	5.20	7.20	6.33	7.40	152	2675	3331	45
III	75	BC-MT	CC-PS	R-GC	HS-US	6.75	6.20	5.80	7.00	152	2666	3282	55
III	76	BC-US	CC-GC	R-PS	HS-MT	7.33	6.67	6.00	6.00	150	2666	3260	60
III	77	BC-US	CC-GC	R-PS	HS-MT	6.20	7.20	6.00	6.60	152	2665	3261	60
III	78	BC-MT	CC-PS	R-GC	HS-US	6.75	7.20	5.80	6.25	152	2663	3283	55
III	79	BC-GC	CC-PS	R-US	HS-MT	5.40	6.60	6.60	7.40	152	2670	3320	48
III	80	BC-GC	CC-PS	R-MT	HS-US	5.40	7.20	6.60	7.00	152	2663	3294	53
III	81	BC-PS	CC-GC	R-MT	HS-US	5.00	7.20	6.60	7.40	152	2665	3307	51
III	82	BC-MT	CC-PS	R-GC	HS-US	6.25	6.60	5.80	7.40	152	2645	3285	55
III	83	BC-GC	CC-PS	R-MT	HS-US	5.40	7.75	6.60	6.60	152	2662	3296	53
III	84	BC-US	CC-PS	R-GC	HS-MT	6.20	6.20	6.20	7.40	152	2661	3315	50
III	85	BC-MT	CC-PS	R-GC	HS-US	6.00	7.20	5.60	7.40	154	2668	3287	55
III	86	BC-PS	CC-GC	R-MT	HS-US	5.00	7.75	6.60	7.00	152	2663	3310	51
III	87	BC-US	CC-PS	R-GC	HS-MT	7.75	6.20	5.80	6.33	150	2666	3316	50
III	88	BC-MT	CC-PS	R-US	HS-GC	5.60	6.60	6.33	7.50	156	2675	3170	79
III	89	BC-PS	CC-GC	R-US	HS-MT	5.50	6.67	6.60	7.40	150	2651	3337	45
III	90	BC-MT	CC-PS	R-GC	HS-US	6.00	7.75	5.60	7.00	154	2667	3289	55
III	91	BC-US	CC-PS	R-GC	HS-MT	5.50	7.20	6.20	7.40	154	2668	3319	50
III	92	BC-PS	CC-US	R-GC	HS-MT	5.20	7.20	6.75	7.00	150	2676	3326	48
III	93	BC-MT	CC-PS	R-GC	HS-US	6.50	6.20	5.80	7.40	152	2656	3290	55
III	94	BC-US	CC-PS	R-GC	HS-MT	6.75	6.60	5.60	7.00	152	2670	3319	50
III	95	BC-PS	CC-GC	R-US	HS-MT	5.00	7.20	6.60	7.40	152	2670	3341	45
III	96	BC-PS	CC-GC	R-MT	HS-US	5.00	7.20	7.00	7.00	152	2670	3315	51
III	97	BC-MT	CC-GC	R-PS	HS-US	5.60	7.20	6.00	7.40	154	2665	3242	66
III	98	BC-MT	CC-GC	R-PS	HS-US	6.75	6.20	6.00	6.60	152	2677	3242	66
III	99	BC-US	CC-GC	R-PS	HS-MT	7.75	6.20	6.00	6.00	150	2677	3271	60
III	100	BC-MT	CC-GC	R-PS	HS-US	6.75	6.67	6.00	6.25	152	2676	3243	66

Table B.41: Current Path Solutions (Phase IV Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.67	5.75	172	3067	2845	45
IV	2	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	5.50	5.50	172	3070	2848	45
IV	3	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	5.50	5.75	172	3071	2852	45
IV	4	BC-PS	CC-GC	R-US	HS-MT	6.50	6.20	5.25	5.25	172	3085	2852	45
IV	5	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	5.50	5.50	172	3070	2839	48
IV	6	BC-PS	CC-GC	R-US	HS-MT	6.50	5.50	5.50	5.50	172	3092	2853	45
IV	7	BC-PS	CC-GC	R-US	HS-MT	6.20	5.80	5.50	5.50	172	3081	2853	45
IV	8	BC-GC	CC-PS	R-US	HS-MT	5.60	5.67	5.67	5.75	172	3055	2841	48
IV	9	BC-PS	CC-GC	R-US	HS-MT	6.50	5.80	5.25	5.50	172	3086	2855	45
IV	10	BC-PS	CC-GC	R-US	HS-MT	5.20	6.20	5.67	5.75	172	3055	2856	45
IV	11	BC-PS	CC-GC	R-MT	HS-US	5.75	5.80	5.50	5.67	172	3067	2830	51
IV	12	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	6.00	172	3057	2859	45
IV	13	BC-GC	CC-PS	R-US	HS-MT	7.00	5.67	5.25	5.25	172	3085	2848	48
IV	14	BC-PS	CC-GC	R-US	HS-MT	7.00	5.80	5.25	5.25	172	3096	2862	45
IV	15	BC-GC	CC-PS	R-US	HS-MT	6.60	5.67	5.25	5.50	172	3075	2852	48
IV	16	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	5.25	5.75	172	3065	2864	45
IV	17	BC-PS	CC-GC	R-US	HS-MT	7.33	5.50	5.25	5.25	172	3107	2865	45
IV	18	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	5.50	6.00	172	3073	2865	45
IV	19	BC-PS	CC-GC	R-US	HS-MT	6.20	6.20	5.25	5.50	172	3075	2866	45
IV	20	BC-PS	CC-US	R-GC	HS-MT	5.75	5.67	5.60	5.75	172	3115	2852	48
IV	21	BC-GC	CC-GC	R-US	HS-MT	6.60	5.80	5.50	5.50	172	3081	2894	40
IV	22	BC-GC	CC-GC	R-US	HS-MT	6.20	6.20	5.50	5.50	172	3070	2894	40
IV	23	BC-PS	CC-GC	R-US	HS-MT	6.20	5.50	5.50	5.75	172	3083	2867	45
IV	24	BC-GC	CC-PS	R-US	HS-MT	7.40	5.33	5.25	5.25	172	3096	2854	48
IV	25	BC-PS	CC-GC	R-US	HS-MT	5.50	6.20	5.50	5.75	172	3060	2867	45
IV	26	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	5.25	6.00	172	3067	2868	45
IV	27	BC-PS	CC-GC	R-US	HS-MT	5.75	6.67	5.25	5.50	172	3064	2868	45
IV	28	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	5.25	5.75	172	3065	2855	48
IV	29	BC-GC	CC-GC	R-US	HS-MT	6.00	5.80	5.67	5.75	172	3067	2896	40
IV	30	BC-GC	CC-GC	R-US	HS-MT	5.60	6.20	5.67	5.75	172	3055	2897	40
IV	31	BC-PS	CC-GC	R-US	HS-MT	6.50	5.50	5.25	5.75	172	3087	2869	45
IV	32	BC-PS	CC-GC	R-US	HS-MT	6.20	5.80	5.25	5.75	172	3076	2869	45
IV	33	BC-PS	CC-GC	R-US	HS-MT	6.20	6.67	5.25	5.25	172	3074	2869	45
IV	34	BC-GC	CC-GC	R-US	HS-MT	6.20	5.80	5.50	5.75	172	3071	2898	40
IV	35	BC-PS	CC-GC	R-MT	HS-US	6.50	5.80	5.33	5.40	172	3081	2844	51
IV	36	BC-PS	CC-GC	R-MT	HS-US	5.75	5.50	5.50	6.00	172	3068	2844	51
IV	37	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	5.67	5.75	170	3037	2871	45
IV	38	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.50	6.00	172	3062	2871	45
IV	39	BC-PS	CC-GC	R-US	HS-MT	5.50	6.67	5.50	5.50	172	3059	2871	45
IV	40	BC-GC	CC-PS	R-US	HS-MT	7.00	5.33	5.25	5.50	172	3086	2858	48
IV	41	BC-PS	CC-GC	R-MT	HS-US	6.20	5.50	5.50	5.67	172	3078	2845	51
IV	42	BC-PS	CC-GC	R-MT	HS-US	5.75	6.20	5.33	5.67	172	3060	2845	51
IV	43	BC-PS	CC-GC	R-MT	HS-US	5.50	6.20	5.50	5.67	172	3055	2845	51
IV	44	BC-GC	CC-GC	R-US	HS-MT	5.60	5.80	5.67	6.00	172	3057	2900	40
IV	45	BC-US	CC-GC	R-GC	HS-MT	5.50	5.80	5.80	6.00	172	3022	2893	41
IV	46	BC-GC	CC-GC	R-MT	HS-US	6.20	5.80	5.50	5.67	172	3067	2876	45
IV	47	BC-GC	CC-PS	R-US	HS-MT	6.60	5.33	5.25	5.75	172	3076	2862	48
IV	48	BC-GC	CC-GC	R-US	HS-MT	7.40	5.80	5.25	5.25	172	3096	2903	40
IV	49	BC-GC	CC-PS	R-US	HS-MT	6.60	6.20	5.25	5.25	172	3074	2862	48
IV	50	BC-GC	CC-PS	R-MT	HS-US	6.20	5.67	5.33	5.67	172	3060	2836	53

Table B.42: Current Path Solutions (Phase IV Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-GC	CC-GC	R-US	HS-MT	7.00	6.20	5.25	5.25	172	3085	2903	40
IV	52	BC-GC	CC-PS	R-US	HS-MT	6.20	6.60	5.25	5.25	172	3063	2863	48
IV	53	BC-PS	CC-GC	R-US	HS-MT	7.00	5.50	5.25	5.50	172	3097	2875	45
IV	54	BC-PS	CC-GC	R-MT	HS-US	5.75	5.80	5.33	6.00	172	3062	2849	51
IV	55	BC-US	CC-PS	R-GC	HS-MT	6.20	5.67	5.33	5.50	172	3041	2855	50
IV	56	BC-US	CC-PS	R-GC	HS-MT	5.75	5.67	5.60	5.75	172	3026	2855	50
IV	57	BC-PS	CC-GC	R-MT	HS-US	6.50	5.50	5.33	5.67	172	3083	2849	51
IV	58	BC-PS	CC-GC	R-MT	HS-US	5.50	5.80	5.50	6.00	172	3057	2850	51
IV	59	BC-GC	CC-GC	R-US	HS-MT	7.00	5.50	5.50	5.50	172	3092	2904	40
IV	60	BC-PS	CC-GC	R-MT	HS-US	6.20	5.80	5.33	5.67	172	3071	2850	51
IV	61	BC-GC	CC-PS	R-US	HS-MT	6.00	5.67	5.50	5.75	172	3060	2863	48
IV	62	BC-PS	CC-US	R-GC	HS-MT	5.75	6.20	5.33	5.50	172	3107	2864	48
IV	63	BC-PS	CC-GC	R-US	HS-MT	5.75	7.20	5.25	5.25	172	3063	2879	45
IV	64	BC-GC	CC-PS	R-US	HS-MT	6.20	5.33	5.25	6.00	172	3067	2866	48
IV	65	BC-PS	CC-US	R-GC	HS-MT	6.50	5.67	5.33	5.50	172	3130	2864	48
IV	66	BC-GC	CC-PS	R-US	HS-MT	5.40	5.67	5.67	6.00	172	3046	2866	48
IV	67	BC-GC	CC-GC	R-US	HS-MT	7.00	5.80	5.25	5.50	172	3086	2907	40
IV	68	BC-PS	CC-GC	R-MT	HS-US	5.75	5.50	5.33	6.25	172	3063	2852	51
IV	69	BC-GC	CC-PS	R-US	HS-MT	6.20	6.20	5.25	5.50	172	3064	2866	48
IV	70	BC-GC	CC-GC	R-US	HS-MT	6.60	6.20	5.25	5.50	172	3075	2907	40
IV	71	BC-PS	CC-GC	R-MT	HS-US	5.50	5.50	5.50	6.25	172	3058	2853	51
IV	72	BC-PS	CC-GC	R-MT	HS-US	5.20	5.80	5.50	6.25	172	3047	2853	51
IV	73	BC-GC	CC-PS	R-MT	HS-US	6.60	5.67	5.33	5.40	172	3070	2840	53
IV	74	BC-GC	CC-GC	R-US	HS-MT	6.60	5.50	5.50	5.75	172	3083	2908	40
IV	75	BC-PS	CC-GC	R-US	HS-MT	5.00	6.20	5.67	6.00	172	3046	2880	45
IV	76	BC-GC	CC-PS	R-US	HS-MT	5.60	5.67	5.50	6.00	172	3051	2867	48
IV	77	BC-GC	CC-PS	R-MT	HS-US	6.00	5.67	5.50	5.67	172	3055	2841	53
IV	78	BC-PS	CC-GC	R-MT	HS-US	6.20	6.20	5.33	5.40	172	3070	2855	51
IV	79	BC-PS	CC-GC	R-US	HS-MT	5.20	6.20	5.50	6.00	172	3051	2881	45
IV	80	BC-GC	CC-PS	R-MT	HS-US	6.60	5.33	5.33	5.67	172	3071	2842	53
IV	81	BC-GC	CC-GC	R-US	HS-MT	6.60	5.80	5.25	5.75	172	3076	2910	40
IV	82	BC-GC	CC-GC	R-US	HS-MT	6.60	6.67	5.25	5.25	172	3074	2910	40
IV	83	BC-GC	CC-GC	R-US	HS-MT	6.20	6.20	5.25	5.75	172	3065	2911	40
IV	84	BC-PS	CC-GC	R-US	HS-MT	6.20	5.50	5.25	6.00	172	3078	2883	45
IV	85	BC-PS	CC-GC	R-MT	HS-US	5.75	6.67	5.33	5.40	172	3059	2857	51
IV	86	BC-PS	CC-GC	R-US	HS-MT	5.00	6.67	5.67	5.75	172	3044	2883	45
IV	87	BC-GC	CC-GC	R-US	HS-MT	6.20	5.50	5.50	6.00	172	3073	2912	40
IV	88	BC-PS	CC-GC	R-US	HS-MT	5.50	6.20	5.25	6.00	172	3055	2884	45
IV	89	BC-PS	CC-GC	R-US	HS-MT	6.50	5.80	5.50	5.50	170	3052	2884	45
IV	90	BC-PS	CC-GC	R-MT	HS-US	5.50	5.80	5.33	6.25	172	3052	2858	51
IV	91	BC-US	CC-PS	R-GC	HS-MT	6.50	5.33	5.33	5.50	172	3052	2864	50
IV	92	BC-GC	CC-US	R-GC	HS-MT	6.20	5.67	5.60	5.75	172	3115	2898	43
IV	93	BC-GC	CC-GC	R-MT	HS-US	6.60	5.50	5.50	5.67	172	3078	2886	45
IV	94	BC-PS	CC-GC	R-MT	HS-US	5.20	5.80	5.75	6.00	172	3052	2858	51
IV	95	BC-US	CC-GC	R-GC	HS-MT	6.00	5.80	5.60	5.75	172	3037	2905	41
IV	96	BC-US	CC-PS	R-GC	HS-MT	5.50	5.67	5.60	6.00	172	3016	2864	50
IV	97	BC-PS	CC-US	R-GC	HS-MT	6.50	5.40	5.33	5.75	172	3131	2871	48
IV	98	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	5.50	5.75	172	3049	2885	45
IV	99	BC-PS	CC-US	R-GC	HS-MT	5.50	5.67	5.60	6.00	172	3105	2871	48
IV	100	BC-GC	CC-PS	R-MT	HS-US	5.60	5.67	5.50	6.00	172	3046	2846	53

B.7 Path A

As discussed earlier, analysis of solutions with partial restrictions on single-car services suggests that these restrictions do not result in severe degradation of LOS, especially relative to a full prohibition. The following solutions limit the use of single-car trains to one route while also introducing constraints that result in branch headways more similar to pre-pandemic operations.

