July 2020

School Bus Routing To Allow Later School Start Times

Rana Eslamifard

SCHOOL BUS ROUTING TO ALLOW LATER SCHOOL START TIMES

A Thesis Presented

by

RANA ESLAMIFARD

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

May 2020

Civil Engineering

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ACKNOWLEDGMENTS

My deep gratitude goes to Dr. Eric Gonzales for all his support, guidance, and patient through my graduate education. This Thesis would have not been possible without his persistent help, timely advice, and enthusiasm.

I thank my committee member and teacher Dr. Eleni Christofa for her constant encouragement, inspiration and kind help throughout this project and my study period.

Above all, I want to thank my parents and brother for their support and encouragement from thousand miles away. Every step that I took in my life and academic journey comes from the confidence, strength, and love they gave me; for that, I am so grateful.

ABSTRACT

SCHOOL BUS ROUTING TO ALLOW LATER SCHOOL START TIMES

MAY 2020

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School districts provide busing services for students who live too far to walk to school. In many districts, a fleet of school buses is used in sequence to transport high school students, then middle school students, and then elementary school students. The result is that high school classes must start much earlier in the morning than the elementary school, and buses may traverse similar routes three times each morning and afternoon. In light of recent research on the benefits of later high school start times and the need to control transportation costs, school districts are seeking efficient school bus routing plans that meet student needs at low cost. This study uses 2018 data for schools in Northampton, Massachusetts, to identify the potential to achieve two objectives: 1) start the high school classes as late as possible in the day, and 2) minimize the cost of busing. The proposed procedure makes use of existing school bus data to optimize bus routes, which can be applicable to smaller cities. A revised routing plan that mixes high school and middle school students on the same buses allows the high school to start 45 minutes later while reducing total school bus operations by 8.5 bus-hours per day. The elementary school and high school start times could also be swapped with minimal effect on the cost of busing.

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CHAPTER 1

INTRODUCTION

School buses are used to provide safe transportation for students that live too far to walk to school. And most comfortable vehicles on the road as they are part of the daily life of students. National Highway Traffic Safety Administration (NHTSA) provides standards for the safety of both buses and routes. It presents guidelines for driver attitude, student management, highway-rail grade crossing safety, route knowledge, etc. (1). In addition to safety aspects, which are heavily regulated for school buses, the efficiency of school buses in moving students quickly, equitably, and cost-effectively are determined by the route design and daily schedule.

Moreover, public expenditure is a concern for school districts. Due to budget shortfalls, districts try to reduce the number of buses used in their daily operations. Additionally, efforts to optimize school bus routing and schedules are widely studied to reduce costs. A school time selection model for Boston relies on a school bus routing algorithm, allowing the school districts to design bus routes, select proper start times, and redeploy buses in each daily operation in order to reduce the annual costs significantly (2). There are several methods to reduce costs, but the constraints lead route planning to focus primarily on components such as schools' start and end times, walking safety factors, bus routes, and the priorities for different school levels.

Among the approaches to reduce busing costs, changing school start times is gaining attention. Studies show that choosing the best school start time contributes to faster student learning (3,4), avoids depression (5), and reduce traffic accidents (6). Starting classes later have been shown to improve the grades for students from different Levels in schools, which change start times, and it can be beneficial for students and school districts since it is cost-effective compared to other educational interventions (7). The American Academy of Sleep Medicine's (AASM) recommends 8-10 hours of sleep for teenagers 13 to 18 years of age and 9-12 hours for the children between 6 to 12 years old, with an association between insufficient sleep and obesity (8). It is common for high schools to start early in the morning, contributing to inadequate sleep among teens.

The physical activity identified as a critical contributor to student wellness and performance in school (9). As a result, students with access to safe walking routes from the place of residence to the entrance of the school building would benefit from walking instead of riding a school bus. A study in Ireland found that 1.5 miles are an appropriate walking distance for students between ages 15 to 17 years old (10). An efficient bus routing plan should transport students that live too far from school to walk while using the fewest resources possible. For this study, no changes have made for elementary schools, and the buses use the same bell time and schedule.

1.1 Motivation

Finding strategies to use a fewer number of buses needed to serve schools are widely dis Northampton. So new routes are designed that allow the high school to start as late as possible. By modifying the route schedules and stops, the study provides a solution to benefit students by starting the high school later and benefit the school district to reduce bus-hours of operations and save money. A diagram of this approach is shown in Figure *1*.

Figure 1: Approach to reorganizing school bus routes

1.2 Research Objectives

As declared in the problem statement, the main goal of this research was to analyze the busing system in Northampton to find a strategy for reducing the transportation cost and providing better transportation to students. This research tried to answer research questions in the following parts.

1.2.1 Optimize Route Design

Route optimization aims to keep the route length short and load full buses. Also, the routing should provide the capability to tier routes. The number of buses, stops, and traffic congestion is an important factor. The following questions aimed to be answered in this research.

- Can we put as many students on the bus?
- Can we have a routing plan that can take all the middle school and high school students from the same route?
- How close can we get the high school and the middle school let-out to elementary school?
- Can time on buses be made shorter?

1.2.2 The Bell Schedule

The bell schedule affects the students' pick-up time. In many districts, the school start time shifts later from 8 am to 9 am. These start times permit the district to use the same drivers for sequential operations. This research tries to find out about the following question:

- According to the bus trip duration in each tier, how late can the school be started?

1.2.3 Coordinate High School and Middle School Calendars and Schedules

Staggering start time lets the same bus drop off older and younger students at different times. It means that students share the same routes, so mixing high school and middle school students could answer the following question:

- Can fewer buses be used by mixing older and younger students?

1.2.4 Walking

In large cities, because of the time limitation walking to a fixed bus stop is considered as a mode for students; however, for a smaller cases door-to-door transportation is preferred. This study tried to provide options for both walking to school and door-to-door transportation. All the options can be reviewed by the district, but it is noteworthy that making students walk to school can reduce total time a student spends on the bus based on guidelines (11), and has health benefits according to physical inactivity caused by machinery life nowadays.

1.3 Scope

Though many alternatives affect transportation cost, and in light of increasing attention for bell times, as early start time has known for creating and educational issues in high school students, the scope of this study is determined by what steps should be taken to design a bus system to meet items as mentioned earlier. It is also recognized that

There are many different scheduling options. This study comes up with three different options for all three school grades. These options provide plan for start time and route plan for three different school levels. In spite of many mathematical algorithms for optimization that have been used for bus routing, the study follows non-mathematical procedure that can reach the district and students' needs at a little cost. Also, this initial bus study helps to increase local information about the city and the busing characteristic, which can be used for as a base source for the future optimization studies in the city of Northampton.

CHAPTER 2

BACKGROUND

A concept relating to the current busing system and regulation are discussed in this section. In response to the school district to create a plan to increase the efficiency of school bus transportation more Also school district policy and bus information that is determined by the number of the routes served by each bus and the number of students riding on each bus are presented in the following sections.

Northampton is a city of 28,500 residents in Western Massachusetts. Northampton Public Schools is the local school district with six schools including one high school (Northampton High School, a.k.a. NHS), one middle school (John F. Kennedy School, a.k.a JFK), and four elementary schools (Jackson Street School, Bridge Street School, Ryan School, and Leeds School). Details regarding the start and end time of the school day provided in Table *1*. As has been shown, the high school start and end times are earlier than other levels. The school hours for high school and middle school are the same, and it is 6.5 hours.

Information regarding the existing routing plan, distances, and the number of buses is provided in Table *2*. Some of the middle school bus routes are experiencing longer travel time due to morning rush and loops in their path. Also, high school students are hurting because of early pick-up and drop off time. The waiting from drop-off to school start time is 25minutes for a student in high school grade, plus the bus travel time and time needed before pick-off time; the current plan does not seem to be a healthy plan.

Table 1: Northampton Public Schools Start and End Times

School	Start (AM)	End (PM)
NHS (high school)	7:30	14:00
JFK (middle school)	7:50	14:20
Bridge Street (elementary school)	9:00	15:10
Jackson Street (elementary school)	9:00	15:10
Leeds (elementary school)	9:00	15:10
Ryan Road (elementary school)	9:00	15:10

Table 2: Schedule and Route Information for The Existing Situation in Northampton Public Schools

School	Route	Number of Students	Total Route Length (mi)	First Pick- Up	Drop Off at School	Longest Riding Time (min)
Tier 1: High School						
NHS	1	38	10.0	06:35	07:05	30
	2	33	7.4	06:42	07:05	23
	3	46	4.4	06:44	07:05	21
Tier 2: Middle School						
JFK	1	42	5.7	07:17	07:40	23
	2	34	8.9	07:13	07:40	27
	3	46	5.7	07:15	07:40	25
	4	41	3.6	07:26	07:40	14
	5	20	9.4	07:13	07:40	27
	6	43	6.1	07:16	07:40	24
	7	22	6.2	07:23	07:40	17
	8	44	4.3	07:26	07:40	14
	9	36	2.6	07:32	07:40	8
Tier 3: Elementary Schools						
Jackson	1	32	4.9	07:55	08:35	40
Bridge	1	30	10.6	07:59	08:35	36
	2	37	10.0	07:59	08:35	36
Ryan	1	25	12.1	08:01	08:35	34
	2	31	6.20	08:14	08:35	19
Leeds	1	11	11.3	08:09	08:35	24
	2	60	8.60	08:13	08:35	22
	3	22	4.50	08:21	08:35	14
	4	51	4.00	08:21	08:35	14
	5	3	5.60	08:13	08:35	22

The current policy in Northampton Public Schools tells that the students in grades 6 to12 (typically 11-18 years of age) with walking distances more than 1.5 miles from their school are eligible for school bus service (12). Students living within 1.5 miles also have busing eligibility if there is not a safe and walkable route to school where seats are available, otherwise ineligible students can apply for bus service for a fee.

The school district provides a school bus service for these schools in three tiers (one for each level of school). Schools' start times are staggered so that school buses can operate in three tiers (one for each level of school). After transporting students to high school, buses go out again to transport middle school students and then go out for the third time to transport students to the elementary schools. As shown in Table *2*, five buses are running in three-tier, four buses in two-tier, and one bus in one-tier for each school's grades. This system consists of 10 buses and 71 seats. For our case, the school district considered 50-52 seats for students in middle school and high school.

shows the daily timeline for the student with the longest commute in each tier, which is from the time that they are picked up in the morning to dropped off by the bus in the afternoon. The timeline presents essential information such as start time, bus trip duration (yellow), waiting time between bus transportation and school start/end time (red), and school hours (green) for the most extended bus trips. This situation analyzed for four main criteria: high school start time, high school and middle school stops, the number of students in each stop, and current routes.

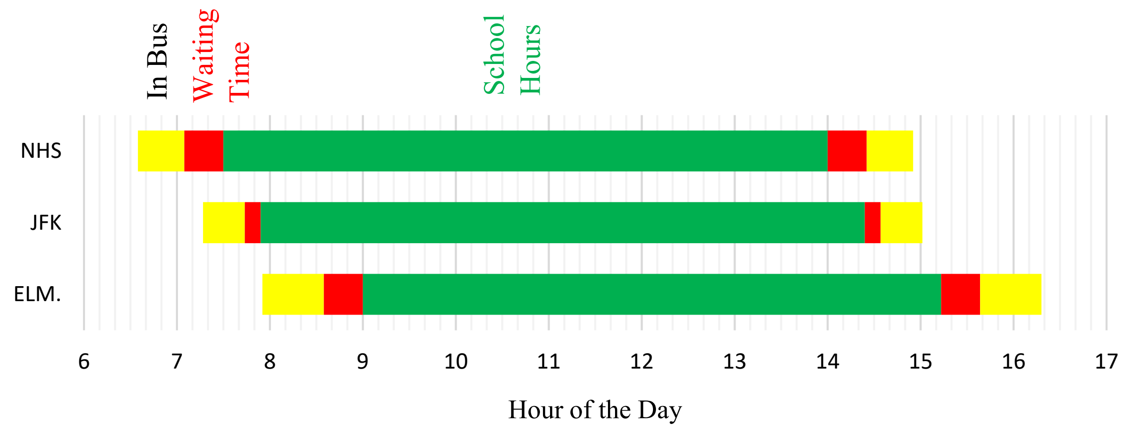


Figure 2: Existing timeline for high school, middle school, and elementary school

CHAPTER 3

METHODOLOGY

To reduce costs and allow schools to start at times that are closer together, school bus routes need to be appropriately organized. In Northampton, the bus routes must be reorganized if the time between the start times of the high school and elementary schools are to be closer together (i.e., the high school is to start later). The students who need school bus service can be assigned to each bus with special-purpose algorithms allowing students from different schools to ride together (13, 14). Some previous bus studies provide a mathematical algorithm to formulate bus routing problem; however, fixed location of bus stops in this study is a limitation which requires an specific method.. So, the proposed study found this method practical for conducting the bus study by using ArcGIS and web map tools in order to create a new routing plan and schedule.

The current school bus system in Northampton works with three tiers of service, meaning that buses are dispatched up to three times in order to serve high school, middle school, and elementary school students. In this study, a two-tier bus system is introduced on each route to pick-up and drop-off high school and middle school students first before the same bus goes to take elementary school students. The proposed methods keep the tiered system but maximize the efficiency and consolidate high school and middle school students to fill the empty seats on the buses. The following sections show the procedures that were employed to meet the research objectives.

3.1 Spatial Analysis

In our network, the first step is to group of bus stops together by school served and their location. This locational analysis is conducted using the distance tool in ArcMap.

Therefore, the bus stops and the location of schools imported in ArcMap, and the shortest path from each stop to the associated school is measured. This shortest-path analysis is used to cluster stops that are on the shortest route to the school.

To design the system structure, a preliminary design is adopted based on the general features of the network (15). The preliminary design is based on an aggregated approach to define different parts of the city, each served by different buses. The city of Northampton was divided into different parts, based on identification of areas with lower traffic congestion, more concentration of bus stops, and the shortest path analysis information. Each part represents a cluster of stops, and the new routes assign buses to pick up students within only one cluster. For example, one bus in the north-west cluster does not make a trip to the north-east cluster.

The required data for this analysis includes the number of students at each stop and the number of stops within 1.5 miles of the middle school and high school, which are extracted from the school district data. The latitude and longitude of each stop and the location of schools were imported to ArcMap. To protect students' privacy, specific school bus stop location cannot be displayed on the map; however, in the ArcMap model, each school has a layer of its bus stops and the number of students. A new feature class is identified for places where existing middle school and high school bus stops are overlapping.

Traffic information, that is provided for time of day, on Google Maps and Bing Maps were used to estimate travel times during the morning peak-hour. It was observed that during the morning peak-hour, travel time varies significantly. as a result, the traffic pattern and times with higher travel time were determined in a time window from 7:00 to

7:30 am in October 2019 while public schools were in regular session in order to choose the best early pick-up time. The optimal start time can reduce the total bus travel time and decrease deadhead time when a bus runs without students to shift between tiers. In the following steps, a route layout is designed using this method for the whole town, including the merged high school and the middle school stops.

3.2 Identification of New Routes

In the new school bus route design, different sections of the city have different characteristics and the following assumptions are considered in this phase:

- The high school and middle school bus routes are consolidated, and high school and middle school students should sit together on the bus. As it can be seen on Figure 2, the middle school has similar routes as the high school, so the consolidation of middle school and high school busing appears to be a promising strategy, and it can maximize the efficient use of the school buses.
- In the first tier, some routes have an intermediate stop at the high school or middle school. This stop allows high school and middle school students to be picked up together and then dropped off at their respective schools. For example, some buses are designated to stop at Northampton high school in the middle of the first tier. In this way, they pick-up high school and middle school students together, drop off high school students first at Northampton high school, and then fill the seats with middle school students that have walked to the high school and finish the first tier at JFK middle school.

Based on the generated clusters, the number of students waiting at each stop, and the location of stops, an initial plan identifies the routes that are better served with an intermediate stop. The result is that more students fill each of the buses. Since the study is looking for an approach to consolidate high school and middle school and reduce the cost of transportation, the effects of new routes on travel time and distance were analyzed.

Finally, the results from both Google Maps and Bing Maps were compared, and the final route plan was considered. The new routing considers constraints provided by school districts:

- Elementary school students cannot start the school day any later than 9:00 AM.
- The high school and elementary school students are not allowed to sit on the same bus together.
- Students must be dropped off at least 10 minutes before the school day starts.

According to the three improvements considered in this work, two routing plans are presented. The main difference is in route 8, representing the situation in which a new route is needed to serve all students that currently take the bus compared to the situation in which students within 1.5 miles of the school must walk.

3.3 Identification of Shortest Repositioning Path

An optimization algorithm is proposed to find the shortest repositioning path for the buses between each tier in order to minimize the delay in the system. The shortest repositioning path is defined by comparing the shortest distance from the last stop in tier 1 to the first stop in tier 2. A set of routes identified from last stop in tier 1 to the first stop in tier 2.

The shortest distance for each pair of stops is obtained from Google Maps. The optimization problem is formulated as follows:

$$\text{Min } \sum_{ij}^{n} X_{ij} d_{ij}$$

$$\text{S.t. } \sum_{i} X_{ij} = 1$$

$$\sum_{j} X_{ij} = 1$$

$$X_{ij} \in \{0,1\} \tag{1}$$

where d_{ij} corresponds to the distance from last stop of tier 1 to the first stop of tier 2, and $X_{ij} = 1$ if route i in tier 1 is linked to route j in tier 2.

3.4 Students' Boarding Time

One of the challenges for calculating new travel times for each route is estimating the time that it takes for the students to board the bus. Assuming that the buses move at the same speed as cars when they are not stopping to pick up or drop off students, route travel times are estimated using Google Maps, and two travel times for the same route calculated. The first travel time is from the current reported schedule, including students boarding time. The second travel time represents the non-stop trip from the first stop to the last stop on the same route. To estimate the travel time for each of these routes, it is necessary to use the existing school bus schedule to estimate the dwell time at the bus stops for students to board. Figure *3* shows a plot of distances between stops versus travel time, based on an existing school bus route. The intercept indicates that there is an average loss and dwell time of 2 minutes per stop. The net travel time (i.e., the difference of the scheduled travel time and the estimated travel time in traffic without bus stops) is divided by the number of students and an average of 8 seconds considered for each student to board the bus at each stop.

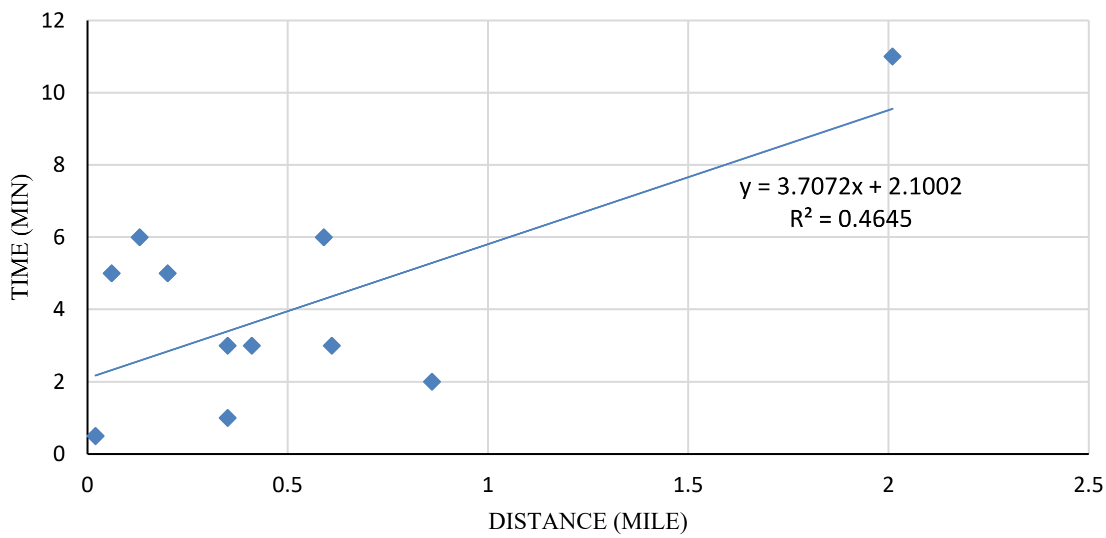


Figure 3: Time versus distance interceptor for one of the existing routes

3.5 Identification of Students Miles and Hours Walked

Identifying students who can walk to school is challenging. Walking has many benefits for both students and schools. In this study, walking was considered as an option to reduce reliance buses and give the students more exercise. Students living within a short distance of school (1.5 miles for middle school and high school students in Northampton) are not guaranteed bus service, as they are expected to be able to walk a safe and reasonable distance. However, it seems that walking in cold areas can be found challenging for younger students. An issue that exists in many communities, including Northampton, is the lack of sidewalks in some parts of the town. Only the streets close to the downtown area have adequate sidewalks and marked crosswalks. In Northampton, many middle school students live close to the high school, which is centrally located in the downtown area.

Therefore, a busing plan is proposed in which middle school students whose current bus stop is within 1.5 miles straight line distance of the high school[1] walk to that school.

Using ArcGIS, a buffer with a radius of 1.5 miles is created. Within this radius, the bus stops, and the number of students are displayed. A new layer, including the stops corresponding to students who can walk to high school was also created in ArcMap, and walking time and distances calculated. In Table 3, The additional students miles walked is fixed and not necessarily known.