The solutions below include the following constraints in addition to the core constraints:

- No more than one single-car service may be included in the solution.
- No more than 4 service patterns may be proposed.
- The headway of a two-car D branch service must be lower than or equal to the headway of a two-car C branch service.
- The headway of a two-car D branch service must be lower than or equal to the headway of a two-car E branch service.

The solutions that comprise "Path A," discussed in more detail in Chapter 5, come from the set of solutions generated from these constraints.

Table B.43: Path A Solutions (Phase I Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.25	4.67	117	2048	3237	50
I	2	BC-MT	CC-PS	R-GC	HS-US	4.60	7.40	7.25	7.75	116	2048	3217	55
I	3	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.25	5.25	118	2048	3246	50
I	4	BC-MT	CC-PS	R-GC	HS-US	4.67	7.40	7.25	7.75	115	2033	3229	55
I	5	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	7.25	4.80	116	2028	3261	50
I	6	BC-MT	CC-PS	R-GC	HS-US	5.33	7.40	6.80	7.20	115	2048	3245	55
I	7	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.25	116	2049	3295	45
I	8	BC-PS	CC-K	R-US	HS-MT	7.00	6.60	6.50	4.67	117	2049	2983	109
I	9	BC-US	CC-K	R-GC	HS-MT	6.33	7.60	7.25	4.33	119	2043	3007	105
I	10	BC-MT	CC-PS	R-GC	HS-US	4.80	7.40	7.25	7.75	114	2019	3254	55
I	11	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.25	5.20	117	2038	3285	50
I	12	BC-MT	CC-PS	R-GC	HS-US	5.33	6.80	6.80	7.75	115	2049	3258	55
I	13	BC-US	CC-K	R-GC	HS-MT	6.60	7.60	6.80	4.33	119	2048	3012	105
I	14	BC-MT	CC-PS	R-GC	HS-US	5.00	7.40	6.80	7.75	115	2038	3258	55
I	15	BC-US	CC-PS	R-GC	HS-MT	6.60	7.40	7.25	5.80	118	2038	3287	50
I	16	BC-MT	CC-GC	R-GC	HS-US	5.00	7.50	7.25	7.75	115	2044	3301	47
I	17	BC-GC	CC-PS	R-MT	HS-US	7.00	6.80	5.50	7.20	115	2047	3271	53
I	18	BC-PS	CC-GC	R-MT	HS-US	7.40	7.50	5.25	6.75	114	2044	3284	51
I	19	BC-PS	CC-K	R-US	HS-MT	6.50	7.60	7.20	4.00	117	2048	2996	109
I	20	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	7.25	5.50	117	2028	3291	50
I	21	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	5.50	6.75	115	2046	3272	53
I	22	BC-US	CC-PS	R-GC	HS-MT	7.67	6.80	6.80	5.50	117	2044	3291	50
I	23	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	7.25	5.25	116	2019	3294	50
I	24	BC-GC	CC-PS	R-MT	HS-US	7.50	7.40	4.80	7.20	115	2046	3275	53
I	25	BC-PS	CC-K	R-MT	HS-US	6.20	6.60	4.25	7.20	117	2052	2973	114
I	26	BC-GC	CC-PS	R-US	HS-MT	7.50	7.40	7.20	5.25	116	2043	3302	48
I	27	BC-PS	CC-K	R-US	HS-MT	6.20	7.60	7.50	4.00	117	2043	2999	109
I	28	BC-GC	CC-PS	R-MT	HS-US	7.50	6.80	5.20	7.20	115	2052	3276	53
I	29	BC-GC	CC-PS	R-MT	HS-US	7.50	7.40	5.20	6.75	115	2051	3276	53
I	30	BC-US	CC-K	R-GC	HS-MT	7.33	6.60	6.50	4.50	118	2044	3021	105
I	31	BC-US	CC-K	R-GC	HS-MT	6.60	7.60	7.25	4.20	118	2033	3021	105
I	32	BC-GC	CC-PS	R-MT	HS-US	6.20	7.40	5.67	7.20	116	2048	3278	53
I	33	BC-PS	CC-K	R-MT	HS-US	6.20	6.60	4.67	6.75	116	2039	2976	114
I	34	BC-GC	CC-GC	R-US	HS-MT	7.50	7.50	7.50	5.25	116	2049	3347	40
I	35	BC-PS	CC-GC	R-MT	HS-US	7.40	7.50	5.67	6.33	114	2049	3293	51
I	36	BC-PS	CC-GC	R-MT	HS-US	6.50	7.50	5.50	7.20	115	2047	3293	51
I	37	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	6.80	5.20	117	2043	3299	50
I	38	BC-PS	CC-GC	R-MT	HS-US	7.40	7.00	5.25	7.20	114	2046	3294	51
I	39	BC-US	CC-K	R-PS	HS-MT	6.60	6.60	6.33	4.67	119	2049	2934	123
I	40	BC-US	CC-GC	R-GC	HS-MT	7.67	7.50	7.25	5.20	117	2049	3343	41
I	41	BC-MT	CC-GC	R-PS	HS-US	5.00	7.50	7.20	7.20	115	2049	3223	66
I	42	BC-GC	CC-PS	R-MT	HS-US	7.50	6.80	5.25	7.20	114	2035	3284	53
I	43	BC-PS	CC-GC	R-MT	HS-US	7.00	7.50	5.20	7.20	115	2052	3297	51
I	44	BC-GC	CC-PS	R-MT	HS-US	7.50	7.40	5.25	6.75	114	2033	3284	53
I	45	BC-PS	CC-US	R-GC	HS-MT	7.40	7.75	7.75	4.80	114	2050	3310	48
I	46	BC-PS	CC-GC	R-MT	HS-US	7.40	7.00	5.67	6.75	114	2051	3298	51
I	47	BC-MT	CC-PS	R-GC	HS-US	5.50	7.40	6.80	7.20	114	2033	3276	55
I	48	BC-PS	CC-K	R-US	HS-MT	6.50	7.60	6.80	4.33	117	2043	3010	109
I	49	BC-GC	CC-K	R-MT	HS-US	6.20	6.60	4.50	7.20	117	2047	3012	108
I	50	BC-US	CC-PS	R-GC	HS-MT	7.33	7.40	6.80	5.50	117	2033	3305	50

Table B.44: Path A Solutions (Phase I Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	51	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	5.20	7.20	115	2041	3287	53
I	52	BC-PS	CC-MT	R-GC	HS-US	7.40	4.75	7.75	7.75	114	2047	3279	55
I	53	BC-GC	CC-PS	R-MT	HS-US	7.50	6.80	5.67	6.75	114	2040	3287	53
I	54	BC-GC	CC-PS	R-MT	HS-US	6.20	7.40	5.25	7.75	116	2043	3288	53
I	55	BC-PS	CC-GC	R-US	HS-MT	7.40	7.50	7.50	5.20	115	2040	3327	45
I	56	BC-GC	CC-PS	R-MT	HS-US	7.50	6.80	4.80	7.75	115	2047	3288	53
I	57	BC-GC	CC-K	R-MT	HS-US	6.60	6.60	4.25	7.20	117	2052	3014	108
I	58	BC-GC	CC-K	R-US	HS-MT	6.60	7.60	7.50	4.00	117	2043	3040	103
I	59	BC-MT	CC-K	R-GC	HS-US	4.20	6.60	6.50	7.75	117	2039	3004	110
I	60	BC-US	CC-GC	R-GC	HS-MT	7.33	7.50	7.25	5.50	117	2040	3349	41
I	61	BC-US	CC-K	R-GC	HS-MT	6.33	7.60	6.80	4.67	119	2038	3034	105
I	62	BC-GC	CC-PS	R-MT	HS-US	6.60	7.40	5.00	7.75	116	2048	3289	53
I	63	BC-US	CC-PS	R-GC	HS-MT	7.67	7.40	6.80	5.25	116	2023	3308	50
I	64	BC-GC	CC-PS	R-MT	HS-US	7.00	6.25	5.50	7.75	115	2048	3290	53
I	65	BC-GC	CC-PS	R-MT	HS-US	6.20	6.80	5.67	7.75	116	2049	3291	53
I	66	BC-PS	CC-GC	R-MT	HS-US	7.40	7.50	4.50	7.75	115	2052	3304	51
I	67	BC-US	CC-K	R-PS	HS-MT	6.33	7.60	7.20	4.00	119	2048	2943	123
I	68	BC-GC	CC-PS	R-MT	HS-US	7.50	6.25	5.67	7.20	114	2041	3292	53
I	69	BC-PS	CC-GC	R-MT	HS-US	7.00	7.50	5.25	7.20	114	2035	3305	51
I	70	BC-US	CC-GC	R-GC	HS-MT	7.67	7.50	7.25	5.25	116	2030	3352	41
I	71	BC-GC	CC-PS	R-MT	HS-US	7.50	7.40	5.67	6.33	114	2038	3293	53
I	72	BC-GC	CC-PS	R-MT	HS-US	6.60	7.40	5.50	7.20	115	2036	3293	53
I	73	BC-US	CC-PS	R-GC	HS-MT	7.00	7.40	6.80	5.80	118	2043	3312	50
I	74	BC-US	CC-K	R-GC	HS-MT	6.33	7.60	7.25	4.50	118	2023	3037	105
I	75	BC-MT	CC-K	R-PS	HS-US	4.20	6.60	6.33	7.20	117	2044	2917	129
I	76	BC-PS	CC-GC	R-MT	HS-US	7.40	7.50	5.00	7.20	114	2040	3307	51
I	77	BC-US	CC-K	R-GC	HS-MT	6.20	7.60	6.80	4.80	120	2048	3038	105
I	78	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	5.25	7.20	114	2023	3294	53
I	79	BC-PS	CC-GC	R-MT	HS-US	7.40	6.50	5.67	7.20	114	2052	3308	51
I	80	BC-GC	CC-K	R-US	HS-MT	7.00	7.60	7.20	4.00	117	2048	3047	103
I	81	BC-US	CC-GC	R-GC	HS-MT	7.00	7.50	7.25	5.80	118	2049	3355	41
I	82	BC-PS	CC-GC	R-MT	HS-US	7.00	7.50	5.67	6.75	114	2040	3309	51
I	83	BC-PS	CC-GC	R-MT	HS-US	7.00	7.50	4.80	7.75	115	2047	3310	51
I	84	BC-PS	CC-GC	R-US	HS-MT	7.40	7.50	7.50	5.25	114	2020	3336	45
I	85	BC-MT	CC-GC	R-PS	HS-US	4.67	7.50	7.20	7.75	115	2040	3236	66
I	86	BC-US	CC-K	R-GC	HS-MT	6.60	6.60	6.50	5.20	119	2044	3042	105
I	87	BC-GC	CC-PS	R-MT	HS-US	7.00	6.80	5.67	7.20	114	2030	3298	53
I	88	BC-US	CC-K	R-GC	HS-MT	6.60	7.60	6.80	4.50	118	2028	3042	105
I	89	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	5.67	6.75	114	2028	3298	53
I	90	BC-PS	CC-K	R-MT	HS-US	6.50	6.60	4.20	7.20	116	2039	2996	114
I	91	BC-MT	CC-PS	R-GC	HS-US	5.50	6.80	6.80	7.75	114	2035	3289	55
I	92	BC-US	CC-K	R-GC	HS-MT	7.00	7.60	7.25	4.00	117	2023	3043	105
I	93	BC-US	CC-K	R-GC	HS-MT	6.00	7.60	7.25	4.80	120	2043	3043	105
I	94	BC-GC	CC-PS	R-MT	HS-US	7.00	7.40	4.80	7.75	115	2036	3299	53
I	95	BC-MT	CC-GC	R-GC	HS-US	5.33	7.50	6.80	7.75	115	2049	3330	47
I	96	BC-GC	CC-K	R-MT	HS-US	6.20	6.00	4.50	7.75	117	2048	3025	108
I	97	BC-GC	CC-PS	R-MT	HS-US	7.00	6.80	5.20	7.75	115	2042	3300	53
I	98	BC-US	CC-GC	R-PS	HS-MT	7.67	7.50	7.20	4.80	116	2035	3268	60
I	99	BC-PS	CC-K	R-MT	HS-US	5.75	7.60	4.80	6.33	117	2050	2998	114
I	100	BC-PS	CC-GC	R-US	HS-MT	7.00	7.50	7.50	5.50	115	2030	3340	45

Table B.45: Path A Solutions (Phase II Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	1	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	6.50	4.00	135	2379	2756	54
II	2	BC-US	CC-PS	R-GC	HS-MT	6.00	6.80	6.80	4.00	137	2379	2783	50
II	3	BC-PS	CC-PS	R-US	HS-MT	5.50	6.80	6.80	4.00	135	2374	2764	54
II	4	BC-US	CC-PS	R-GC	HS-MT	5.60	6.80	6.80	4.33	137	2369	2786	50
II	5	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	6.80	4.50	138	2379	2787	50
II	6	BC-US	CC-PS	R-GC	HS-MT	5.60	7.40	6.80	4.00	137	2367	2788	50
II	7	BC-PS	CC-PS	R-US	HS-MT	5.20	6.80	6.80	4.20	136	2383	2769	54
II	8	BC-US	CC-PS	R-GC	HS-MT	6.20	6.80	6.50	4.00	137	2383	2790	50
II	9	BC-PS	CC-GC	R-US	HS-MT	5.75	7.00	6.80	4.00	135	2385	2811	45
II	10	BC-US	CC-GC	R-GC	HS-MT	5.60	7.50	7.25	4.00	137	2374	2832	41
II	11	BC-US	CC-PS	R-GC	HS-MT	5.40	7.40	7.25	4.00	137	2362	2793	50
II	12	BC-US	CC-PS	R-GC	HS-MT	5.60	6.80	6.50	4.50	138	2383	2794	50
II	13	BC-PS	CC-PS	R-US	HS-MT	6.20	6.80	6.25	4.00	135	2383	2773	54
II	14	BC-GC	CC-PS	R-US	HS-MT	6.20	6.80	6.50	4.00	135	2379	2802	48
II	15	BC-US	CC-PS	R-GC	HS-MT	5.40	7.40	6.80	4.20	138	2377	2795	50
II	16	BC-PS	CC-PS	R-US	HS-MT	6.20	6.25	6.25	4.33	135	2385	2776	54
II	17	BC-US	CC-GC	R-GC	HS-MT	5.40	7.50	7.25	4.20	138	2383	2839	41
II	18	BC-US	CC-PS	R-GC	HS-MT	5.20	7.40	7.25	4.20	138	2372	2800	50
II	19	BC-US	CC-PS	R-GC	HS-MT	5.60	7.40	6.50	4.20	138	2382	2802	50
II	20	BC-GC	CC-PS	R-US	HS-MT	5.60	6.80	6.80	4.20	136	2383	2811	48
II	21	BC-PS	CC-PS	R-US	HS-MT	6.50	6.25	6.25	4.20	134	2375	2783	54
II	22	BC-US	CC-PS	R-GC	HS-MT	6.60	6.25	6.20	4.20	136	2380	2804	50
II	23	BC-US	CC-PS	R-NS	HS-MT	5.60	7.40	7.20	4.20	138	2382	2854	40
II	24	BC-GC	CC-PS	R-US	HS-MT	6.60	6.80	6.25	4.00	135	2383	2814	48
II	25	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	6.25	4.33	135	2374	2787	54
II	26	BC-PS	CC-GC	R-US	HS-MT	5.75	7.50	6.50	4.00	135	2379	2828	45
II	27	BC-US	CC-PS	R-PS	HS-MT	5.60	6.80	6.67	4.00	137	2374	2716	68
II	28	BC-GC	CC-PS	R-US	HS-MT	6.00	6.80	6.80	4.00	135	2374	2816	48
II	29	BC-PS	CC-PS	R-US	HS-MT	5.50	6.25	6.25	4.80	136	2385	2788	54
II	30	BC-GC	CC-GC	R-US	HS-MT	6.20	7.00	6.80	4.00	135	2385	2857	40
II	31	BC-US	CC-PS	R-GC	HS-MT	6.33	6.80	6.50	4.00	135	2354	2809	50
II	32	BC-PS	CC-PS	R-US	HS-MT	5.20	6.80	6.50	4.50	136	2379	2789	54
II	33	BC-GC	CC-PS	R-US	HS-MT	6.60	6.25	6.25	4.33	135	2385	2817	48
II	34	BC-PS	CC-PS	R-US	HS-MT	5.75	7.40	6.25	4.00	135	2372	2789	54
II	35	BC-PS	CC-PS	R-US	HS-MT	5.75	6.25	6.25	4.67	135	2375	2790	54
II	36	BC-PS	CC-PS	R-US	HS-MT	5.50	6.80	6.50	4.33	135	2369	2790	54
II	37	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	6.80	4.00	133	2344	2790	54
II	38	BC-PS	CC-PS	R-MT	HS-US	5.75	5.80	4.50	6.33	133	2369	2764	59
II	39	BC-US	CC-GC	R-GC	HS-MT	6.33	7.00	6.80	4.00	135	2360	2852	41
II	40	BC-US	CC-GC	R-GC	HS-MT	6.60	6.50	6.50	4.20	136	2386	2852	41
II	41	BC-PS	CC-PS	R-MT	HS-US	5.50	5.80	4.67	6.33	134	2381	2765	59
II	42	BC-PS	CC-PS	R-MT	HS-US	6.20	5.80	4.50	6.00	133	2379	2765	59
II	43	BC-PS	CC-PS	R-US	HS-MT	5.50	6.80	6.25	4.50	136	2383	2791	54
II	44	BC-PS	CC-PS	R-MT	HS-US	5.75	6.25	4.50	6.00	133	2367	2765	59
II	45	BC-PS	CC-PS	R-US	HS-MT	5.75	6.80	6.50	4.20	134	2359	2792	54
II	46	BC-US	CC-PS	R-GC	HS-MT	6.20	6.80	6.80	4.00	135	2349	2812	50
II	47	BC-US	CC-PS	R-GC	HS-MT	5.20	6.80	6.80	4.80	138	2369	2812	50
II	48	BC-PS	CC-PS	R-MT	HS-US	5.75	5.80	4.80	6.00	133	2374	2765	59
II	49	BC-PS	CC-PS	R-MT	HS-US	5.50	6.25	4.67	6.00	134	2380	2766	59
II	50	BC-PS	CC-PS	R-MT	HS-US	6.20	6.25	4.50	5.67	133	2377	2766	59

Table B.46: Path A Solutions (Phase II Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-PS	CC-PS	R-US	HS-MT	5.50	7.40	6.50	4.00	135	2367	2792	54
II	52	BC-PS	CC-PS	R-MT	HS-US	6.20	5.80	4.80	5.67	133	2384	2766	59
II	53	BC-PS	CC-PS	R-MT	HS-US	5.75	6.25	4.80	5.67	133	2372	2766	59
II	54	BC-US	CC-PS	R-NS	HS-MT	6.33	6.80	6.40	4.33	137	2383	2861	40
II	55	BC-PS	CC-PS	R-US	HS-MT	5.20	6.80	6.80	4.33	135	2364	2793	54
II	56	BC-US	CC-GC	R-GC	HS-MT	6.00	7.50	6.80	4.00	137	2379	2856	41
II	57	BC-US	CC-PS	R-PS	HS-MT	5.40	6.80	6.67	4.20	138	2383	2723	68
II	58	BC-US	CC-PS	R-NS	HS-MT	6.33	6.80	6.75	4.20	136	2369	2863	40
II	59	BC-US	CC-PS	R-GC	HS-MT	5.60	6.80	6.80	4.50	136	2349	2816	50
II	60	BC-PS	CC-GC	R-US	HS-MT	5.75	7.00	6.50	4.33	135	2380	2836	45
II	61	BC-US	CC-PS	R-NS	HS-MT	6.33	7.40	6.40	4.00	137	2382	2864	40
II	62	BC-PS	CC-PS	R-US	HS-MT	5.20	7.40	6.80	4.00	135	2362	2796	54
II	63	BC-PS	CC-GC	R-US	HS-MT	5.50	7.50	6.80	4.00	135	2374	2837	45
II	64	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	6.80	4.67	137	2359	2817	50
II	65	BC-US	CC-PS	R-GC	HS-MT	6.33	6.80	5.80	4.33	137	2383	2817	50
II	66	BC-PS	CC-GC	R-US	HS-MT	6.50	6.50	6.50	4.20	134	2381	2838	45
II	67	BC-US	CC-GC	R-GC	HS-MT	5.60	7.50	6.80	4.33	137	2369	2858	41
II	68	BC-PS	CC-PS	R-US	HS-MT	5.20	7.40	6.50	4.20	136	2377	2797	54
II	69	BC-US	CC-PS	R-NS	HS-MT	6.60	6.80	6.75	4.00	135	2359	2866	40
II	70	BC-PS	CC-PS	R-MT	HS-US	5.50	5.80	5.00	6.00	134	2386	2771	59
II	71	BC-MT	CC-PS	R-GC	HS-US	4.40	6.25	6.20	6.33	133	2365	2789	55
II	72	BC-US	CC-PS	R-NS	HS-MT	5.60	6.80	6.75	4.80	138	2379	2866	40
II	73	BC-US	CC-PS	R-GC	HS-MT	5.40	6.80	6.50	4.80	138	2374	2819	50
II	74	BC-PS	CC-PS	R-US	HS-MT	7.00	6.25	6.25	4.00	133	2365	2799	54
II	75	BC-US	CC-GC	R-GC	HS-MT	5.40	7.50	6.80	4.50	138	2379	2860	41
II	76	BC-PS	CC-PS	R-MT	HS-US	5.50	6.25	5.00	5.67	134	2385	2772	59
II	77	BC-US	CC-PS	R-GC	HS-MT	6.00	6.80	6.80	4.20	136	2359	2819	50
II	78	BC-US	CC-PS	R-GC	HS-MT	5.40	7.40	6.80	4.33	137	2358	2819	50
II	79	BC-US	CC-PS	R-GC	HS-MT	6.33	6.25	6.20	4.50	136	2370	2819	50
II	80	BC-US	CC-PS	R-GC	HS-MT	6.33	7.40	5.80	4.00	137	2382	2820	50
II	81	BC-US	CC-PS	R-GC	HS-MT	6.33	6.25	5.80	4.67	137	2385	2820	50
II	82	BC-PS	CC-PS	R-US	HS-MT	5.50	7.40	6.25	4.20	136	2382	2800	54
II	83	BC-US	CC-PS	R-NS	HS-MT	6.20	6.80	6.75	4.33	137	2379	2868	40
II	84	BC-PS	CC-PS	R-US	HS-MT	5.50	6.80	6.80	4.20	134	2354	2800	54
II	85	BC-US	CC-PS	R-GC	HS-MT	5.20	7.40	6.80	4.50	138	2367	2821	50
II	86	BC-US	CC-GC	R-GC	HS-MT	5.40	7.00	6.80	4.80	138	2380	2862	41
II	87	BC-US	CC-PS	R-GC	HS-MT	6.00	6.80	6.50	4.33	137	2374	2821	50
II	88	BC-NS	CC-PS	R-US	HS-MT	6.20	6.80	6.80	4.20	136	2383	2872	39
II	89	BC-US	CC-PS	R-GC	HS-MT	5.60	7.40	7.25	4.00	135	2333	2821	50
II	90	BC-PS	CC-GC	R-US	HS-MT	5.20	7.50	6.80	4.20	136	2383	2842	45
II	91	BC-US	CC-GC	R-GC	HS-MT	6.20	7.50	6.50	4.00	137	2383	2862	41
II	92	BC-US	CC-GC	R-GC	HS-MT	5.40	7.50	7.25	4.33	137	2364	2863	41
II	93	BC-PS	CC-PS	R-US	HS-MT	6.20	6.80	6.50	4.00	133	2349	2802	54
II	94	BC-GC	CC-PS	R-US	HS-MT	5.60	6.80	6.50	4.50	136	2379	2830	48
II	95	BC-US	CC-PS	R-GC	HS-MT	6.33	6.80	6.20	4.20	136	2369	2823	50
II	96	BC-PS	CC-PS	R-MT	HS-US	6.50	5.80	4.67	5.67	132	2371	2776	59
II	97	BC-US	CC-PS	R-NS	HS-MT	6.20	7.40	6.75	4.00	137	2377	2870	40
II	98	BC-PS	CC-PS	R-MT	HS-US	6.20	6.25	4.80	5.40	133	2382	2776	59
II	99	BC-PS	CC-PS	R-US	HS-MT	5.00	6.80	6.80	4.50	136	2374	2803	54
II	100	BC-US	CC-GC	R-GC	HS-MT	6.00	7.00	6.80	4.33	137	2380	2864	41