Table 3: Students Walked Miles and Hours from Fixed Stops

Stops	Number of Students	Distance (mi.)	Students Walked Miles	Duration (minutes)	Students Walked Hours
Barret St.	18	1.3	23.4	21	6.30
186 Jackson St.	18	1.1	19.8	22	6.60
211 N. Elm St.	9	0.8	7.2	16	2.40
182 Prospect St.	9	1.1	9.9	21	3.15
134 State St.	9	1.3	11.7	26	3.90
222 Elm St.	18	0.6	10.8	11	3.30
309 Elm St.	5	0.4	2	7	0.58
63 Riverside Dr.	9	0.3	2.7	7	1.05
311 Riverside Dr.	9	0.9	8.1	18	2.70
Sum	104	7.8	95.60	-	29.98

[1] A straight-line distance of 1 mile is expected to prevent the actual network distance of any students' walk from exceeding 1.5 miles.

CHAPTER 4

APPLICATION OF METHODS IN NORTHAMPTON

In many cities, the school bus routing problem can be modeled by implementing a mathematical algorithm with a large set of data and computing a solution. A computational solution approach is one way to solve the routing problem. However, they can solve a combined problem with some fixed assumptions that do not apply to other cases. For instance, a time window for bell time cannot be adjusted for some districts, although it is flexible in some others. Here, possible methods are introduced to illustrate the impact of different school bus routing strategies on feasible school start times, travel times for students, and operating costs.

As mentioned earlier, this work seeks to combine bus trips for high school and middle school with a single bus. By serving two levels of schools with shared bus routes, the system is designed to achieve shorter trip time and access to schools. The new model is a two-tier system in which the buses serve high school and middle school in one tier and the elementary school in the second tier. As part of the re-routing plan, the timings have changed for each school grade, following the idea that slight changes in school start times can make it possible to link more trips together in a single bus route.

4.1 Case 1 High school and Middle School Start First, Students Walk Within 1.5 Miles

In this case, high school and middle school start at the same time. Optimal scenarios for each school are based on enforcement of the policy that the students should walk if they are within 1.5 miles of the nearest school, so middle school students living within 1.5 miles of Northampton High School (NHS) should walk to NHS, and high school students living within 1.5 miles of John F. Kennedy Middle School (JFK) should walk to JFK.

Newly designed routes can let the buses serve both high school and middle school. On every journey, the buses pick-up students until the maximum capacity of 50-52 seats reached. In the intermediate stop, high school or middle school students are dropped off, and the bus continues to board the rest of the students associated with the final school. It means that after the intermediate stop, students with the same grade level travel together. The buses run in the shortest possible path and are routed to maximize utilization of capacity, thereby reducing total travel time for the entire system.

The re-routing of buses for combined service of middle school and high school students allows the bell time to be changed to 8:00 AM, and the students arrive ten minutes before the classes start. This represents a shift of the high school start time to 30 minutes later and the middle school start time to 10 minutes later than in the existing schedule. Based on the traffic congestion in the morning and bell time for high school and middle school, the best start time is suggested for each route. A common feature of bus plans is that the first tier ends at 7:50 AM for all routes. This feature allows the buses to move to the second tier start location as soon as possible and can reduce the deadhead time. This case also reduces the number of required buses from nine to eight for the first tier. The eight buses can board all the middle school and high school students with this plan. This routing plan is shown in Figure *4*, which shows 8 colored lines for the 8 proposed school bus routes.

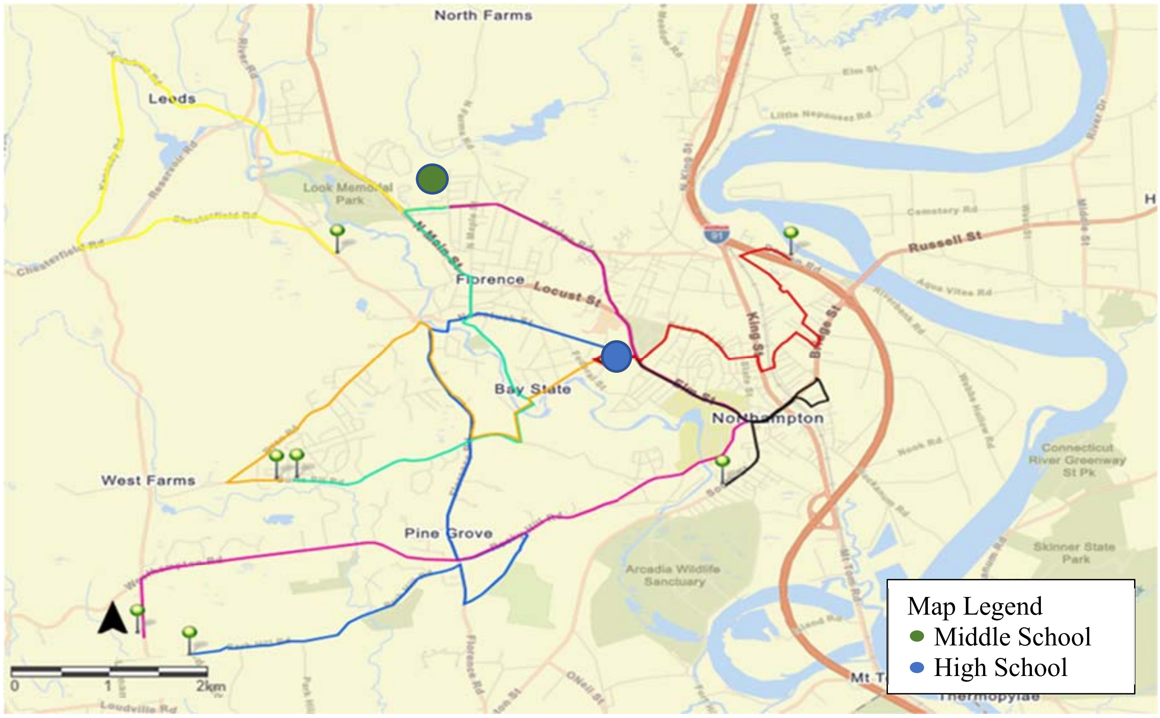


Figure 4: New school bus routes for middle school and high school in Case 1

The adoption of new routes allows the system to run with eight buses. The bus stops in the existing routing plan are remained the same in our new model. The difference is that they are combined into different routes.

In Figure 5, the changes for the proposed two-tier system, including the students' pick up and waiting time, and the school bell time are illustrated. We use the consolidating approach for the high school and the middle school to achieve the best plan for the system. The optimized repositioning time is the key to the improvement of the performance of the buses in both tiers. The elementary school routing plan remained unchanged, so the revised routing and schedule for the high school and middle school is presented relative to the fixed elementary school schedule.

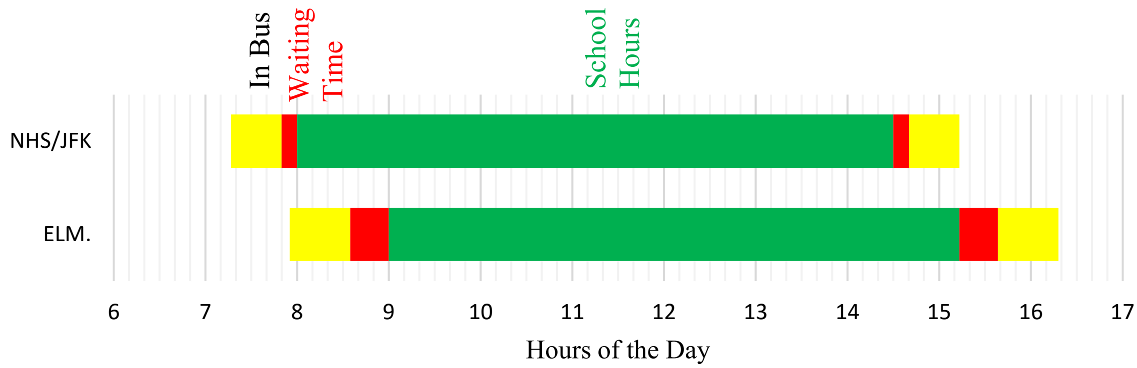


Figure 5: Case 1 timeline for the worst-case condition

4.2 Case 2 High School and Middle School Start First, No Student Forced to Walk

In Case 2, middle school students could either wait for the bus or walk to school. The walking distances are planned to be less than 1.5 miles. However, the buses are routes to carry all students that currently sign up for bus service, and there is no limitation for picking up those who need the ride. As a result, the system requires nine buses and adopts a new route plan for this change. This new route covers the stops in a 1.5 miles radius of high school, and students who were forced to walk in case 1. The route structure for Case 2 is illustrated in Figure 7. The assigned bell time, repositioning time, and the pickup and drop off schedule for nine buses (two of which share route 6) are shown in

Table 4.

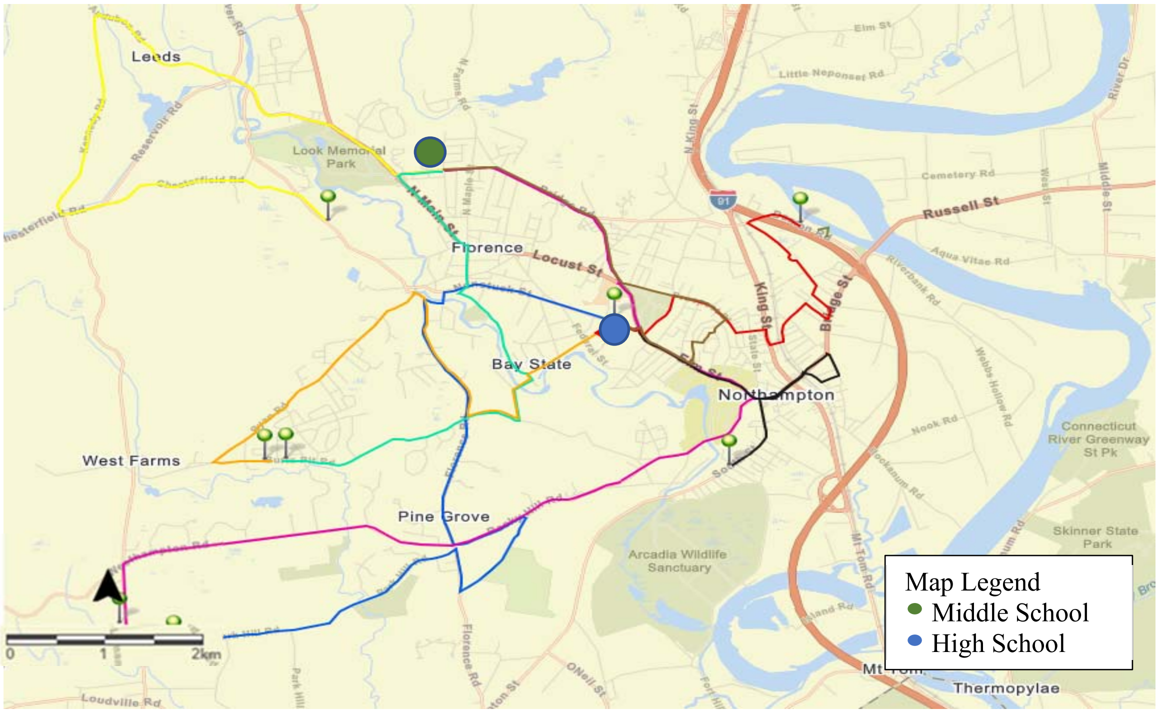


Figure 6: New school bus routes for middle school and high school in Case 2

Table 4: Schedule of Case 2 Bus Routes in Northampton, Massachusetts

School	Route	Number of Students	Total Route Length (mi)	First Pick- Up	Drop Off at School	Longest Riding Time (min)
Tier 1: High School and Middle School						
NHS/JFK	1	55	8.5	07:20	07:50	30
	2	55	9.0	07:18	07:50	32
	3	60	9.3	07:17	07:50	33
	4	42	4.5	07:30	07:50	20
	5	38	7.6	07:23	07:50	27
	6 A	50	2.95	07:20	07:50	30
	6 B	43	2.95	07:23	07:50	27
	7	56	7.1	07:15	07:50	35
	8	50	5.0	07:25	07:50	25

4.3 Case 3 Elementary School Starts First, Students Within 1.5 Miles Walk

In Case 3, we investigate a situation in which the elementary school switches the start time with high school and middle school so that the elementary school starts first. In many districts, the start times are spaced in a way that release the high school students before the elementary school. Such a system designed for the older students to be able to care for their younger siblings. Despite this challenge, we consider this tiered model as a way to achieve the latest possible high school start time. The waiting time is reduced for the elementary schools as the bus drops students off only 10 minutes before class starts, and the school bell time is moved earlier, but the same route plan for the elementary school tier with ten buses continues to run (Tier 3 in Table *2* and Tier 1 in Table *5*).

Table 5: Schedule of Case 3 Bus Routes in Northampton, Massachusetts

School	Route	Students	Total Route Length (mi)	First Pick- Up	Drop Off at School	Longest Riding Time (min)
Tier 1: Elementary Schools						
Jackson	1	32	4.90	07:10	07:50	40
Bridge	1	30	10.61	07:14	07:50	36
	2	37	10.00	07:14	07:50	36
Ryan	1	25	12.14	07:16	07:50	34
	2	31	6.17	07:31	07:50	19
Leeds	1	11	11.27	07:26	07:50	24
	2	60	8.62	07:28	07:50	22
	3	22	4.48	07:36	07:50	14
	4	51	4.00	07:36	07:50	14
	5	3	5.61	07:28	07:50	22
Tier 2: High School and Middle School						
NHS/JFK	1	66	9.30	08:17	08:50	33
	2	60	9.30	08:17	08:50	33
	3	42	4.50	08:30	08:50	20
	4	58	7.60	08:23	08:50	27
	5	50	6.20	08:18	08:50	32
	6	50	6.20	08:22	08:50	28
		68	6.20	08:20	08:50	30
	7	66	9.00	08:17	08:50	33

The high school and middle school route plan follow the route plan that was established in Case 1, but the bell time is moved later. In the routing scenario, the walking mode is the same as that for Case 1, with students within 1.5 miles from the high school walking to that school. Since the routes follow the same design as Case 1, the trip durations also remain the same.

The timeline in Figure *7* illustrates an overview of the changes for the trip duration and the repositioning of school start times for a two-tier system in Case 3. These indicate a reduction in bus hours of operations. This model shows that switching the order provides an opportunity to dismiss the buses sooner than the existing model, which would reduce operating costs. Despite the potential for transportation cost savings and later high school start time, the complex policy problem of considering the need for high school students to have time available in the afternoon to care for younger siblings or participate in extracurricular activities should also be considered before overhauling the school bus routing and bell schedule.

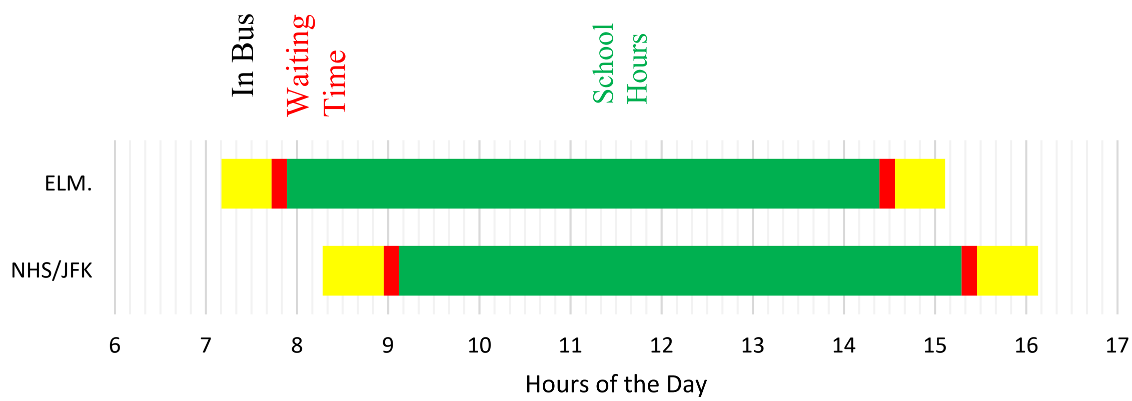


Figure 7: Case 3 timeline for the worst condition

CHAPTER 5

RESULTS AND FINDINGS

This study presents a method for re-routing buses and adjusting school schedules that does not require a complicated mathematical algorithm or high-powered computing resources. The main goal of this study is to identify a school bus routing plan and schedule for six public schools that is safe for the students and allows maximum flexibility for scheduling the school start times. The proposed approach uses a strategy that matches the district scale and needs by first clustering bus stops where students need to be picked up, and then defining routes that connect these stops to schools with the shortest travel time. The arrangements are flexible and beneficial for both the school district and students. Table *6* summarizes the details and the critical differences in the performance measures. For all the cases, we defined a network in which a bus could serve the three levels of schools in two tiers: the high school and middle school together, and the elementary schools separately. In existing conditions, empty seats bring extra costs to the school, so mixing high school and middle school students fills empty seats in the buses, and as a result, it is possible to save one bus for the school.

With the new routing suggestion, it is expected that travel time will be reduced or remain the same for students as the current routing plan. The study found that by combining busing of high school and middle school students, the two schools could start at the same time. This start time can also be moved closer to the elementary schools' start time, which would have the effect of allow the high school to start up to 30 minutes later than it does currently. A limitation of this study is that it does not perform stop assignment, and new bus routes are designed only to link existing stops in a more efficient manner. However, the estimates of new bus hours of operation and bus miles traveled show a potential reduction compared to the existing condition.

Table 6: Performance Measures for Each School Bus Routing Case

Performance Measure	Existing	Case 1	Case 2	Case 3
Maximum Number of Buses for Middle/High School	9	8	9	8
Number of Buses for Elementary Schools	10	10	10	10
Daily Bus-Hours of Operations	28	19.4	23	24.4
Daily Bus-Miles of Operations	152	135	141	135
Maximum Ride Time for Elementary Schools (min)	40	40	40	40
Maximum Ride Time for Middle/High School (min)	30	33	35	33
Student Hours Walked	-	29.98	-	29.98
Students Miles Walked	-	95.6	-	95.6

The maximum ride time experienced by a student increased by three to five minutes in the proposed model (depending on the case) compared to the existing schedule (see Table 6). This increase in ride time is small compared to the change in school start time, which is 30 minutes later, so the net effect is that all students in high school and middle school grades are able to leave their home later in the morning.

The suggested plan for forcing students within 1.5 miles straight-line distance to walk in Case 2 has health and educational benefits. The longest walking time is approximately 26 minutes for students who live further from NHS.

Approximate cost data from Northampton Public Schools indicate that each bus costs $340 per day to operate a single tier of service and an 20% ($68) for each additional tier. Based on the existing schedule for school busing in three tiers, we estimate that each additional tier adds approximately 0.5 hours of operations, which implies an operating cost of $65 per bus-hour. The remaining costs are assumed to be the fixed costs that are independent of operation, which amount to $281 per day. These cost parameters are used to estimate the daily busing cost associated with each of the cases.

The data in Table *6* show that that assigning some student to walk and a later school start time (Case 1) outperforms the current model, reducing the cost of bus operations by $585 per day. These changes are intended to make the students more active and increase their academic performance in the morning. An additional benefit is that the proposed plan reduces total bus-hours and bus-miles traveled, even if all students that currently ride the bus continue to do so (Case 2). Critical changes such as switching schools order are also beneficial from a bus operating cost perspective, although there are other consequences of making the elementary schools start before the high school and middle school that make Case 3 challenging to implement.

CHAPTER 6

DISCUSSION AND RECOMMENDATIONS

This study sought to identify possible ways to reduce the costs of transportation for public school buses and provide a later high school start time in Northampton, Massachusetts. Different procedures were considered to achieve this goal with minimum data and computational requirements by making changes in scheduling and route planning. The study took several steps to find applicable methods and results to show that small cities could use the same methodology. Two critical factors were considered to ensure that the school district and the students ultimately benefit from any re-organization of the busing:

1. A later start time helps students to improve their study performance in class.
2. Reducing bus-hours or operations can reduce transportation expenditures for the school district.

Consolidating the high school and the middle school students onto common bus routes is possible with a new routing plan and by adjusting the schedule so that both schools start at the same time. New routing plans are proposed for three different cases, each of which satisfies the objectives of reducing bus operations and allowing the high school to start later. The method proposed uses clustering to assign routes to the different part of the city, so changes in the demand or stop locations may be accommodated by the same routing plan.

6.1 Results for Application to Northampton, Massachusetts

The proposed procedure is applicable for small cities, like Northampton. For a larger network, however, the optimization may be complicated by additional constraints or the much larger amount of data involved. In this study, the flexibility to adjust school start times provided an opportunity to investigate different cases in which schools switch their starting order to reduce costs.

For the application of the proposed procedure, we consider the constraints of the Northampton Public Schools policy, which states that

1. Elementary schools cannot begin later than 9 AM.
2. The high school must end before elementary school.
3. The high school and middle school students cannot be on the same bus as elementary school students.