Table B.47: Path A Solutions (Phase III Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-US	CC-PS	R-GC	HS-MT	5.33	6.60	6.40	4.00	154	2665	2638	50
III	2	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	6.33	4.00	152	2676	2666	45
III	3	BC-US	CC-PS	R-GC	HS-MT	5.50	6.60	6.20	4.00	154	2670	2647	50
III	4	BC-US	CC-PS	R-GC	HS-MT	5.75	6.60	5.80	4.00	154	2675	2653	50
III	5	BC-PS	CC-GC	R-US	HS-MT	5.00	6.67	6.60	4.00	152	2671	2676	45
III	6	BC-GC	CC-PS	R-US	HS-MT	5.40	6.60	6.33	4.00	152	2665	2680	48
III	7	BC-US	CC-PS	R-GC	HS-MT	6.20	6.20	5.80	4.00	152	2656	2676	50
III	8	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	6.60	4.00	150	2641	2697	45
III	9	BC-US	CC-PS	R-GC	HS-MT	5.50	7.20	5.80	4.00	154	2663	2679	50
III	10	BC-PS	CC-GC	R-US	HS-MT	5.00	7.20	6.33	4.00	152	2665	2701	45
III	11	BC-GC	CC-PS	R-US	HS-MT	5.20	6.60	6.60	4.00	152	2660	2690	48
III	12	BC-US	CC-PS	R-GC	HS-MT	6.75	5.67	5.60	4.00	152	2672	2685	50
III	13	BC-PS	CC-GC	R-US	HS-MT	4.75	7.20	6.60	4.00	152	2660	2706	45
III	14	BC-PS	CC-GC	R-US	HS-MT	5.20	7.20	6.20	4.00	152	2670	2706	45
III	15	BC-US	CC-GC	R-PS	HS-MT	5.50	6.67	6.00	4.00	154	2676	2639	60
III	16	BC-US	CC-GC	R-PS	HS-MT	5.33	6.67	6.33	4.00	154	2671	2640	60
III	17	BC-US	CC-GC	R-PS	HS-MT	5.20	6.67	6.67	4.00	154	2666	2645	60
III	18	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	5.33	4.00	152	2677	2701	50
III	19	BC-US	CC-PS	R-GC	HS-MT	6.50	6.20	5.60	4.00	152	2661	2704	50
III	20	BC-PS	CC-GC	R-US	HS-MT	4.75	7.75	6.33	4.00	152	2654	2733	45
III	21	BC-US	CC-GC	R-PS	HS-MT	6.00	6.20	6.00	4.00	152	2657	2662	60
III	22	BC-PS	CC-MT	R-GC	HS-US	5.50	4.33	6.20	6.25	150	2673	2686	55
III	23	BC-PS	CC-GC	R-US	HS-MT	4.60	7.20	7.00	4.00	152	2655	2736	45
III	24	BC-US	CC-PS	R-GC	HS-MT	6.00	7.20	5.33	4.00	154	2673	2717	50
III	25	BC-US	CC-GC	R-PS	HS-MT	6.20	6.20	5.67	4.00	152	2662	2666	60
III	26	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	6.75	7.00	151	2675	2690	55
III	27	BC-PS	CC-GC	R-US	HS-MT	4.40	7.20	7.20	4.00	152	2650	2739	45
III	28	BC-US	CC-GC	R-PS	HS-MT	6.50	5.80	5.67	4.00	152	2673	2668	60
III	29	BC-US	CC-PS	R-GC	HS-MT	6.75	6.20	5.33	4.00	152	2666	2720	50
III	30	BC-US	CC-PS	R-GC	HS-MT	7.00	5.67	5.60	4.00	150	2643	2721	50
III	31	BC-US	CC-GC	R-PS	HS-MT	5.50	7.20	5.67	4.00	154	2670	2670	60
III	32	BC-PS	CC-MT	R-GC	HS-US	5.20	4.20	6.40	6.60	149	2650	2693	55
III	33	BC-US	CC-GC	R-PS	HS-MT	5.33	7.20	6.00	4.00	154	2665	2670	60
III	34	BC-GC	CC-PS	R-US	HS-MT	4.75	7.75	6.33	4.00	154	2672	2733	48
III	35	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	6.40	6.60	150	2659	2698	55
III	36	BC-US	CC-PS	R-GC	HS-MT	6.50	6.60	5.33	4.00	152	2655	2726	50
III	37	BC-PS	CC-GC	R-US	HS-MT	4.60	7.75	6.60	4.00	152	2649	2748	45
III	38	BC-GC	CC-PS	R-US	HS-MT	4.60	7.20	7.00	4.00	154	2673	2736	48
III	39	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.40	7.00	151	2669	2702	55
III	40	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	6.20	6.60	150	2664	2704	55
III	41	BC-GC	CC-PS	R-US	HS-MT	4.40	7.20	7.20	4.00	154	2668	2739	48
III	42	BC-PS	CC-GC	R-US	HS-MT	4.75	7.20	7.00	4.00	150	2625	2752	45
III	43	BC-PS	CC-GC	R-US	HS-MT	4.20	7.75	7.00	4.00	154	2673	2752	45
III	44	BC-US	CC-GC	R-PS	HS-MT	4.67	7.75	6.67	4.00	156	2673	2681	60
III	45	BC-PS	CC-MT	R-GC	HS-US	5.50	4.33	5.80	6.60	150	2669	2705	55
III	46	BC-PS	CC-US	R-GC	HS-MT	5.00	7.20	6.40	4.00	150	2661	2741	48
III	47	BC-PS	CC-US	R-GC	HS-MT	4.75	7.20	6.75	4.00	150	2656	2741	48
III	48	BC-MT	CC-PS	R-GC	HS-US	5.40	6.60	6.40	4.00	154	2655	2707	55
III	49	BC-US	CC-GC	R-PS	HS-MT	5.75	7.20	5.40	4.00	154	2675	2686	60
III	50	BC-US	CC-GC	R-PS	HS-MT	6.00	6.67	5.67	4.00	152	2651	2686	60

Table B.48: Path A Solutions (Phase III Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-PS	CC-GC	R-US	HS-MT	4.60	7.20	7.20	4.00	150	2621	2759	45
III	52	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	6.75	7.00	151	2664	2712	55
III	53	BC-GC	CC-PS	R-US	HS-MT	4.60	7.75	6.60	4.00	154	2667	2748	48
III	54	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	6.20	7.00	151	2674	2713	55
III	55	BC-US	CC-GC	R-PS	HS-MT	6.50	6.20	5.40	4.00	152	2667	2689	60
III	56	BC-PS	CC-US	R-GC	HS-MT	5.20	7.20	6.20	4.00	150	2666	2747	48
III	57	BC-PS	CC-US	R-GC	HS-MT	5.50	7.20	5.80	4.00	150	2671	2748	48
III	58	BC-PS	CC-MT	R-GC	HS-US	5.75	4.33	5.60	6.60	150	2673	2716	55
III	59	BC-PS	CC-MT	R-GC	HS-US	4.40	4.33	6.75	7.00	152	2673	2717	55
III	60	BC-GC	CC-PS	R-US	HS-MT	4.75	7.20	7.00	4.00	152	2644	2752	48
III	61	BC-US	CC-GC	R-PS	HS-MT	6.20	6.67	5.40	4.00	152	2656	2695	60
III	62	BC-US	CC-PS	R-GC	HS-MT	7.00	6.20	5.20	4.00	152	2671	2746	50
III	63	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	6.40	7.40	151	2670	2719	55
III	64	BC-GC	CC-GC	R-US	HS-MT	4.40	7.75	7.20	4.00	154	2668	2796	40
III	65	BC-US	CC-PS	R-GC	HS-MT	7.33	5.67	5.33	4.00	150	2648	2749	50
III	66	BC-GC	CC-PS	R-US	HS-MT	4.60	7.20	7.20	4.00	152	2639	2759	48
III	67	BC-PS	CC-GC	R-US	HS-MT	4.40	7.75	7.00	4.00	152	2644	2773	45
III	68	BC-PS	CC-US	R-GC	HS-MT	4.60	7.20	7.20	4.00	150	2651	2759	48
III	69	BC-MT	CC-PS	R-GC	HS-US	5.80	6.20	6.20	4.00	154	2671	2725	55
III	70	BC-US	CC-GC	R-PS	HS-MT	5.33	7.75	5.67	4.00	154	2659	2703	60
III	71	BC-PS	CC-MT	R-GC	HS-US	4.75	4.33	6.40	7.00	150	2649	2727	55
III	72	BC-US	CC-GC	R-PS	HS-MT	6.75	5.80	5.67	4.00	150	2644	2703	60
III	73	BC-PS	CC-GC	R-US	HS-MT	4.20	7.75	7.20	4.00	152	2639	2775	45
III	74	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	6.40	7.00	149	2640	2728	55
III	75	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.75	7.00	149	2635	2728	55
III	76	BC-PS	CC-MT	R-GC	HS-US	5.20	4.33	5.80	7.00	150	2659	2729	55
III	77	BC-PS	CC-MT	R-GC	HS-US	4.60	4.00	6.75	7.40	151	2666	2730	55
III	78	BC-PS	CC-MT	R-GC	HS-US	5.00	4.00	6.20	7.40	151	2675	2730	55
III	79	BC-US	CC-GC	R-PS	HS-MT	5.50	7.75	5.40	4.00	154	2663	2707	60
III	80	BC-PS	CC-US	R-GC	HS-MT	5.75	4.67	5.80	6.00	150	2676	2767	48
III	81	BC-GC	CC-GC	R-US	HS-MT	4.20	7.75	7.50	4.00	154	2663	2809	40
III	82	BC-MT	CC-PS	R-GC	HS-US	6.00	6.20	5.80	4.00	154	2676	2732	55
III	83	BC-US	CC-GC	R-PS	HS-MT	6.75	6.20	5.20	4.00	152	2672	2711	60
III	84	BC-PS	CC-MT	R-GC	HS-US	4.60	4.33	6.75	7.00	150	2644	2737	55
III	85	BC-PS	CC-MT	R-GC	HS-US	5.00	4.33	6.20	7.00	150	2654	2738	55
III	86	BC-GC	CC-PS	R-US	HS-MT	4.40	7.75	7.00	4.00	154	2662	2773	48
III	87	BC-PS	CC-MT	R-GC	HS-US	5.00	4.20	5.80	7.40	151	2669	2738	55
III	88	BC-MT	CC-PS	R-GC	HS-US	5.80	6.60	5.80	4.00	154	2665	2737	55
III	89	BC-PS	CC-US	R-GC	HS-MT	4.40	7.67	6.75	4.00	152	2675	2773	48
III	90	BC-GC	CC-PS	R-US	HS-MT	4.20	7.75	7.20	4.00	154	2657	2775	48
III	91	BC-PS	CC-US	R-GC	HS-MT	5.00	4.20	6.40	6.60	151	2678	2775	48
III	92	BC-PS	CC-MT	R-GC	HS-US	4.60	4.20	6.40	7.40	151	2659	2741	55
III	93	BC-PS	CC-MT	R-GC	HS-US	4.75	4.20	6.20	7.40	151	2664	2742	55
III	94	BC-PS	CC-MT	R-GC	HS-US	4.40	4.00	7.20	7.40	151	2661	2742	55
III	95	BC-US	CC-GC	R-PS	HS-MT	7.00	5.80	5.40	4.00	150	2649	2720	60
III	96	BC-PS	CC-MT	R-GC	HS-US	5.20	4.20	5.60	7.40	151	2674	2744	55
III	97	BC-PS	CC-MT	R-GC	HS-US	5.50	4.33	5.60	7.00	150	2664	2745	55
III	98	BC-PS	CC-MT	R-GC	HS-US	4.75	4.00	6.75	7.40	149	2636	2745	55
III	99	BC-PS	CC-US	R-GC	HS-MT	5.75	4.33	5.80	6.33	150	2677	2779	48
III	100	BC-US	CC-PS	R-GC	HS-MT	7.00	6.60	5.00	4.00	152	2665	2773	50

Table B.49: Path A Solutions (Phase IV Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-GC	R-US	HS-MT	5.20	5.80	5.67	4.00	162	2860	2500	45
IV	2	BC-PS	CC-GC	R-US	HS-MT	5.75	5.50	5.50	4.00	162	2876	2507	45
IV	3	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	5.25	4.00	162	2870	2509	45
IV	4	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.50	4.00	162	2865	2512	45
IV	5	BC-GC	CC-GC	R-US	HS-MT	5.60	5.80	5.67	4.00	162	2860	2541	40
IV	6	BC-US	CC-GC	R-GC	HS-MT	5.50	5.80	5.80	4.00	162	2826	2534	41
IV	7	BC-PS	CC-GC	R-US	HS-MT	5.20	4.25	5.25	5.25	172	3040	2516	45
IV	8	BC-GC	CC-PS	R-US	HS-MT	6.20	5.33	5.25	4.00	162	2870	2507	48
IV	9	BC-GC	CC-PS	R-US	HS-MT	5.40	5.67	5.67	4.00	162	2849	2507	48
IV	10	BC-PS	CC-GC	R-US	HS-MT	5.00	6.20	5.67	4.00	162	2849	2521	45
IV	11	BC-GC	CC-PS	R-US	HS-MT	5.60	5.67	5.50	4.00	162	2854	2509	48
IV	12	BC-PS	CC-GC	R-US	HS-MT	5.00	4.50	5.25	5.25	173	3050	2522	45
IV	13	BC-PS	CC-GC	R-US	HS-MT	5.20	6.20	5.50	4.00	162	2854	2523	45
IV	14	BC-PS	CC-GC	R-US	HS-MT	6.20	5.50	5.25	4.00	162	2881	2524	45
IV	15	BC-GC	CC-GC	R-US	HS-MT	6.20	5.50	5.50	4.00	162	2876	2553	40
IV	16	BC-PS	CC-GC	R-US	HS-MT	5.50	6.20	5.25	4.00	162	2859	2525	45
IV	17	BC-US	CC-PS	R-GC	HS-MT	5.50	5.67	5.60	4.00	162	2820	2506	50
IV	18	BC-PS	CC-US	R-GC	HS-MT	5.50	5.67	5.60	4.00	162	2908	2512	48
IV	19	BC-GC	CC-GC	R-US	HS-MT	6.20	5.80	5.25	4.00	162	2870	2555	40
IV	20	BC-GC	CC-GC	R-US	HS-MT	5.60	4.25	5.25	5.25	172	3040	2557	40
IV	21	BC-PS	CC-GC	R-US	HS-MT	5.50	5.80	5.67	4.00	160	2831	2531	45
IV	22	BC-US	CC-GC	R-GC	HS-MT	5.33	6.20	5.80	4.00	162	2815	2552	41
IV	23	BC-PS	CC-US	R-GC	HS-MT	5.75	5.67	5.33	4.00	162	2913	2518	48
IV	24	BC-PS	CC-GC	R-US	HS-MT	4.75	6.20	6.00	4.00	162	2844	2534	45
IV	25	BC-GC	CC-PS	R-US	HS-MT	6.00	5.67	5.25	4.00	162	2859	2521	48
IV	26	BC-GC	CC-GC	R-US	HS-MT	5.40	6.20	5.67	4.00	162	2849	2562	40
IV	27	BC-GC	CC-GC	R-US	HS-MT	5.40	4.50	5.25	5.25	173	3050	2563	40
IV	28	BC-US	CC-GC	R-GC	HS-MT	5.75	5.80	5.60	4.00	162	2831	2555	41
IV	29	BC-GC	CC-GC	R-US	HS-MT	6.00	5.80	5.50	4.00	162	2865	2563	40
IV	30	BC-PS	CC-US	R-GC	HS-MT	5.75	5.20	4.67	4.67	169	3023	2522	48
IV	31	BC-GC	CC-GC	R-US	HS-MT	5.60	6.20	5.50	4.00	162	2854	2564	40
IV	32	BC-PS	CC-GC	R-US	HS-MT	5.20	4.50	5.20	5.25	173	3055	2536	45
IV	33	BC-PS	CC-NS	R-US	HS-MT	5.75	6.00	5.67	4.00	162	2882	2578	37
IV	34	BC-US	CC-GC	R-NS	HS-MT	5.50	6.20	6.20	4.00	162	2820	2605	32
IV	35	BC-GC	CC-GC	R-US	HS-MT	6.60	5.50	5.25	4.00	162	2881	2565	40
IV	36	BC-PS	CC-GC	R-US	HS-MT	5.75	5.80	5.50	4.00	160	2836	2538	45
IV	37	BC-PS	CC-US	R-GC	HS-MT	5.00	6.00	5.80	4.00	162	2892	2524	48
IV	38	BC-PS	CC-US	R-GC	HS-MT	5.50	5.40	4.67	4.67	170	3032	2525	48
IV	39	BC-PS	CC-GC	R-US	HS-MT	5.00	4.67	5.25	5.25	172	3029	2539	45
IV	40	BC-PS	CC-US	R-GC	HS-MT	6.20	5.40	5.33	4.00	162	2924	2526	48
IV	41	BC-GC	CC-PS	R-US	HS-MT	5.60	5.67	5.67	4.00	160	2820	2528	48
IV	42	BC-PS	CC-GC	R-US	HS-MT	5.00	4.25	5.25	5.50	172	3031	2540	45
IV	43	BC-US	CC-GC	R-GC	HS-MT	5.50	6.20	5.60	4.00	162	2820	2561	41
IV	44	BC-PS	CC-GC	R-US	HS-MT	4.75	4.50	5.25	5.50	173	3040	2541	45
IV	45	BC-PS	CC-GC	R-US	HS-MT	4.60	6.20	6.20	4.00	162	2839	2541	45
IV	46	BC-PS	CC-US	R-GC	HS-MT	4.75	6.20	5.80	4.00	162	2881	2527	48
IV	47	BC-PS	CC-GC	R-US	HS-MT	5.50	4.25	5.20	5.25	172	3045	2541	45
IV	48	BC-PS	CC-GC	R-US	HS-MT	5.50	4.20	5.25	5.25	171	3031	2542	45
IV	49	BC-PS	CC-GC	R-US	HS-MT	5.20	6.20	5.67	4.00	160	2820	2542	45
IV	50	BC-US	CC-GC	R-GC	HS-MT	5.20	6.20	6.20	4.00	162	2810	2562	41