Although the district limitations have an impact on the design, the results demonstrate efficient improvements comparing to the current condition. The new routes have several benefits compared to the previous design:

1. The buses are utilized closer to their full capacity.
2. Unlike the current condition, the buses are neither running empty nor over-occupied, so they can carry additional students in the future.
3. With this optimized approach, there is no conflict in the bus operations in each route.
4. The new routing is simple and easy to understand for the bus drivers, avoids loops that are inefficient or difficult to maneuver, and tries to choose the direction taking the minimum number of a left turns into consideration.

In this study, the identical start time for the high school and the middle school contributes to a coordinated schedule for elementary schools and could lower the traffic jams near their entrance. Travel times for students in the proposed cases are similar to the existing travel times, but with the later high school and middle school start times, no student must leave home earlier in the morning. Furthermore, the proposed routes reduce bus operations, saving and estimated $585 per day.

6.2 Recommendations

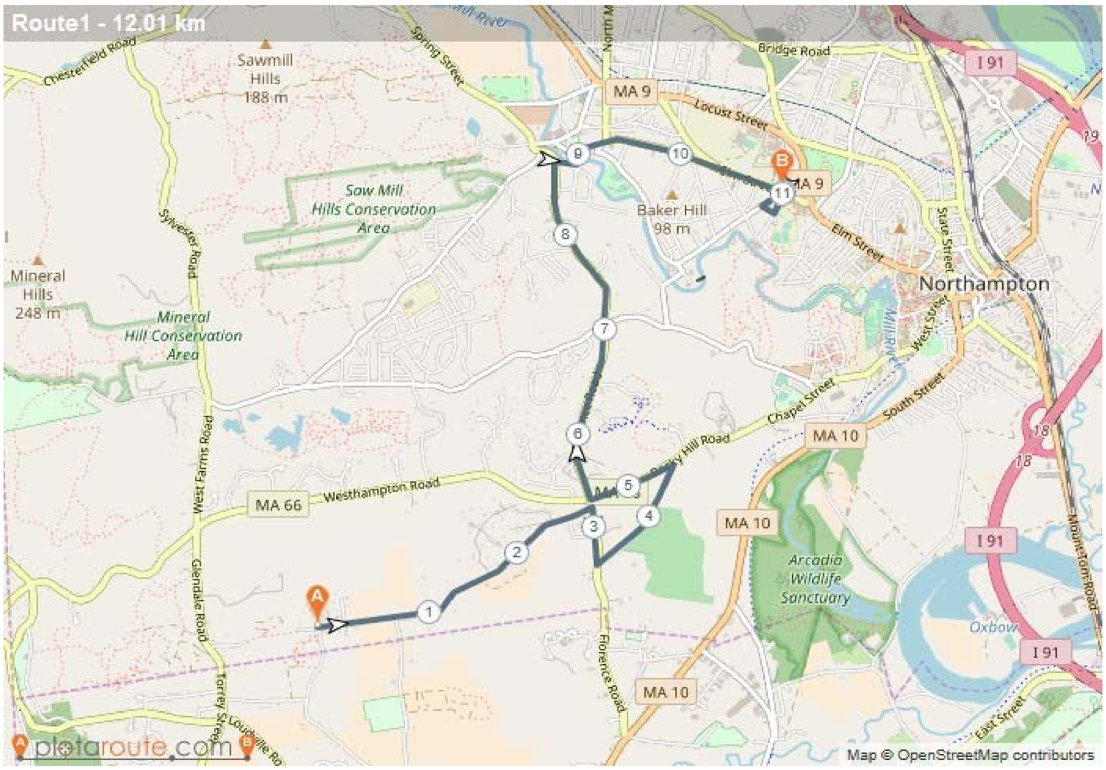
The bus service can be improved by adding buses to the fleet in order to reduce the riding time for students. Although adding buses can create an initial cost for the system, shorter routes, and bus-hours in the new stand-alone option with two tiers can operate with the same amount that the district is paying in existing condition.

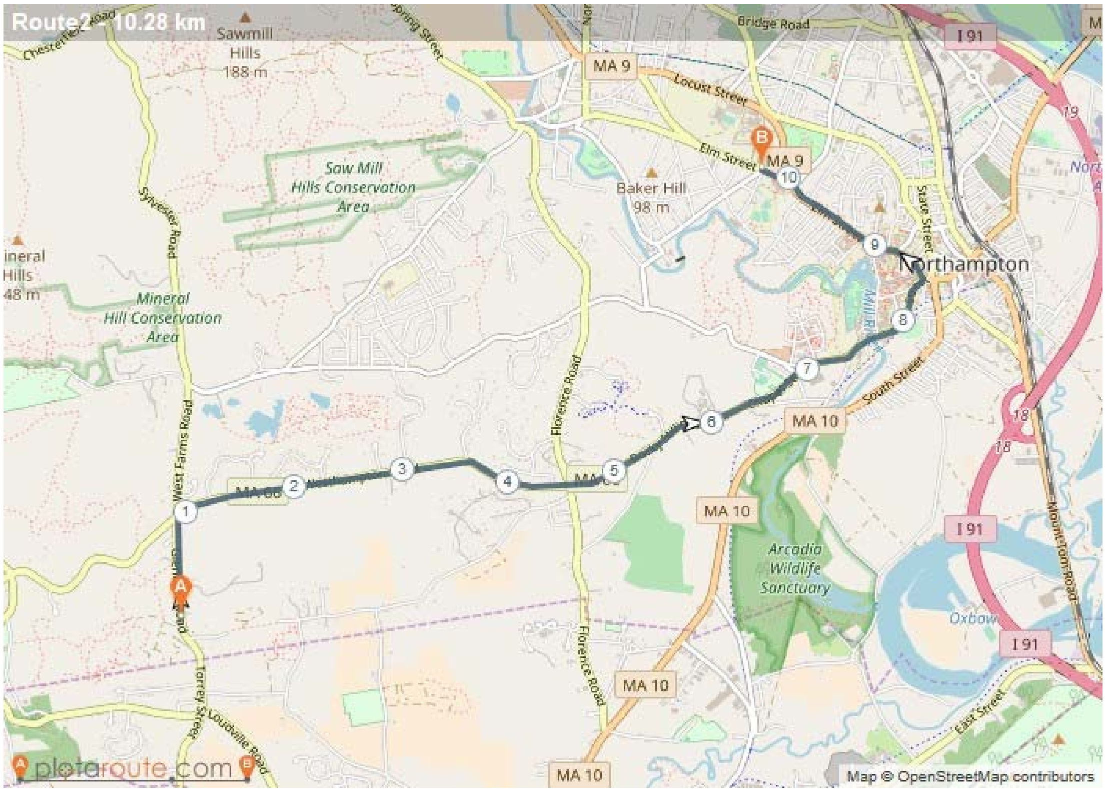
As proposed in the study, school districts in small cities with fixed stops can take advantage of using clustering method to renew their bus route. This method group stops with the same characteristics and prevent school buses from going on loop to pick up students from stops that have formerly been passed on that route.

APPENDICES

APPENDIX A

PROPOSED ROUTES





Route2 - 10.28 km
Sawmill Hills 188 m
Saw Mill Hills Conservation Area
Baker Hill 98 m
Northampton
Mineral Hill Conservation Area
Arcadia Wildlife Sanctuary
Oxbow
MA 9
MA 10
MA 66
I 91
Elm Street
Locust Street
Bridge Road
State Street
South Street
Florence Road
West Farms Road
Sylvester Road
Torrey Street
Loudville Road
Mountain Road
East Street
Mill River
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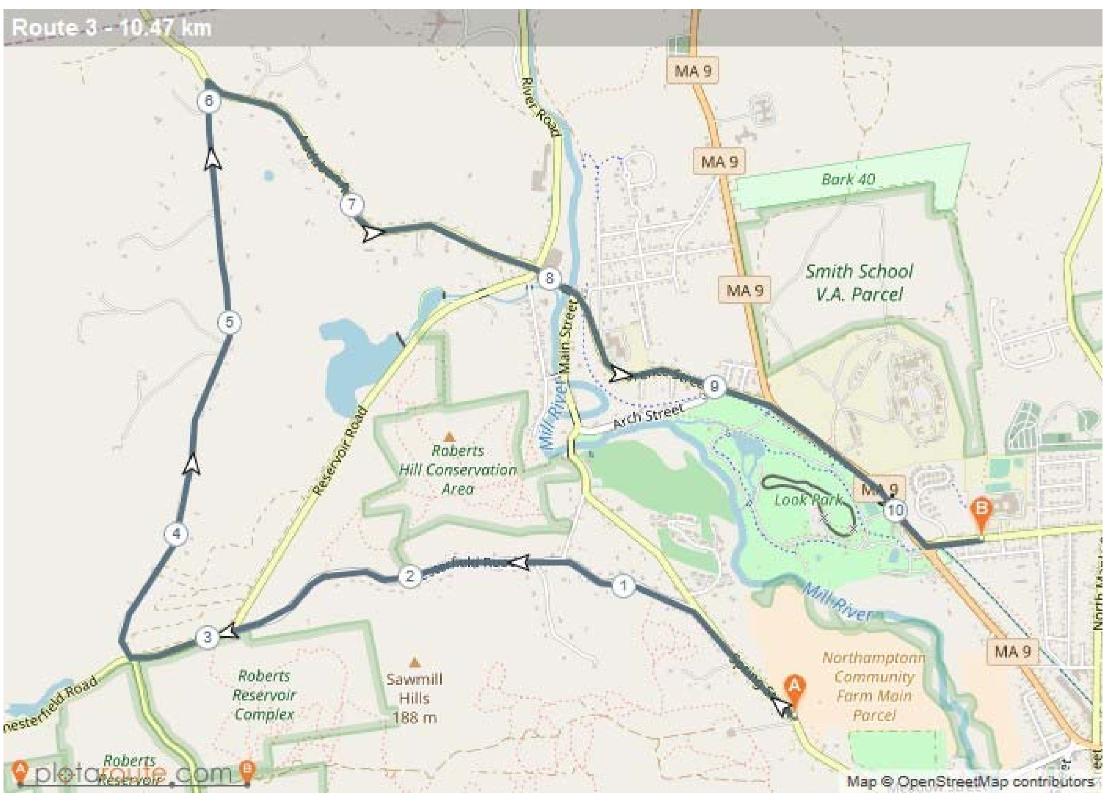

Route 3 - 10.47 km
River Road
MA 9
Bark 40
Smith School V.A. Parcel
Main Street
Mill River
Arch Street
Reservoir Road
Roberts Hill Conservation Area
Look Park
Roberts Reservoir Complex
Sawmill Hills 188 m
Northampton Community Farm Main Parcel
Chesterfield Road
Roberts Reservoir
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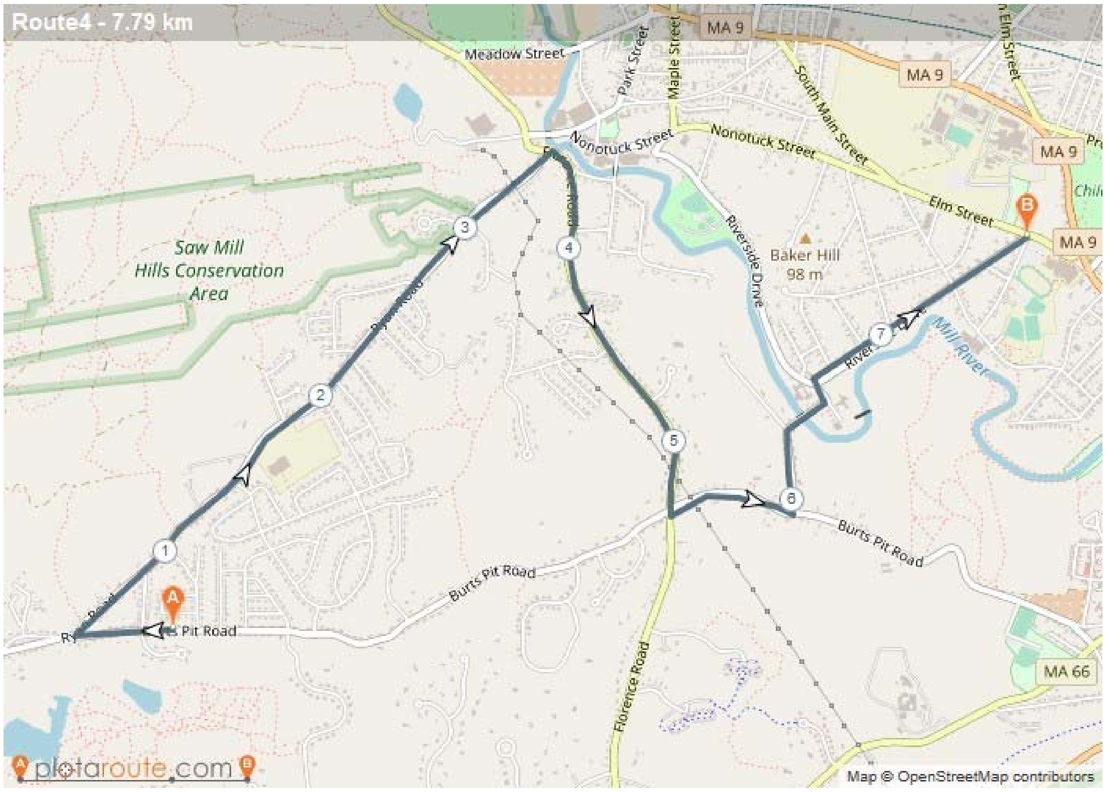
Route4 - 7.79 km
Meadow Street
MA 9
Park Street
Maple Street
South Main Street
Nonotuck Street
Elm Street
Saw Mill Hills Conservation Area
Riverside Drive
Baker Hill
98 m
Mill River
Burts Pit Road
Florence Road
MA 66
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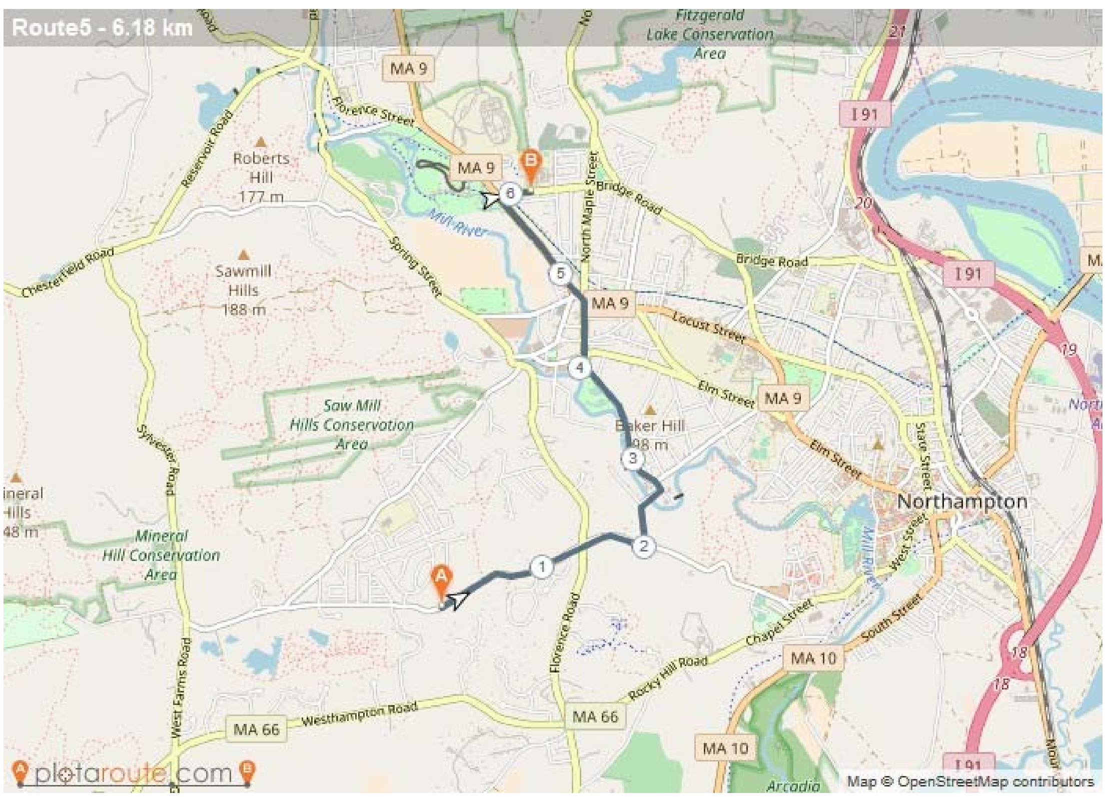
Route5 - 6.18 km
Fitzgerald Lake Conservation Area
MA 9
I 91
Florence Street
Reservoir Road
Roberts Hill
177 m
Bridge Road
North Maple Street
Mill River
Chesterfield Road
Sawmill Hills
188 m
Spring Street
Locust Street
Elm Street
Saw Mill Hills Conservation Area
Baker Hill
98 m
State Street
Northampton
Sylvester Road
Mineral Hill Conservation Area
West Street
Chapel Street
South Street
MA 10
Florence Road
Rocky Hill Road
West Farms Road
MA 66
Westhampton Road
Arcadia
plotaroute.com
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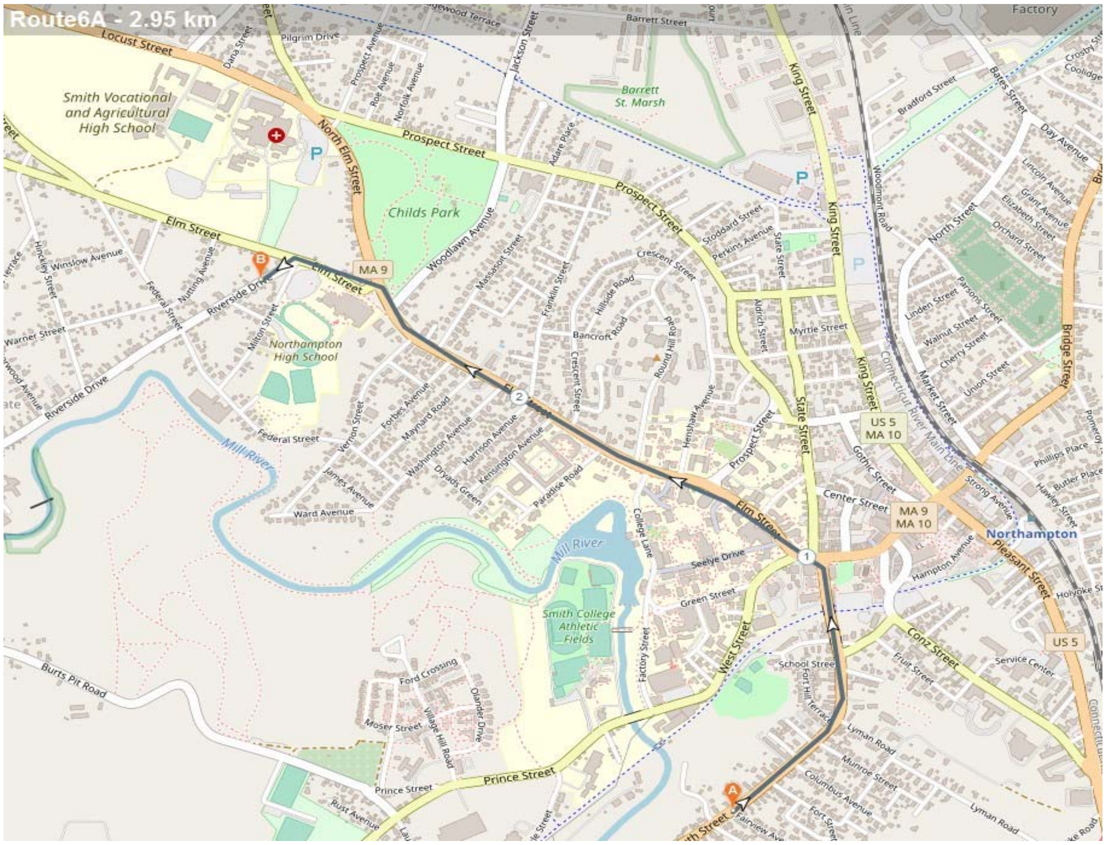
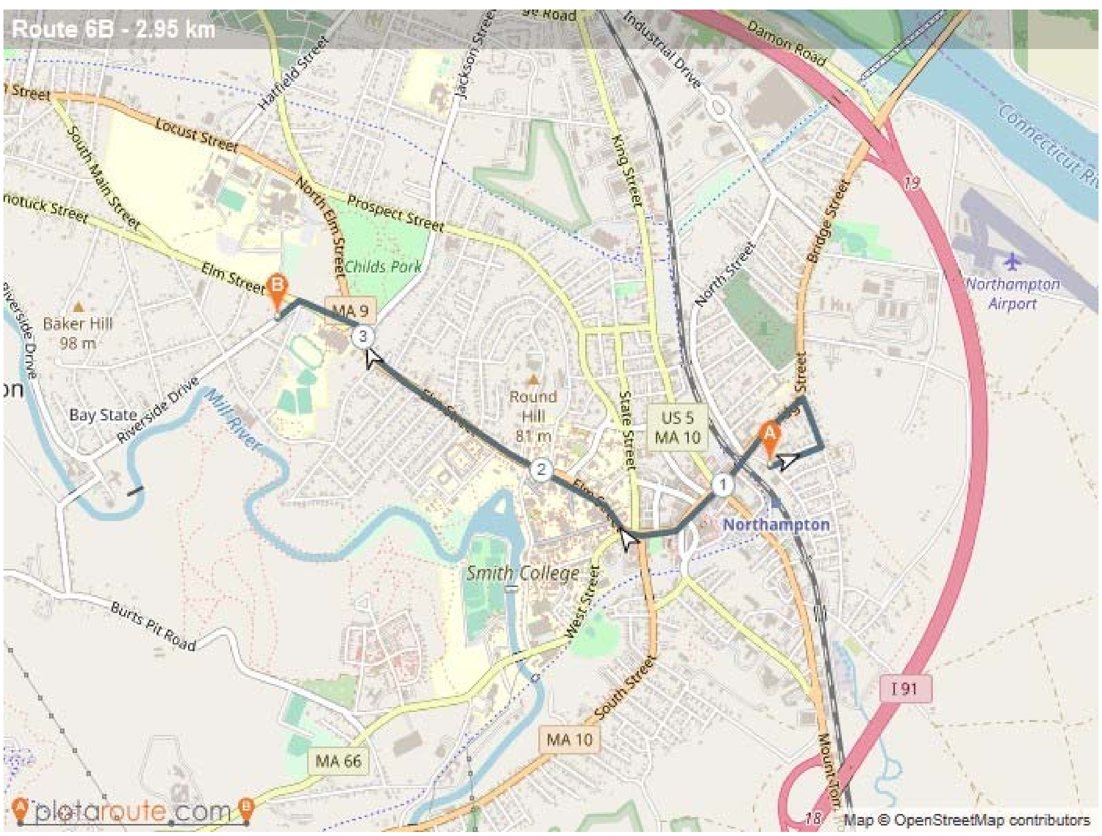