Table B.50: Path A Solutions (Phase IV Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-PS	CC-GC	R-US	HS-MT	5.20	4.50	5.25	5.25	171	3020	2542	45
IV	52	BC-US	CC-PS	R-GC	HS-MT	5.75	5.67	5.33	4.00	162	2825	2522	50
IV	53	BC-PS	CC-GC	R-US	HS-MT	5.20	6.67	5.25	4.00	162	2848	2543	45
IV	54	BC-PS	CC-GC	R-US	HS-MT	4.75	4.25	5.50	5.50	172	3026	2543	45
IV	55	BC-US	CC-PS	R-GC	HS-MT	6.00	5.33	5.33	4.00	162	2836	2523	50
IV	56	BC-PS	CC-US	R-GC	HS-MT	5.20	6.00	5.60	4.00	162	2897	2530	48
IV	57	BC-PS	CC-GC	R-US	HS-MT	4.75	6.67	5.67	4.00	162	2838	2544	45
IV	58	BC-PS	CC-GC	R-US	HS-MT	5.75	4.25	5.00	5.25	172	3050	2544	45
IV	59	BC-GC	CC-PS	R-US	HS-MT	5.60	4.00	5.25	5.25	172	3040	2531	48
IV	60	BC-PS	CC-GC	R-US	HS-MT	5.50	4.50	5.00	5.25	173	3059	2544	45
IV	61	BC-GC	CC-PS	R-US	HS-MT	5.40	4.20	5.25	5.25	173	3050	2532	48
IV	62	BC-PS	CC-US	R-GC	HS-MT	5.00	4.80	5.20	5.25	167	2965	2531	48
IV	63	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	5.20	4.00	162	2864	2545	45
IV	64	BC-NS	CC-GC	R-US	HS-MT	6.33	5.80	5.67	4.00	162	2860	2617	31
IV	65	BC-PS	CC-US	R-GC	HS-MT	5.20	4.67	5.20	5.25	166	2956	2532	48
IV	66	BC-PS	CC-GC	R-US	HS-MT	5.75	4.00	5.25	5.25	170	3022	2547	45
IV	67	BC-PS	CC-GC	R-US	HS-MT	5.50	4.25	5.25	5.25	170	3011	2547	45
IV	68	BC-PS	CC-GC	R-US	HS-MT	5.75	4.50	4.80	5.25	173	3064	2547	45
IV	69	BC-PS	CC-GC	R-US	HS-MT	4.75	5.00	5.25	5.25	173	3039	2548	45
IV	70	BC-PS	CC-US	R-GC	HS-MT	4.75	5.00	5.20	5.25	168	2974	2534	48
IV	71	BC-GC	CC-PS	R-US	HS-MT	5.60	6.20	5.25	4.00	162	2848	2535	48
IV	72	BC-GC	CC-GC	R-US	HS-MT	6.00	6.20	5.25	4.00	162	2859	2576	40
IV	73	BC-PS	CC-US	R-NS	HS-MT	5.00	6.20	6.20	4.00	162	2886	2582	39
IV	74	BC-GC	CC-PS	R-US	HS-MT	6.20	5.67	5.20	4.00	162	2864	2536	48
IV	75	BC-US	CC-GC	R-GC	HS-MT	6.20	5.50	5.33	4.00	162	2847	2569	41
IV	76	BC-PS	CC-GC	R-US	HS-MT	6.50	5.50	5.20	4.00	162	2886	2549	45
IV	77	BC-PS	CC-NS	R-US	HS-MT	5.50	6.00	6.00	4.00	162	2877	2590	37
IV	78	BC-GC	CC-GC	R-US	HS-MT	5.60	4.50	5.20	5.25	173	3055	2577	40
IV	79	BC-GC	CC-PS	R-US	HS-MT	5.40	4.25	5.25	5.25	172	3029	2537	48
IV	80	BC-PS	CC-GC	R-US	HS-MT	6.20	5.80	5.20	4.00	162	2875	2550	45
IV	81	BC-US	CC-GC	R-GC	HS-MT	5.75	5.80	5.80	4.00	160	2796	2570	41
IV	82	BC-PS	CC-GC	R-MT	HS-US	5.20	4.50	5.00	5.40	173	3045	2523	51
IV	83	BC-GC	CC-US	R-GC	HS-MT	6.00	5.67	5.60	4.00	162	2908	2564	43
IV	84	BC-PS	CC-US	R-NS	HS-MT	5.20	5.00	5.25	5.25	168	2984	2584	39
IV	85	BC-PS	CC-GC	R-US	HS-MT	5.00	6.67	5.50	4.00	162	2843	2551	45
IV	86	BC-PS	CC-US	R-GC	HS-MT	5.20	4.80	5.00	5.25	167	2970	2537	48
IV	87	BC-PS	CC-GC	R-US	HS-MT	5.75	6.20	5.25	4.00	160	2829	2551	45
IV	88	BC-GC	CC-US	R-GC	HS-MT	6.20	5.67	5.33	4.00	162	2913	2565	43
IV	89	BC-US	CC-GC	R-GC	HS-MT	6.00	5.80	5.33	4.00	162	2836	2571	41
IV	90	BC-GC	CC-US	R-GC	HS-MT	5.40	6.00	5.80	4.00	162	2892	2565	43
IV	91	BC-PS	CC-GC	R-MT	HS-US	5.75	4.50	5.00	5.00	173	3064	2525	51
IV	92	BC-GC	CC-GC	R-US	HS-MT	5.40	4.67	5.25	5.25	172	3029	2580	40
IV	93	BC-PS	CC-NS	R-US	HS-MT	4.75	6.40	6.33	4.00	162	2857	2593	37
IV	94	BC-GC	CC-GC	R-US	HS-MT	5.20	6.20	6.00	4.00	162	2844	2580	40
IV	95	BC-PS	CC-US	R-GC	HS-MT	5.00	6.20	5.60	4.00	162	2886	2538	48
IV	96	BC-PS	CC-US	R-NS	HS-MT	5.50	4.80	5.25	5.25	167	2975	2586	39
IV	97	BC-PS	CC-US	R-GC	HS-MT	5.75	5.40	4.50	4.67	170	3037	2538	48
IV	98	BC-PS	CC-US	R-GC	HS-MT	5.75	5.67	5.60	4.00	160	2879	2538	48
IV	99	BC-PS	CC-US	R-GC	HS-MT	5.20	4.33	5.33	5.50	164	2923	2539	48
IV	100	BC-PS	CC-NS	R-US	HS-MT	5.50	6.40	5.67	4.00	162	2871	2593	37

B.8 Path B

As mentioned in the discussion of solutions with strict restrictions on single-car trains, short-turning the C branch at Kenmore can be a viable strategy to reduce wait time at the cost of additional transfers. Comparisons between the different types of restrictions on single-car trains suggest that changing the routes that single-car trains are assigned to have minimal impacts on wait time. Therefore, the solutions below utilize the Cleveland Circle - Kenmore routing in conjunction with single-car trains to avoid mixing single-car and two-car train operations in the Central Subway while maintaining a level of service closer to that of Path A than to that of the Current Plan.

The solutions below include the following constraints in addition to the core constraints:

- Exactly one single-car service must be included in the solution, which terminates at Cleveland Circle and turns around at Kenmore. No other single-car services are permitted.

- The headway of the D branch service must be lower than or equal to the headway of the C branch service.

- The headway of the D branch service must be lower than or equal to the headway of the E branch service.

The solutions that comprise "Path B," discussed in more detail in Chapter 5, come from the set of solutions generated from these constraints.

Table B.51: Path B Solutions (Phase I Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	1	BC-MT	CC-K	R-GC	HS-US	6.20	4.40	7.75	7.75	120	2047	3240	110
I	2	BC-MT	CC-K	R-GC	HS-US	6.40	4.40	7.25	7.75	120	2051	3240	110
I	3	BC-MT	CC-K	R-GC	HS-US	6.40	4.20	7.75	7.75	119	2037	3256	110
I	4	BC-MT	CC-K	R-GC	HS-US	6.67	4.20	7.25	7.75	119	2042	3269	110
I	5	BC-US	CC-K	R-GC	HS-MT	7.33	4.40	6.80	7.20	118	2047	3299	105
I	6	BC-PS	CC-K	R-US	HS-MT	6.50	4.80	7.20	7.20	117	2046	3279	109
I	7	BC-US	CC-K	R-GC	HS-MT	6.33	4.20	7.75	7.75	119	2047	3304	105
I	8	BC-PS	CC-K	R-US	HS-MT	7.40	4.40	6.80	7.20	116	2042	3285	109
I	9	BC-PS	CC-K	R-US	HS-MT	7.00	4.80	6.80	7.20	117	2051	3285	109
I	10	BC-MT	CC-K	R-GC	HS-US	6.40	4.40	7.75	7.75	118	2017	3277	110
I	11	BC-PS	CC-K	R-US	HS-MT	7.40	4.00	7.20	7.20	116	2048	3289	109
I	12	BC-PS	CC-K	R-US	HS-MT	7.00	4.40	7.20	7.20	116	2037	3289	109
I	13	BC-US	CC-K	R-PS	HS-MT	7.33	4.40	6.67	6.80	118	2051	3218	123
I	14	BC-MT	CC-K	R-GC	HS-US	6.20	4.80	7.75	7.75	119	2026	3281	110
I	15	BC-MT	CC-K	R-GC	HS-US	6.40	4.80	7.25	7.75	119	2031	3282	110
I	16	BC-MT	CC-K	R-PS	HS-US	6.67	4.20	7.20	7.20	119	2047	3190	129
I	17	BC-MT	CC-K	R-PS	HS-US	5.75	4.80	7.67	7.75	121	2051	3192	129
I	18	BC-MT	CC-K	R-GC	HS-US	7.00	4.80	6.80	7.20	119	2046	3285	110
I	19	BC-MT	CC-K	R-GC	HS-US	6.67	4.00	7.75	7.75	118	2028	3285	110
I	20	BC-PS	CC-K	R-US	HS-MT	5.75	4.40	7.50	7.75	118	2051	3294	109
I	21	BC-US	CC-K	R-PS	HS-MT	6.60	4.40	7.20	7.20	118	2037	3224	123
I	22	BC-US	CC-K	R-GC	HS-MT	7.67	4.80	6.80	6.80	117	2036	3317	105
I	23	BC-MT	CC-K	R-PS	HS-US	6.00	4.40	7.67	7.75	120	2042	3197	129
I	24	BC-US	CC-K	R-PS	HS-MT	6.60	4.80	6.67	7.20	119	2051	3226	123
I	25	BC-MT	CC-K	R-PS	HS-US	6.40	4.40	6.67	7.75	120	2051	3197	129
I	26	BC-MT	CC-K	R-GC	HS-US	6.67	4.40	7.25	7.75	118	2022	3290	110
I	27	BC-US	CC-K	R-PS	HS-MT	6.33	4.80	7.20	7.20	119	2046	3227	123
I	28	BC-MT	CC-K	R-PS	HS-US	6.20	4.40	7.20	7.75	120	2047	3199	129
I	29	BC-US	CC-K	R-GC	HS-MT	6.60	4.00	7.75	7.75	118	2038	3321	105
I	30	BC-GC	CC-K	R-US	HS-MT	7.00	4.80	7.20	7.20	117	2046	3331	103
I	31	BC-MT	CC-K	R-PS	HS-US	6.40	4.80	7.20	7.20	119	2036	3203	129
I	32	BC-US	CC-K	R-GC	HS-MT	7.33	5.33	6.80	6.80	118	2045	3324	105
I	33	BC-PS	CC-K	R-MT	HS-US	7.40	4.80	6.60	7.20	117	2051	3278	114
I	34	BC-US	CC-K	R-GC	HS-MT	6.33	4.40	7.75	7.75	118	2027	3325	105
I	35	BC-US	CC-K	R-GC	HS-MT	7.67	4.40	6.50	7.20	118	2051	3325	105
I	36	BC-US	CC-K	R-GC	HS-MT	6.60	4.40	7.25	7.75	118	2032	3326	105
I	37	BC-PS	CC-K	R-MT	HS-US	6.50	4.80	7.20	7.20	117	2041	3279	114
I	38	BC-US	CC-K	R-GC	HS-MT	7.67	4.20	6.80	7.20	117	2037	3326	105
I	39	BC-MT	CC-K	R-GC	HS-US	7.00	4.20	6.80	7.75	119	2047	3298	110
I	40	BC-MT	CC-K	R-GC	HS-US	6.67	4.80	6.80	7.75	119	2036	3298	110
I	41	BC-MT	CC-K	R-GC	HS-US	6.00	5.33	7.75	7.75	120	2035	3299	110
I	42	BC-MT	CC-K	R-GC	HS-US	6.20	5.33	7.25	7.75	120	2040	3300	110
I	43	BC-GC	CC-K	R-US	HS-MT	7.50	4.80	6.80	7.20	117	2051	3336	103
I	44	BC-US	CC-K	R-NS	HS-MT	7.67	4.40	7.20	7.20	118	2051	3377	95
I	45	BC-PS	CC-K	R-MT	HS-US	6.20	4.40	7.20	7.75	118	2051	3282	114
I	46	BC-US	CC-K	R-GC	HS-MT	6.33	4.80	7.25	7.75	119	2041	3329	105
I	47	BC-PS	CC-K	R-US	HS-MT	7.40	4.20	7.20	7.20	115	2028	3310	109
I	48	BC-PS	CC-K	R-US	HS-MT	7.40	5.33	6.80	6.80	116	2040	3310	109
I	49	BC-PS	CC-K	R-MT	HS-US	5.75	4.40	7.50	7.75	118	2047	3283	114
I	50	BC-MT	CC-K	R-PS	HS-US	6.67	4.40	7.20	7.20	118	2027	3211	129

Table B.52: Path B Solutions (Phase I Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
I	51	BC-US	CC-K	R-PS	HS-MT	7.00	4.00	7.20	7.20	118	2048	3240	123
I	52	BC-GC	CC-K	R-US	HS-MT	6.20	4.40	7.50	7.75	118	2051	3340	103
I	53	BC-MT	CC-K	R-GC	HS-US	6.40	5.33	6.80	7.75	120	2045	3304	110
I	54	BC-GC	CC-K	R-US	HS-MT	7.50	4.40	7.20	7.20	116	2037	3341	103
I	55	BC-MT	CC-K	R-PS	HS-US	6.67	4.80	6.67	7.20	119	2041	3213	129
I	56	BC-US	CC-K	R-PS	HS-MT	7.00	4.40	6.67	7.20	118	2042	3242	123
I	57	BC-MT	CC-K	R-PS	HS-US	6.20	4.20	7.67	7.75	119	2032	3213	129
I	58	BC-MT	CC-K	R-PS	HS-US	7.00	4.80	6.67	6.75	119	2051	3213	129
I	59	BC-MT	CC-K	R-GC	HS-US	7.33	4.40	6.80	7.20	118	2037	3305	110
I	60	BC-US	CC-K	R-GC	HS-MT	6.60	4.80	6.80	7.75	119	2046	3334	105
I	61	BC-MT	CC-K	R-GC	HS-US	6.67	4.20	7.75	7.75	117	2008	3306	110
I	62	BC-PS	CC-K	R-MT	HS-US	7.40	4.00	7.20	7.20	116	2043	3289	114
I	63	BC-PS	CC-K	R-MT	HS-US	7.00	4.40	7.20	7.20	116	2032	3289	114
I	64	BC-PS	CC-K	R-US	HS-MT	6.50	4.20	7.20	7.75	117	2047	3316	109
I	65	BC-MT	CC-K	R-PS	HS-US	6.40	4.20	7.20	7.75	119	2037	3216	129
I	66	BC-US	CC-K	R-PS	HS-MT	7.67	4.20	6.67	6.80	117	2042	3245	123
I	67	BC-MT	CC-K	R-NS	HS-US	7.00	4.20	7.60	7.75	119	2047	3357	101
I	68	BC-MT	CC-K	R-NS	HS-US	6.67	4.80	7.60	7.75	119	2036	3357	101
I	69	BC-MT	CC-K	R-GC	HS-US	7.00	4.00	7.25	7.75	118	2033	3310	110
I	70	BC-PS	CC-K	R-MT	HS-US	6.50	4.20	7.20	7.75	117	2042	3292	114
I	71	BC-MT	CC-K	R-PS	HS-US	6.40	5.33	6.67	7.20	120	2050	3219	129
I	72	BC-PS	CC-K	R-US	HS-MT	6.20	4.20	7.50	7.75	117	2042	3319	109
I	73	BC-US	CC-K	R-GC	HS-MT	7.33	4.80	6.80	7.20	117	2026	3341	105
I	74	BC-MT	CC-K	R-PS	HS-US	6.20	5.33	7.20	7.20	120	2045	3221	129
I	75	BC-US	CC-K	R-GC	HS-MT	7.00	4.00	7.25	7.75	118	2043	3342	105
I	76	BC-US	CC-K	R-GC	HS-MT	6.60	4.20	7.75	7.75	117	2018	3342	105
I	77	BC-GC	CC-K	R-MT	HS-US	6.60	4.40	7.20	7.75	118	2051	3323	108
I	78	BC-MT	CC-K	R-NS	HS-US	6.40	5.33	7.60	7.75	120	2045	3363	101
I	79	BC-US	CC-K	R-NS	HS-MT	6.60	4.80	7.60	7.75	119	2046	3393	95
I	80	BC-PS	CC-K	R-MT	HS-US	7.40	4.40	7.00	7.20	116	2037	3299	114
I	81	BC-PS	CC-K	R-MT	HS-US	7.00	4.80	7.00	7.20	117	2046	3299	114
I	82	BC-PS	CC-K	R-US	HS-MT	7.40	4.80	6.80	7.20	115	2021	3326	109
I	83	BC-MT	CC-K	R-PS	HS-US	6.67	4.20	6.67	7.75	119	2042	3226	129
I	84	BC-US	CC-K	R-GC	HS-MT	7.67	4.40	6.80	7.20	116	2017	3347	105
I	85	BC-US	CC-K	R-GC	HS-MT	6.20	4.80	7.75	7.75	119	2036	3347	105
I	86	BC-MT	CC-K	R-GC	HS-US	7.00	4.40	6.80	7.75	118	2027	3318	110
I	87	BC-MT	CC-K	R-GC	HS-US	6.40	4.80	7.75	7.75	117	1997	3318	110
I	88	BC-GC	CC-K	R-MT	HS-US	6.20	4.40	7.50	7.75	118	2047	3329	108
I	89	BC-US	CC-K	R-GC	HS-MT	7.00	5.33	6.80	7.20	118	2035	3348	105
I	90	BC-GC	CC-K	R-MT	HS-US	7.00	4.80	7.20	7.20	117	2041	3331	108
I	91	BC-PS	CC-K	R-US	HS-MT	6.50	4.00	7.50	7.75	116	2033	3329	109
I	92	BC-US	CC-K	R-GC	HS-MT	7.67	5.33	6.50	6.80	118	2050	3350	105
I	93	BC-MT	CC-K	R-PS	HS-US	6.40	4.00	7.67	7.75	118	2023	3229	129
I	94	BC-US	CC-K	R-GC	HS-MT	7.00	4.40	6.80	7.75	118	2037	3350	105
I	95	BC-PS	CC-K	R-US	HS-MT	7.40	4.40	7.20	7.20	114	2007	3330	109
I	96	BC-PS	CC-K	R-MT	HS-US	6.20	5.33	7.20	7.20	118	2050	3304	114
I	97	BC-PS	CC-K	R-US	HS-MT	7.00	4.80	7.20	7.20	115	2016	3331	109
I	98	BC-MT	CC-K	R-GC	HS-US	5.75	6.00	7.75	7.75	121	2045	3322	110
I	99	BC-US	CC-K	R-PS	HS-MT	7.33	4.80	6.67	6.80	117	2031	3259	123
I	100	BC-MT	CC-K	R-PS	HS-US	7.00	4.00	7.20	7.20	118	2038	3231	129

Table B.53: Path B Solutions (Phase II Solutions 1 through 50)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	1	BC-MT	CC-K	R-GC	HS-US	4.80	4.20	6.80	7.20	141	2381	2814	110
II	2	BC-MT	CC-K	R-NS	HS-US	5.33	4.40	6.75	6.75	140	2381	2868	101
II	3	BC-MT	CC-K	R-GC	HS-US	5.20	4.40	6.50	6.75	140	2376	2825	110
II	4	BC-MT	CC-K	R-NS	HS-US	5.50	4.40	6.40	6.75	140	2386	2873	101
II	5	BC-MT	CC-K	R-GC	HS-US	5.75	4.20	6.20	6.33	139	2381	2827	110
II	6	BC-MT	CC-K	R-GC	HS-US	5.33	4.40	6.20	6.75	140	2381	2828	110
II	7	BC-MT	CC-K	R-GC	HS-US	5.33	4.20	6.50	6.75	139	2367	2829	110
II	8	BC-MT	CC-K	R-GC	HS-US	5.50	4.40	5.80	6.75	140	2386	2829	110
II	9	BC-MT	CC-K	R-GC	HS-US	5.00	4.80	6.50	6.75	141	2385	2829	110
II	10	BC-PS	CC-K	R-US	HS-MT	5.75	4.00	6.00	6.40	136	2382	2839	109
II	11	BC-MT	CC-K	R-GC	HS-US	5.00	4.00	6.80	7.20	140	2372	2830	110
II	12	BC-MT	CC-K	R-NS	HS-US	5.50	4.20	6.75	6.75	139	2371	2878	101
II	13	BC-PS	CC-K	R-US	HS-MT	5.50	4.00	6.25	6.40	136	2377	2842	109
II	14	BC-US	CC-K	R-GC	HS-MT	5.60	4.40	6.20	6.40	138	2371	2863	105
II	15	BC-MT	CC-K	R-GC	HS-US	4.80	4.40	6.80	7.20	140	2361	2834	110
II	16	BC-PS	CC-K	R-US	HS-MT	5.75	4.40	6.00	6.20	136	2381	2844	109
II	17	BC-MT	CC-K	R-GC	HS-US	5.50	4.20	6.20	6.75	139	2371	2838	110
II	18	BC-MT	CC-K	R-GC	HS-US	5.50	4.00	6.50	6.75	138	2357	2839	110
II	19	BC-US	CC-K	R-GC	HS-MT	6.60	4.40	5.80	5.80	136	2366	2869	105
II	20	BC-MT	CC-K	R-NS	HS-US	5.33	4.00	6.75	7.20	140	2382	2888	101
II	21	BC-US	CC-K	R-NS	HS-MT	5.60	4.80	6.40	6.40	139	2385	2920	95
II	22	BC-PS	CC-K	R-US	HS-MT	5.75	4.40	5.75	6.40	136	2376	2852	109
II	23	BC-MT	CC-K	R-GC	HS-US	5.50	4.80	6.20	6.33	139	2370	2843	110
II	24	BC-PS	CC-K	R-US	HS-MT	5.20	4.40	6.25	6.40	136	2366	2852	109
II	25	BC-US	CC-K	R-GC	HS-MT	6.33	4.80	5.80	5.80	137	2375	2873	105
II	26	BC-MT	CC-K	R-GC	HS-US	5.20	4.00	6.50	7.20	140	2377	2845	110
II	27	BC-PS	CC-K	R-US	HS-MT	5.50	4.40	6.00	6.40	136	2371	2855	109
II	28	BC-US	CC-K	R-GC	HS-MT	5.60	4.80	5.80	6.40	139	2385	2875	105
II	29	BC-PS	CC-K	R-MT	HS-US	5.20	4.20	6.33	6.33	137	2381	2829	114
II	30	BC-US	CC-K	R-GC	HS-MT	5.40	4.80	6.20	6.40	139	2380	2876	105
II	31	BC-MT	CC-K	R-PS	HS-US	5.20	4.40	6.33	6.33	140	2381	2756	129
II	32	BC-MT	CC-K	R-PS	HS-US	5.33	4.40	6.00	6.33	140	2386	2756	129
II	33	BC-MT	CC-K	R-GC	HS-US	5.33	4.00	6.20	7.20	140	2382	2848	110
II	34	BC-MT	CC-K	R-GC	HS-US	5.75	4.40	6.20	6.33	138	2361	2848	110
II	35	BC-GC	CC-K	R-US	HS-MT	6.20	4.00	6.00	6.40	136	2382	2885	103
II	36	BC-MT	CC-K	R-NS	HS-US	5.20	4.00	7.20	7.20	140	2377	2897	101
II	37	BC-MT	CC-K	R-GC	HS-US	5.00	4.40	6.50	7.20	140	2366	2850	110
II	38	BC-US	CC-K	R-NS	HS-MT	5.40	4.20	6.75	6.80	139	2381	2926	95
II	39	BC-MT	CC-K	R-GC	HS-US	5.33	4.40	6.50	6.75	138	2346	2850	110
II	40	BC-US	CC-K	R-GC	HS-MT	5.20	4.20	6.50	6.80	139	2376	2879	105
II	41	BC-US	CC-K	R-GC	HS-MT	6.00	4.00	6.20	6.40	138	2382	2879	105
II	42	BC-MT	CC-K	R-PS	HS-US	5.00	4.00	6.67	6.75	140	2377	2759	129
II	43	BC-PS	CC-K	R-US	HS-MT	5.75	4.20	6.00	6.40	135	2362	2859	109
II	44	BC-MT	CC-K	R-GC	HS-US	5.00	4.20	6.80	7.20	139	2352	2851	110
II	45	BC-PS	CC-K	R-MT	HS-US	6.50	4.40	5.67	6.00	136	2386	2833	114
II	46	BC-MT	CC-K	R-GC	HS-US	4.67	4.80	6.80	7.20	141	2370	2851	110
II	47	BC-MT	CC-K	R-NS	HS-US	5.75	4.20	6.40	6.75	139	2376	2899	101
II	48	BC-MT	CC-K	R-NS	HS-US	5.50	4.40	6.75	6.75	138	2351	2899	101
II	49	BC-MT	CC-K	R-PS	HS-US	5.33	4.20	6.33	6.33	139	2371	2760	129
II	50	BC-US	CC-K	R-GC	HS-MT	5.20	4.00	6.80	6.80	138	2362	2880	105

Table B.54: Path B Solutions (Phase II Solutions 51 through 100)