Route6A - 2.95 km
Smith Vocational and Agricultural High School
Childs Park
Northampton High School
Mill River
Smith College Athletic Fields
Northampton
Elm Street
Prospect Street
King Street
State Street
MA 9
US 5 MA 10


Route 6B - 2.95 km
Childs Park
Baker Hill 98 m
Round Hill 81 m
Smith College
Northampton
Northampton Airport
Connecticut River
MA 9
US 5 MA 10
MA 10
MA 66
I 91
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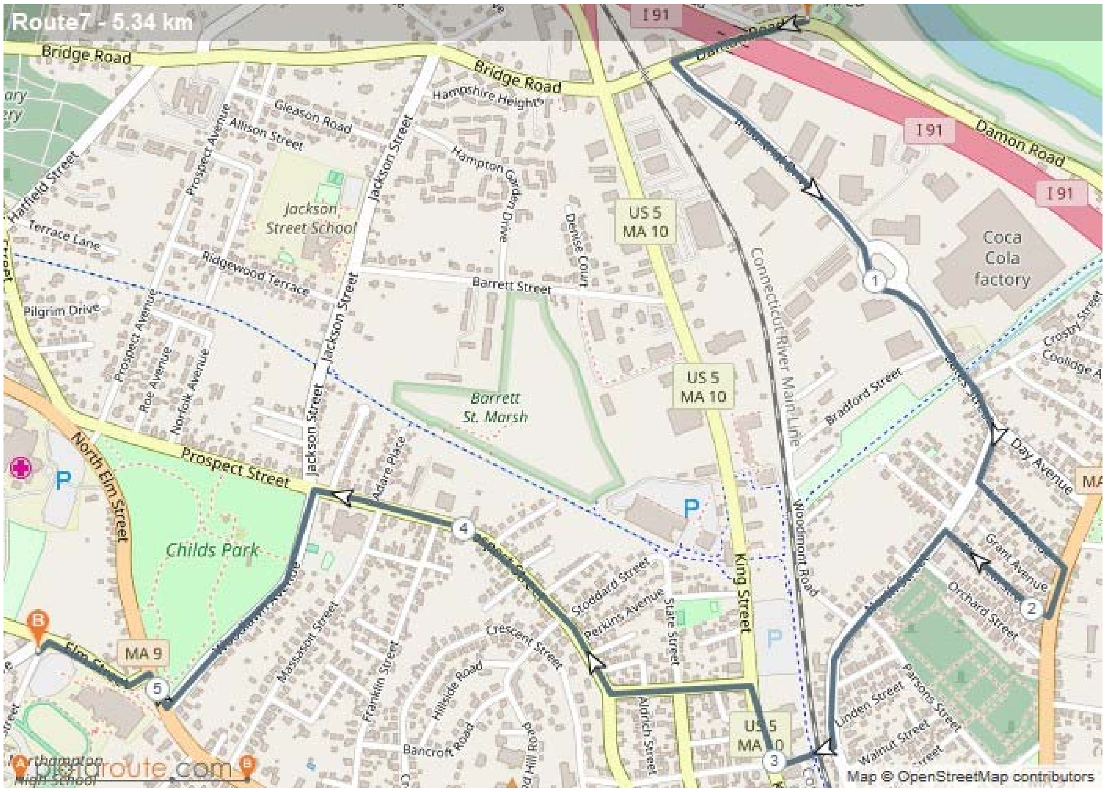
Route7 - 5.34 km
Bridge Road
Gleason Road
Allison Street
Hampshire Heights
Hampton Gardens Drive
Jackson Street School
Jackson Street
Hatfield Street
Terrace Lane
Ridgewood Terrace
Barrett Street
Pilgrim Drive
Prospect Avenue
Roe Avenue
Norfolk Avenue
Barrett St. Marsh
Denise Court
US 5
MA 10
I 91
Damon Road
Industrial Drive
Connecticut River Main Line
Coca Cola factory
Bradford Street
Day Avenue
Grant Avenue
Orchard Street
Prospect Street
North Elm Street
Childs Park
Woodlawn Avenue
Adare Place
Massasoit Street
Franklin Street
Hillside Road
Crescent Street
Stoddard Street
Perkins Avenue
State Street
King Street
Woodmont Road
Aldrich Street
Bancroft Road
Linden Street
Walnut Street
Parsons Street
Elm Street
MA 9
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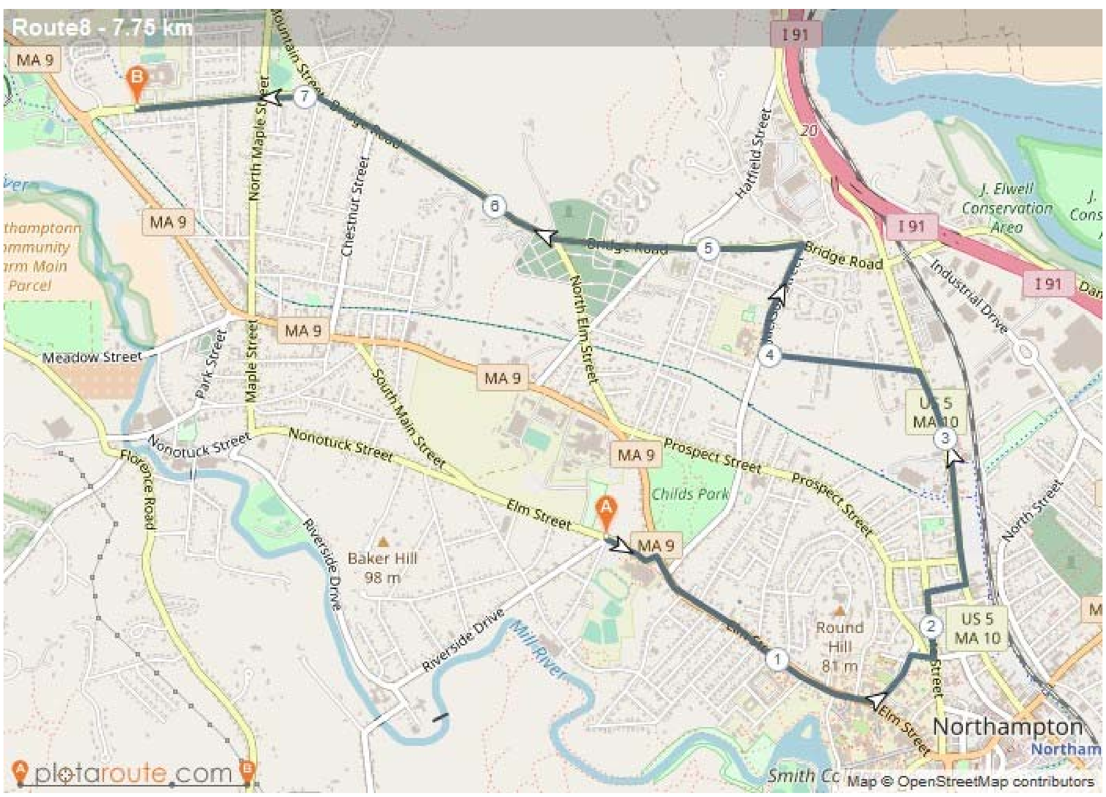
Route8 - 7.75 km
MA 9
I 91
North Maple Street
Chestnut Street
Bridge Road
Hatfield Street
J. Elwell Conservation Area
Industrial Drive
North Elm Street
Meadow Street
Park Street
Maple Street
South Main Street
Nonotuck Street
Florence Road
Riverside Drive
Baker Hill 98 m
Mill River
Elm Street
Prospect Street
Childs Park
US 5
MA 10
North Street
Round Hill 81 m
Northampton
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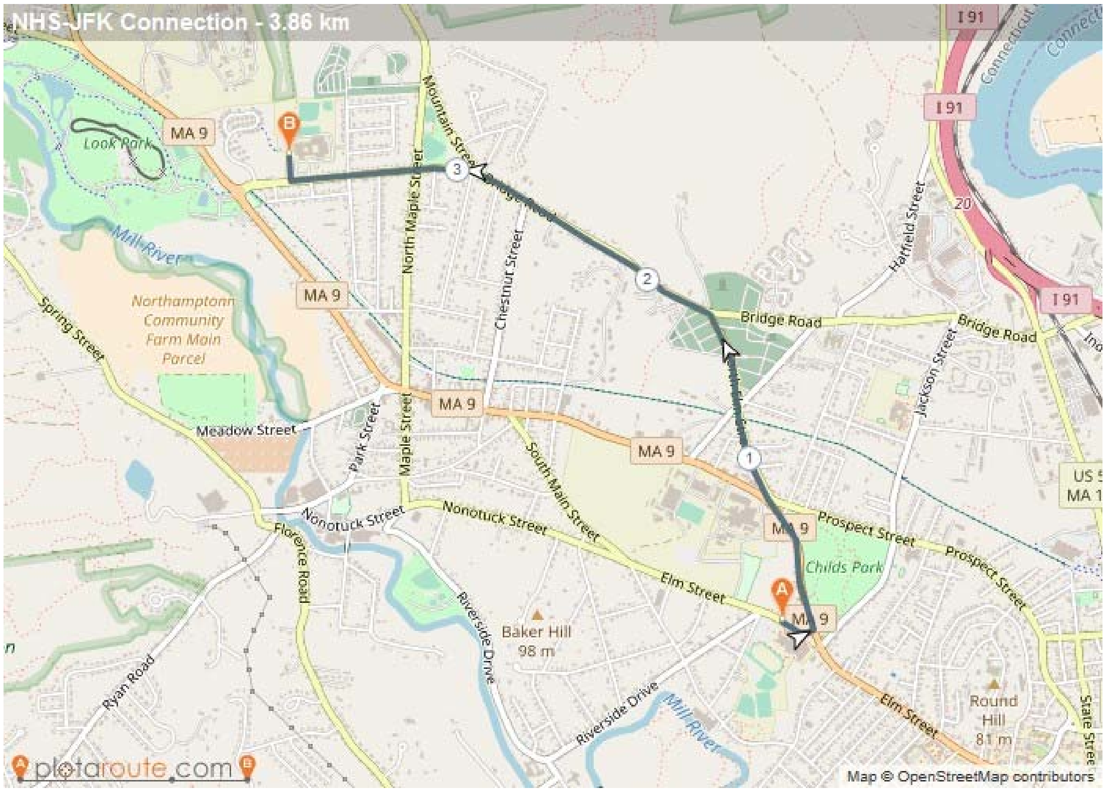
NHS-JFK Connection - 3.86 km
Look Park
MA 9
Mill River
Northampton Community Farm Main Parcel
Spring Street
Meadow Street
Park Street
Maple Street
North Maple Street
Mountain Street
Chestnut Street
South Main Street
Nonotuck Street
Florence Road
Riverside Drive
Ryan Road
Baker Hill
98 m
Elm Street
Bridge Road
Prospect Street
Childs Park
Jackson Street
Hatfield Street
I 91
Round Hill
81 m
Map © OpenStreetMap contributors
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APPENDIX B