Phase	Solution Number	Service Patterns				Headways (min)				Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
II	51	BC-MT	CC-K	R-GC	HS-US	6.00	4.00	6.20	6.33	138	2372	2853	110
II	52	BC-PS	CC-K	R-US	HS-MT	6.20	4.40	5.75	6.20	136	2386	2862	109
II	53	BC-US	CC-K	R-GC	HS-MT	6.33	4.20	5.80	6.20	137	2376	2882	105
II	54	BC-MT	CC-K	R-NS	HS-US	5.00	4.40	7.20	7.20	140	2366	2901	101
II	55	BC-PS	CC-K	R-US	HS-MT	5.50	4.20	6.25	6.40	135	2357	2862	109
II	56	BC-MT	CC-K	R-GC	HS-US	4.80	4.80	6.50	7.20	141	2375	2854	110
II	57	BC-PS	CC-K	R-US	HS-MT	6.50	4.80	5.75	5.80	135	2375	2862	109
II	58	BC-GC	CC-K	R-US	HS-MT	6.20	4.40	6.00	6.20	136	2381	2891	103
II	59	BC-MT	CC-K	R-GC	HS-US	5.75	4.20	5.80	6.75	139	2376	2855	110
II	60	BC-MT	CC-K	R-PS	HS-US	4.80	4.40	6.67	6.75	140	2366	2763	129
II	61	BC-US	CC-K	R-GC	HS-MT	6.20	4.40	5.80	6.20	138	2386	2884	105
II	62	BC-US	CC-K	R-GC	HS-MT	6.00	4.40	6.20	6.20	138	2381	2885	105
II	63	BC-MT	CC-K	R-NS	HS-US	5.33	4.40	6.40	7.20	140	2376	2904	101
II	64	BC-US	CC-K	R-GC	HS-MT	7.00	4.00	5.80	5.80	136	2377	2885	105
II	65	BC-MT	CC-K	R-NS	HS-US	5.75	4.00	6.75	6.75	138	2362	2904	101
II	66	BC-GC	CC-K	R-US	HS-MT	6.00	4.00	6.25	6.40	136	2377	2893	103
II	67	BC-MT	CC-K	R-GC	HS-US	6.20	4.40	5.80	6.00	138	2376	2857	110
II	68	BC-PS	CC-K	R-US	HS-MT	5.20	4.80	6.00	6.40	137	2380	2865	109
II	69	BC-US	CC-K	R-GC	HS-MT	5.40	4.20	6.20	6.80	139	2381	2886	105
II	70	BC-GC	CC-K	R-US	HS-MT	5.60	4.40	6.25	6.40	136	2366	2893	103
II	71	BC-PS	CC-K	R-MT	HS-US	5.50	4.00	6.33	6.33	136	2372	2839	114
II	72	BC-MT	CC-K	R-NS	HS-US	5.20	4.40	6.75	7.20	140	2371	2905	101
II	73	BC-US	CC-K	R-NS	HS-MT	5.60	4.00	6.75	6.80	138	2372	2934	95
II	74	BC-MT	CC-K	R-NS	HS-US	4.80	4.80	7.20	7.20	141	2375	2905	101
II	75	BC-MT	CC-K	R-PS	HS-US	5.50	4.20	6.00	6.33	139	2376	2766	129
II	76	BC-US	CC-K	R-PS	HS-MT	5.20	4.20	6.33	6.40	139	2381	2795	123
II	77	BC-US	CC-K	R-GC	HS-MT	5.40	4.00	6.50	6.80	138	2367	2887	105
II	78	BC-MT	CC-K	R-GC	HS-US	5.50	4.40	6.20	6.75	138	2351	2859	110
II	79	BC-PS	CC-K	R-US	HS-MT	5.75	4.00	6.25	6.40	134	2348	2867	109
II	80	BC-US	CC-K	R-NS	HS-MT	6.00	4.40	6.40	6.40	138	2376	2935	95
II	81	BC-PS	CC-K	R-US	HS-MT	5.50	4.80	5.75	6.40	137	2385	2867	109
II	82	BC-MT	CC-K	R-GC	HS-US	5.33	4.40	5.80	7.20	140	2376	2860	110
II	83	BC-US	CC-K	R-GC	HS-MT	6.60	4.80	5.50	5.80	137	2380	2889	105
II	84	BC-MT	CC-K	R-GC	HS-US	5.75	4.80	5.80	6.33	139	2375	2860	110
II	85	BC-MT	CC-K	R-GC	HS-US	5.50	4.20	6.50	6.75	137	2337	2860	110
II	86	BC-GC	CC-K	R-MT	HS-US	5.60	4.20	6.33	6.33	137	2381	2870	108
II	87	BC-MT	CC-K	R-GC	HS-US	6.20	4.00	5.80	6.33	138	2377	2861	110
II	88	BC-MT	CC-K	R-GC	HS-US	6.00	4.80	5.80	6.00	139	2385	2861	110
II	89	BC-PS	CC-K	R-US	HS-MT	6.20	4.20	6.00	6.20	135	2371	2870	109
II	90	BC-PS	CC-K	R-MT	HS-US	5.75	4.80	5.67	6.33	137	2385	2843	114
II	91	BC-GC	CC-K	R-US	HS-MT	6.20	4.40	5.75	6.40	136	2376	2898	103
II	92	BC-MT	CC-K	R-NS	HS-US	5.33	4.20	6.75	7.20	139	2362	2909	101
II	93	BC-MT	CC-K	R-NS	HS-US	5.00	4.80	6.75	7.20	141	2380	2909	101
II	94	BC-MT	CC-K	R-PS	HS-US	5.50	4.00	6.33	6.33	138	2362	2770	129
II	95	BC-PS	CC-K	R-MT	HS-US	5.75	4.00	6.20	6.33	136	2377	2844	114
II	96	BC-MT	CC-K	R-US	HS-NS	5.00	4.40	6.80	7.25	142	2386	2860	111
II	97	BC-MT	CC-K	R-NS	HS-US	5.33	4.80	6.75	6.75	139	2360	2910	101
II	98	BC-US	CC-K	R-GC	HS-MT	6.33	4.00	6.20	6.20	136	2362	2891	105
II	99	BC-US	CC-K	R-GC	HS-MT	6.00	4.40	5.80	6.40	138	2376	2891	105
II	100	BC-MT	CC-K	R-GC	HS-US	4.67	4.40	6.50	7.75	142	2386	2863	110

Table B.55: Path B Solutions (Phase III Solutions 1 through 50)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	1	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.00	6.75	7.00	6.80	156	2671	2873	110
III	2	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.00	6.40	7.00	6.80	156	2676	2885	110
III	3	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.20	6.40	6.60	6.80	155	2675	2915	105
III	4	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.20	6.40	6.60	6.80	155	2665	2888	110
III	5	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.60	6.40	6.60	6.80	156	2674	2892	110
III	6	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.20	6.75	7.00	6.80	155	2651	2894	110
III	7	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.20	6.40	7.40	6.80	157	2675	2895	110
III	8	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.00	6.75	7.40	6.80	156	2661	2900	110
III	9	BC-US	CC-K	R-GC	HS-MT	K-PS	6.00	4.00	6.40	6.60	6.80	154	2666	2930	105
III	10	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.00	6.40	7.40	6.80	156	2666	2902	110
III	11	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.00	6.40	6.60	6.80	154	2656	2904	110
III	12	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.20	6.40	7.00	6.80	155	2655	2905	110
III	13	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.60	6.75	7.00	6.80	156	2660	2908	110
III	14	BC-MT	CC-K	R-GC	HS-US	K-PS	5.00	4.20	7.20	7.40	6.80	157	2665	2908	110
III	15	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.60	6.40	7.00	6.80	156	2665	2910	110
III	16	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.20	6.20	6.60	6.80	155	2670	2910	110
III	17	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.00	6.75	7.00	5.80	156	2677	2911	110
III	18	BC-MT	CC-K	R-GC	HS-US	K-PS	5.20	4.20	6.75	7.40	6.80	157	2670	2912	110
III	19	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.20	6.60	6.60	6.80	153	2670	2948	103
III	20	BC-MT	CC-K	R-GC	HS-US	K-PS	4.80	4.60	7.20	7.40	6.80	158	2674	2912	110
III	21	BC-US	CC-K	R-GC	HS-MT	K-PS	7.00	4.20	5.80	6.00	6.80	153	2675	2942	105
III	22	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.00	6.20	6.60	6.80	154	2671	2944	105
III	23	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.20	6.75	7.40	5.80	157	2677	2921	110
III	24	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.20	6.75	7.40	6.80	155	2641	2921	110
III	25	BC-US	CC-K	R-GC	HS-MT	K-PS	6.00	4.20	6.40	6.60	6.80	153	2646	2950	105
III	26	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.20	6.40	7.00	6.80	155	2665	2951	105
III	27	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.00	6.40	7.00	6.80	154	2646	2922	110
III	28	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.00	6.33	6.60	6.80	152	2666	2959	103
III	29	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.20	6.33	6.60	6.80	153	2675	2959	103
III	30	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.20	6.40	7.40	6.80	155	2646	2923	110
III	31	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	5.00	6.40	7.00	6.80	157	2674	2923	110
III	32	BC-US	CC-K	R-GC	HS-MT	K-PS	5.33	4.20	6.75	7.00	6.80	155	2660	2953	105
III	33	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.00	6.20	7.40	6.80	156	2671	2925	110
III	34	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.20	6.40	6.60	5.80	155	2672	2925	110
III	35	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.20	6.40	6.60	6.80	153	2636	2925	110
III	36	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.00	6.75	7.00	6.80	154	2651	2956	105
III	37	BC-MT	CC-K	R-GC	HS-US	K-PS	6.25	4.20	5.80	6.60	6.80	155	2675	2927	110
III	38	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.60	6.40	6.60	6.80	154	2655	2956	105
III	39	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.20	6.20	7.00	6.80	155	2660	2928	110
III	40	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.00	6.75	7.40	5.80	156	2667	2928	110
III	41	BC-US	CC-K	R-GC	HS-MT	K-PS	6.50	4.00	5.80	6.60	6.80	154	2676	2957	105
III	42	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.60	6.20	6.33	6.80	154	2670	2958	105
III	43	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.60	6.40	6.60	6.80	154	2645	2929	110
III	44	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.00	6.40	6.60	5.80	154	2672	2958	105
III	45	BC-PS	CC-K	R-US	HS-MT	K-GC	5.50	4.20	6.60	6.60	7.20	153	2677	2938	109
III	46	BC-US	CC-K	R-GC	HS-MT	K-PS	6.50	4.20	6.20	6.33	6.80	153	2660	2960	105
III	47	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.20	6.75	7.00	5.80	155	2657	2931	110
III	48	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.60	6.20	7.00	6.80	156	2670	2932	110
III	49	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.00	5.80	7.40	6.80	156	2676	2932	110
III	50	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	5.00	6.40	6.60	6.80	155	2664	2962	105

Table B.56: Path B Solutions (Phase III Solutions 51 through 100)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
III	51	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.00	7.20	7.40	5.80	156	2662	2933	110
III	52	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	5.00	6.40	6.60	6.80	155	2654	2934	110
III	53	BC-MT	CC-K	R-GC	HS-US	K-PS	6.50	4.00	6.20	6.25	6.80	154	2671	2934	110
III	54	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.20	5.80	7.00	6.80	155	2665	2935	110
III	55	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.20	6.20	6.60	6.80	153	2651	2964	105
III	56	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.60	6.75	7.00	5.80	156	2666	2936	110
III	57	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.60	6.75	7.00	6.80	154	2630	2936	110
III	58	BC-MT	CC-K	R-GC	HS-US	K-PS	6.25	4.00	6.20	6.60	6.80	154	2661	2936	110
III	59	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.60	6.40	7.40	6.80	156	2655	2937	110
III	60	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.60	6.33	6.33	6.80	152	2665	2973	103
III	61	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.00	6.40	7.00	6.80	154	2656	2966	105
III	62	BC-US	CC-K	R-GC	HS-MT	K-PS	6.75	4.20	5.80	6.33	6.80	153	2665	2966	105
III	63	BC-GC	CC-K	R-MT	HS-US	K-PS	6.20	4.20	6.20	6.60	6.80	153	2675	2947	108
III	64	BC-GC	CC-K	R-MT	HS-US	K-PS	5.60	4.20	6.60	6.60	6.80	153	2665	2948	108
III	65	BC-US	CC-K	R-GC	HS-MT	K-PS	5.33	4.60	6.40	7.00	6.80	156	2674	2968	105
III	66	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.00	6.40	7.40	5.80	156	2672	2939	110
III	67	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.60	5.80	7.00	6.80	156	2674	2940	110
III	68	BC-MT	CC-K	R-GC	HS-US	K-PS	5.20	5.00	6.75	7.00	6.80	157	2669	2940	110
III	69	BC-US	CC-K	R-GC	HS-MT	K-PS	7.33	4.00	5.80	6.00	6.80	152	2666	2969	105
III	70	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.20	6.40	7.00	6.80	153	2626	2943	110
III	71	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.20	6.40	7.00	5.80	155	2662	2943	110
III	72	BC-US	CC-K	R-GC	HS-MT	K-PS	6.50	4.60	5.80	6.33	6.80	154	2674	2972	105
III	73	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.20	6.20	7.00	6.80	155	2670	2972	105
III	74	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.20	6.33	6.60	6.80	151	2646	2980	103
III	75	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	4.00	6.20	7.00	6.80	154	2651	2944	110
III	76	BC-MT	CC-K	R-GC	HS-US	K-PS	5.20	4.20	7.20	7.40	5.80	157	2672	2945	110
III	77	BC-MT	CC-K	R-GC	HS-US	K-PS	6.00	5.00	6.20	6.25	6.80	155	2669	2945	110
III	78	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.20	6.20	7.40	6.80	155	2651	2945	110
III	79	BC-US	CC-K	R-GC	HS-MT	K-PS	5.20	4.60	6.75	7.00	6.80	156	2670	2975	105
III	80	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.60	6.40	7.00	6.80	154	2635	2947	110
III	81	BC-MT	CC-K	R-GC	HS-US	K-PS	5.60	4.60	6.40	7.00	5.80	156	2671	2947	110
III	82	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.60	5.80	6.60	6.80	154	2665	2976	105
III	83	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.20	6.75	7.00	5.80	155	2667	2976	105
III	84	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.20	6.75	7.00	6.80	153	2631	2976	105
III	85	BC-MT	CC-K	R-GC	HS-US	K-PS	5.80	4.00	6.75	7.00	5.80	154	2648	2948	110
III	86	BC-GC	CC-K	R-MT	HS-US	K-PS	6.00	4.20	6.40	6.60	6.80	153	2670	2958	108
III	87	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	5.50	6.40	6.60	6.80	156	2663	2948	110
III	88	BC-US	CC-K	R-GC	HS-MT	K-PS	6.00	4.60	6.20	6.60	6.80	154	2660	2977	105
III	89	BC-US	CC-K	R-GC	HS-MT	K-PS	5.33	4.00	6.40	7.40	6.80	156	2676	2978	105
III	90	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.20	6.75	7.40	5.80	155	2647	2949	110
III	91	BC-US	CC-K	R-GC	HS-MT	K-PS	6.50	4.20	5.80	6.60	6.80	153	2655	2978	105
III	92	BC-US	CC-K	R-GC	HS-MT	K-PS	6.00	4.20	5.80	7.00	6.80	155	2675	2978	105
III	93	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	5.00	6.75	7.00	6.80	155	2639	2949	110
III	94	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	5.00	6.75	7.00	5.80	157	2675	2949	110
III	95	BC-MT	CC-K	R-GC	HS-US	K-GC	5.25	5.00	6.75	7.00	7.20	157	2675	2949	110
III	96	BC-MT	CC-K	R-GC	HS-US	K-PS	5.00	4.60	7.20	7.40	6.80	156	2645	2949	110
III	97	BC-MT	CC-K	R-GC	HS-US	K-PS	5.40	4.60	6.20	7.40	6.80	156	2660	2950	110
III	98	BC-MT	CC-K	R-GC	HS-US	K-PS	6.25	4.60	6.20	6.25	6.80	154	2660	2950	110
III	99	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.20	6.40	6.60	5.80	153	2652	2979	105
III	100	BC-PS	CC-K	R-MT	HS-US	K-GC	5.75	4.20	6.40	6.60	7.20	153	2677	2933	114