EXISTING NORTHAMPTON SCHOOL BUS SCHEDULES

	Route Schedule			
	Northampton Public Schools			
Anchor:	Northampton High School		Start Time:	6:42 AM
			End Time:	7:05
Route:	1		Total Time:	29:03:00
			Total Distance:	7.39 mi.
			Total Riders:	38
Time	Stop	Distance (mi.)	Pick-up	Drop off
6:35	1		2	
		0.07		
6:35	2		1	
		0.34		
6:36	3		2	
		3.9		
6:46	4		1	
		0.81		
6:49	5		2	
		0.06		
6:49	6		1	
		0.43		
6:50	7		11	
		1.48		
6:54	8		15	
		0.69		
6:57	9		3	
		2.19		
7:05	NHHS			38

	Route Schedule			
	Northampton Public Schools			
Anchor:	Northampton High School		Start Time:	6:35 AM
			End Time:	7:05
Route:	2		Total Time:	29:37:00
			Total Distance:	9.98 mi.
			Total Riders:	33
Time	Stop	Distance (mi.)	Pick-up	Drop off
6:42 AM	1		6	
		0.82		
6:45 AM	2		10	
		0.74		
6:48 AM	3		1	
		0.5		
6:49 AM	4		1	
		0.1		
6:50 AM	5		2	
		0.1		
6:50 AM	6		1	
		0.3		
6:51 AM	7		1	
		0.17		
6:52 AM	8		4	
		0.61		
6:54 AM	9		1	
		1.45		
6:58 AM	10		1	
		0.04		
6:58 AM	11		1	
		0.16		
6:58 AM	12		1	
		0.24		
6:59 AM	13		3	
		2.2		
7:05 AM	NHS			33

	Route Schedule		
	Northampton Public Schools		
Anchor:	Northampton High School	Start Time:	6:44 AM
		End Time:	7:05
Route:	3	Total Time:	20:15:00
		Total Distance:	4.36 mi.
		Total Riders:	46

Time	Stop	Distance (mi.)	Pick-up	Drop off
6:44 AM	1		0	
		0.04		
6:44 AM	2		4	
		0.21		
6:46 AM	3		8	
		0.88		
6:50 AM	4		16	
		0.47		
6:53 AM	5		3	
		0		
6:53 AM	6		1	
		0.26		
6:55 AM	7		5	
		0.83		
6:57 AM	8		7	
		0		
6:58 AM	9		2	
		0.16		
6:59 AM	10			
		0.02		
6:59 AM	11			
		1.5		
7:05 AM	NHS			46

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:17 AM
			End Time:	7:40 AM
Route:	4		Total Time:	22:54:00
			Total Distance:	5.68 mi.
			Total Riders:	42

Time	Stop	Distance (mi.)	Pick-up	Drop off
7:17 AM	1		2	
		0.54		
7:18 AM	2		1	
		0.15		
7:19 AM	3		2	
		0.08		
7:19 AM	4		1	
		0.43		
7:20 AM	5		2	
		0.28		
7:21 AM	6		8	
		0.08		
7:22 AM	7		4	
		0.07		
7:23 AM	8		1	
		0.05		
7:23 AM	9		2	
		0.07		
7:24 AM	10		5	
		0.07		
7:24 AM	11		3	
		0.21		
7:25 AM	12		3	
		1.79		
7:33 AM	13		8	
		2.6		
7:40 AM	JFK			42

	Route Schedule			
	Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:13 AM
			End Time:	7:40 AM
Route:	5		Total Time:	26:49:00
			Total Distance:	8.88 mi.
			Total Riders:	34

Time	Stop	Distance (mi.)	Pick-up	Drop off
7:13 AM	1			
		0.16		
7:13 AM	2		1	
		0.04		
7:13 AM	3		1	
		0.19		
7:14 AM	4		1	
		0.34		
7:14 AM	5		3	
		0.41		
7:15 AM	6		1	
		0.35		
7:16 AM	7		1	
		0.22		
7:17 AM	8		1	
		0.13		
7:17 AM	9		2	
		0.30		
7:18 AM	10		1	
		0.18		
7:19 AM	11		1	
		0.11		
7:19 AM	12		1	
		0.28		
7:20 AM	13		1	
		2.39		
7:25 AM	14		1	
		0.89		
7:29 AM	15		18	
		2.65		
7:40 AM	JFK			34

	Route Schedule			
	Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:15 AM
			End Time:	7:40 AM
Route:	6		Total Time:	24:37:00
			Total Distance:	5.7 mi.
			Total Riders:	46

Time	Stop	Distance	Pick-up	Drop off
7:15 AM	1			
		0.25		
7:15 AM	2		1	
		0.08		
7:16 AM	3		1	
		0.11		
7:17 AM	4		2	
		0.11		
7:17 AM	5		9	
		0.42		
7:20 AM	6		5	
		0.74		
7:23 AM	7		1	
		0.84		
7:26 AM	8		9	
		0.56		
7:28 AM	9		9	
		1.01		
7:34 AM	10		9	
		1.59		
7:40 AM	JFK			46

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:26 AM
			End Time:	7:40 AM
Route:	7		Total Time:	13:34:00
			Total Distance:	3.85 mi.
			Total Riders:	41
Time	Stop	Distance (mi.)	Pick-up	Drop off
7:26 AM	1		9	
		0.4		
7:28 AM	2		9	
		0.82		
7:31 AM	3		18	
		0.19		
7:32 AM	4		5	
		2.44		
7:40 AM	JFK			41

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:16 AM
			End Time:	7:40 AM
Route:	8		Total Time:	23:32:00
			Total Distance:	6.11 mi.
			Total Riders:	43
Time	Stop	Distance (mi.)	Pick-up	Drop off
7:16 AM	1			
		0.24		
7:17 AM	2		4	
		0.31		
7:19 AM	3		7	
		1.55		
7:26 AM	4		8	
		0.32		
7:27 AM	5		24	
		3.66		
7:40 AM	JFK			43

	Route Schedule Northampton Public Schools		
Anchor:	John F. Kennedy	Start Time:	7:13 AM
		End Time:	7:40 AM
Route:	9	Total Time:	26:35:00
		Total Distance:	9.41 mi.
		Total Riders:	24

Time	Stop	Distance (mi.)	Pick-up	Drop off
7:13 AM	1		3	
		0.32		
7:14 AM	2		1	
		1.17		
7:17 AM	3		1	
		0.43		
7:18 AM	4		1	
		0.11		
7:19 AM	5		1	
		0.39		
7:20 AM	6		2	
		0.17		
7:20 AM	7		1	
		0.24		
7:21 AM	8		1	
		0.47		
7:23 AM	9		1	
		0.32		
7:24 AM	10		1	
		0.05		
7:24 AM	11		1	
		1.8		
7:29 AM	12		1	
		0.31		
7:30 AM	13		1	
		0.16		
7:30 AM	14		1	
		0.24		
7:31 AM	15		2	
		0.07		
7:31 AM	16		1	
		0.11		
7:31 AM	17		3	

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:13 AM
			End Time:	7:40 AM
Route:	9 (continued)		Total Time:	26:35:00
			Total Distance:	9.41 mi.
			Total Riders:	24
Time	**Stop**	**Distance (mi.)**	**Pick-up**	**Drop off**
		0.65		
7:33 AM	18		1	
7:40 AM	JFK	2.13		24

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:16 AM
			End Time:	7:40 AM
Route:	10		Total Time:	23:32:00
			Total Distance:	6.11 mi.
			Total Riders:	43
Time	**Stop**	**Distance (mi.)**	**Pick-up**	**Drop off**
7:23 AM	1		1	
		0.07		
7:24 AM	2		1	
		0.69		
7:25 AM	3		1	
		2.74		
7:32 AM	4		1	
		0.47		
7:33 AM	5		1	
		0.83		
7:36 AM	6		17	
		1.44		
7:40 AM	JFK			22

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		End Time:	7:40 AM
			Total Time:	13:08:00
Route:	11		Total Distance:	4.34 mi.
			Total Riders:	44
Time	Stop	Distance (mi.)	Pick-up	Drop off
7:26 AM	1		15	
		0.47		
7:28 AM	2		3	
		0.26		
7:30 AM	3		16	
		0.83		
7:33 AM	4		9	
		0.13		
7:33 AM	5		1	
		0.33		
7:34 AM	6			
		0.02		
7:35 AM	7			
		2.3		
7:40 AM	JFK			44

	Route Schedule Northampton Public Schools			
Anchor:	John F. Kennedy		Start Time:	7:16 AM
			End Time:	7:40 AM
Route:	12		Total Time:	23:32:00
			Total Distance:	6.11 mi.
			Total Riders:	43
	Stop	Distance (mi.)	Pick-up	Drop off
7:32 AM	1		18	
		0.43		
7:34 AM	2		18	
		2.12		
7:40 AM	JFK			36

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