Table B.57: Path B Solutions (Phase IV Solutions 1 through 50)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	1	BC-PS	CC-K	R-MT	HS-US		4.60	5.00	5.00	5.00		173	3009	2459	114
IV	2	BC-PS	CC-K	R-MT	HS-US		4.60	5.50	5.00	5.00		172	2989	2511	114
IV	3	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.00	5.25	5.25	6.80	172	3034	2593	103
IV	4	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.20	5.25	5.25	6.80	173	3044	2593	103
IV	5	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.20	5.25	5.25	7.20	173	3050	2567	109
IV	6	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.20	5.25	5.50	6.80	173	3034	2597	103
IV	7	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.00	5.50	5.50	6.80	172	3020	2605	103
IV	8	BC-GC	CC-K	R-US	HS-MT	K-PS	5.40	4.20	5.50	5.50	6.80	173	3029	2605	103
IV	9	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.20	5.20	5.25	6.80	173	3048	2608	103
IV	10	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.20	5.33	5.50	6.80	173	2999	2603	105
IV	11	BC-GC	CC-K	R-MT	HS-US	K-PS	5.60	4.20	5.33	5.40	6.80	173	3029	2586	108
IV	12	BC-PS	CC-K	R-US	HS-MT	K-GC	5.20	4.20	5.50	5.50	7.20	173	3035	2584	109
IV	13	BC-PS	CC-K	R-GC	HS-MT	US-GC	4.60	4.20	4.67	5.25	7.33	173	3024	2491	128
IV	14	BC-GC	CC-K	R-US	HS-MT	K-GC	6.20	4.20	5.25	5.25	7.20	173	3050	2614	103
IV	15	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.20	5.25	5.25	5.80	173	3050	2614	103
IV	16	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.20	5.25	5.25	6.80	171	3014	2614	103
IV	17	BC-PS	CC-K	R-US	HS-MT	K-GC	5.50	4.20	5.25	5.50	7.20	173	3040	2587	109
IV	18	BC-PS	CC-K	R-GC	HS-MT	US-GC	4.75	4.20	4.50	5.25	7.33	173	3029	2494	128
IV	19	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.00	5.25	5.50	6.80	172	3025	2617	103
IV	20	BC-NS	CC-K	R-US	HS-MT	K-PS	6.67	4.20	5.25	5.25	6.80	173	3044	2662	94
IV	21	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.00	5.25	5.50	7.20	172	3031	2592	109
IV	22	BC-PS	CC-K	R-GC	HS-MT	US-GC	4.75	4.20	4.67	5.20	7.33	173	3034	2497	128
IV	23	BC-PS	CC-K	R-US	HS-MT	K-GC	6.20	4.00	5.25	5.25	7.20	172	3041	2593	109
IV	24	BC-PS	CC-K	R-US	HS-MT	K-PS	6.50	4.20	4.80	5.25	6.80	173	3058	2593	109
IV	25	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.00	5.25	5.75	6.80	172	3015	2621	103
IV	26	BC-GC	CC-K	R-US	HS-MT	K-PS	5.40	4.20	5.25	5.75	6.80	173	3024	2621	103
IV	27	BC-GC	CC-K	R-MT	HS-US	K-PS	6.20	4.20	5.00	5.40	6.80	173	3039	2595	108
IV	28	BC-PS	CC-K	R-US	HS-MT	K-GC	5.50	4.00	5.50	5.50	7.20	172	3026	2594	109
IV	29	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.20	5.50	5.50	6.80	171	2999	2625	103
IV	30	BC-GC	CC-K	R-US	HS-MT	K-GC	5.60	4.20	5.50	5.50	7.20	173	3035	2625	103
IV	31	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.20	5.50	5.50	5.80	173	3035	2625	103
IV	32	BC-PS	CC-K	R-MT	HS-US	K-PS	6.50	4.20	5.00	5.00	6.80	173	3058	2571	114
IV	33	BC-GC	CC-K	R-MT	HS-US	K-PS	6.20	4.20	5.20	5.20	6.80	173	3044	2599	108
IV	34	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.00	5.33	5.50	6.80	172	2990	2618	105
IV	35	BC-GC	CC-K	R-US	HS-MT	K-PS	6.60	4.20	5.00	5.25	6.80	173	3053	2626	103
IV	36	BC-US	CC-K	R-GC	HS-MT	K-PS	6.00	4.20	5.20	5.25	6.80	173	3014	2620	105
IV	37	BC-GC	CC-K	R-US	HS-MT	K-PS	5.20	4.00	5.67	5.75	6.80	172	3005	2628	103
IV	38	BC-GC	CC-K	R-US	HS-MT	K-PS	5.00	4.20	5.67	5.75	6.80	173	3014	2628	103
IV	39	BC-GC	CC-K	R-MT	HS-US	K-PS	5.60	4.20	5.20	5.67	6.80	173	3024	2601	108
IV	40	BC-GC	CC-K	R-MT	HS-US	K-PS	5.60	4.00	5.33	5.67	6.80	172	3010	2601	108
IV	41	BC-GC	CC-K	R-MT	HS-US	K-PS	5.40	4.20	5.33	5.67	6.80	173	3019	2602	108
IV	42	BC-GC	CC-K	R-US	HS-MT	K-PS	6.60	4.00	5.20	5.25	6.80	172	3039	2628	103
IV	43	BC-PS	CC-K	R-US	HS-MT	K-GC	5.20	4.20	5.25	5.75	7.20	173	3030	2601	109
IV	44	BC-NS	CC-K	R-US	HS-MT	K-PS	6.33	4.20	5.25	5.50	6.80	173	3034	2672	94
IV	45	BC-GC	CC-K	R-US	HS-MT	K-PS	5.40	4.00	5.50	5.75	6.80	172	3010	2629	103
IV	46	BC-GC	CC-K	R-US	HS-MT	K-PS	5.20	4.20	5.50	5.75	6.80	173	3019	2629	103
IV	47	BC-PS	CC-K	R-MT	HS-US	K-GC	5.50	4.20	5.33	5.40	7.20	173	3035	2575	114
IV	48	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.20	5.00	5.50	6.80	173	3044	2630	103
IV	49	BC-PS	CC-K	R-GC	HS-MT	US-GC	5.00	4.20	4.33	5.25	7.33	173	3034	2507	128
IV	50	BC-PS	CC-K	R-US	HS-MT	K-GC	4.75	4.20	5.67	5.75	7.20	173	3020	2602	109

Table B.58: Path B Solutions (Phase IV Solutions 51 through 100)

Phase	Solution Number	Service Patterns					Headways (min)					Fleet Requirement	Estimated Total Operator Hours	Expected Wait Time (min per 1000 pax)	Transfers (per 1000 pax)
IV	51	BC-US	CC-K	R-GC	HS-MT	K-PS	5.33	4.00	5.60	5.75	6.80	172	2975	2623	105
IV	52	BC-US	CC-K	R-GC	HS-MT	K-PS	5.33	4.20	5.33	5.75	6.80	173	2990	2624	105
IV	53	BC-NS	CC-K	R-US	HS-MT	K-PS	7.00	4.00	5.25	5.25	6.80	172	3034	2675	94
IV	54	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.00	5.20	5.50	6.80	172	3029	2632	103
IV	55	BC-US	CC-K	R-GC	HS-MT	K-PS	5.20	4.20	5.60	5.75	6.80	173	2985	2624	105
IV	56	BC-GC	CC-K	R-MT	HS-US	K-PS	6.20	4.00	5.20	5.40	6.80	172	3025	2606	108
IV	57	BC-US	CC-K	R-NS	HS-MT	K-PS	5.50	4.20	5.67	5.75	6.80	173	2994	2672	95
IV	58	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.20	5.20	5.50	6.80	173	3039	2632	103
IV	59	BC-GC	CC-K	R-MT	HS-US	K-PS	6.00	4.20	5.20	5.40	6.80	173	3034	2606	108
IV	60	BC-GC	CC-K	R-MT	HS-US	K-PS	6.00	4.00	5.33	5.40	6.80	172	3020	2606	108
IV	61	BC-PS	CC-K	R-GC	HS-MT	US-GC	5.00	5.00	4.67	4.67	7.33	173	3042	2510	128
IV	62	BC-GC	CC-K	R-MT	HS-US	K-PS	5.40	4.00	5.50	5.67	6.80	172	3005	2607	108
IV	63	BC-GC	CC-K	R-MT	HS-US	K-PS	5.20	4.20	5.50	5.67	6.80	173	3014	2607	108
IV	64	BC-GC	CC-K	R-US	HS-MT	K-GC	6.60	4.00	5.25	5.25	7.20	172	3041	2634	103
IV	65	BC-GC	CC-K	R-US	HS-MT	K-PS	6.60	4.00	5.25	5.25	5.80	172	3041	2634	103
IV	66	BC-GC	CC-K	R-US	HS-MT	K-PS	6.60	4.00	5.25	5.25	6.80	170	3005	2634	103
IV	67	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.20	5.20	5.50	7.20	173	3045	2607	109
IV	68	BC-PS	CC-K	R-MT	HS-US	K-GC	5.75	4.20	5.20	5.40	7.20	173	3040	2580	114
IV	69	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.60	5.25	5.25	6.80	172	3023	2635	103
IV	70	BC-US	CC-K	R-GC	HS-MT	K-PS	5.50	4.00	5.33	5.75	6.80	172	2980	2627	105
IV	71	BC-PS	CC-K	R-MT	HS-US	K-GC	5.75	4.00	5.33	5.40	7.20	172	3026	2580	114
IV	72	BC-PS	CC-K	R-US	HS-MT	K-GC	5.00	4.00	5.67	5.75	7.20	172	3011	2607	109
IV	73	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	5.00	5.25	5.25	6.80	173	3032	2635	103
IV	74	BC-GC	CC-K	R-MT	HS-US	K-PS	6.60	4.20	5.00	5.20	6.80	173	3048	2609	108
IV	75	BC-US	CC-K	R-GC	HS-MT	K-PS	6.20	4.00	5.20	5.25	6.80	172	3005	2628	105
IV	76	BC-MT	CC-K	R-GC	HS-US	K-PS	5.25	4.20	5.60	5.67	6.80	173	2975	2599	110
IV	77	BC-PS	CC-K	R-MT	HS-US	K-GC	5.20	4.20	5.33	5.67	7.20	173	3025	2581	114
IV	78	BC-PS	CC-K	R-US	HS-MT	K-GC	6.20	4.20	5.20	5.25	7.20	173	3055	2608	109
IV	79	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.20	5.20	5.75	6.80	173	3029	2636	103
IV	80	BC-PS	CC-K	R-US	HS-MT	K-GC	5.20	4.00	5.50	5.75	7.20	172	3016	2609	109
IV	81	BC-US	CC-K	R-GC	HS-MT	K-PS	5.75	4.20	5.20	5.50	6.80	173	3004	2629	105
IV	82	BC-PS	CC-K	R-US	HS-MT	K-GC	5.00	4.20	5.50	5.75	7.20	173	3025	2609	109
IV	83	BC-NS	CC-K	R-US	HS-MT	K-PS	6.33	4.00	5.50	5.50	6.80	172	3020	2680	94
IV	84	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.60	5.25	5.25	7.20	172	3030	2609	109
IV	85	BC-GC	CC-K	R-MT	HS-US	K-PS	6.20	4.00	5.00	5.67	6.80	172	3020	2611	108
IV	86	BC-GC	CC-K	R-MT	HS-US	K-PS	6.00	4.20	5.00	5.67	6.80	173	3029	2611	108
IV	87	BC-PS	CC-K	R-GC	HS-MT	US-GC	4.40	4.20	4.67	5.50	7.33	173	3014	2515	128
IV	88	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.00	5.25	5.50	5.80	172	3031	2638	103
IV	89	BC-GC	CC-K	R-US	HS-MT	K-GC	6.20	4.00	5.25	5.50	7.20	172	3031	2638	103
IV	90	BC-GC	CC-K	R-US	HS-MT	K-PS	6.20	4.00	5.25	5.50	6.80	170	2995	2638	103
IV	91	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.20	5.25	5.50	6.80	171	3004	2638	103
IV	92	BC-GC	CC-K	R-US	HS-MT	K-GC	6.00	4.20	5.25	5.50	7.20	173	3040	2638	103
IV	93	BC-GC	CC-K	R-US	HS-MT	K-PS	6.00	4.20	5.25	5.50	5.80	173	3040	2638	103
IV	94	BC-GC	CC-K	R-US	HS-MT	K-PS	5.60	4.60	5.25	5.50	6.80	172	3013	2638	103
IV	95	BC-PS	CC-K	R-US	HS-MT	K-GC	5.50	4.00	5.25	5.75	7.20	172	3021	2611	109
IV	96	BC-PS	CC-K	R-MT	HS-US	K-GC	5.75	4.20	5.00	5.67	7.20	173	3035	2585	114
IV	97	BC-GC	CC-K	R-US	HS-MT	K-PS	6.60	4.20	5.20	5.20	6.80	173	3058	2640	103
IV	98	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.20	5.25	5.50	7.20	171	3011	2612	109
IV	99	BC-PS	CC-K	R-US	HS-MT	K-GC	5.75	4.20	5.25	5.50	6.20	173	3047	2612	109
IV	100	BC-PS	CC-K	R-GC	HS-MT	US-GC	5.20	4.20	4.20	5.25	7.33	173	3039	2518	128

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