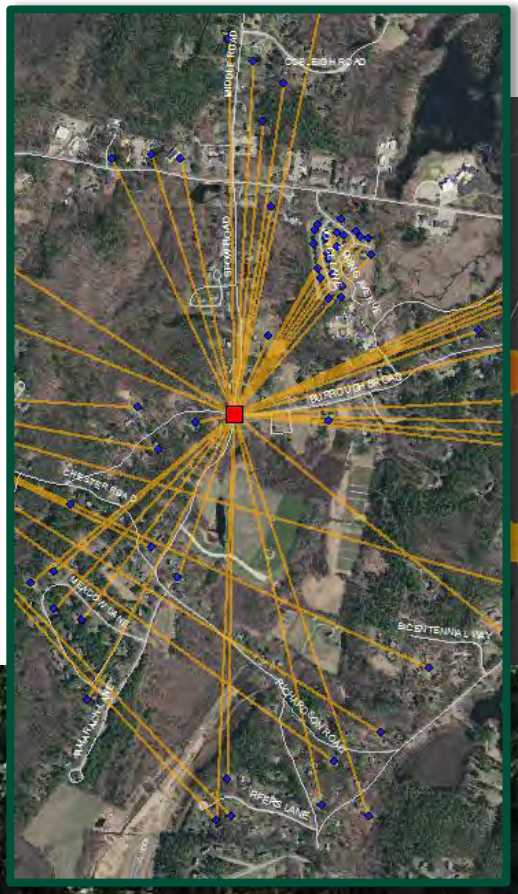
ACTON- BOXBOROUGH REGIONAL SCHOOL DISTRICT

School Bus Routing Analysis to Accommodate Delayed High School Start Times

TWO-TIER ROUTING SYSTEM ASSESSMENT



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ACTON-BOXBOROUGH REGIONAL SCHOOL DISTRICT
ACTON 1955 BOXBOROUGH MASSACHUSETTS

GPI
Greenman-Pedersen, Inc.

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INTRODUCTION

The Acton-Boxborough Regional School District (ABRSD) has been proactive in investigating delayed high school start times as a result of the national scientific research validating the academic and health benefits of additional sleep for high school students. School transportation becomes a critical operational and fiscal aspect when altering school scheduling. The potential for school start time modifications provides the ABRSD the opportunity to assess their existing transportation practices but also an opportunity to analyze the implications of merging from a three-tier start time/routing system to a two-tier start time/routing system which has been favored in the past. As such, Greenman-Pedersen, Inc. (GPI) has prepared this school bus routing analysis to assess the Acton-Boxborough Regional School District's current transportation practices and the potential impacts a two-tier start time/routing system would have on the students, staff, and community.

ABRSD CURRENT TRANSPORTATION PRACTICES

Prior to the development of new bus routing techniques, it is important to understand the current complexities of the existing transportation system in order to efficiently and sustainably provide optimal routing. The Acton-Boxborough Regional School District consists of one high school, one junior high school, and six K-6 grade schools and currently operates a three-tier start time/routing system. The District provides a school-choice option, meaning students are not regionally assigned to a school, therefore making bus routing a significant, and ever-changing task. The school choice option also leads to additional buses which are significantly underutilized as they must complete a trip within the operating time window. These "cross-town" buses servicing Boxborough students attending school in Acton and Acton students attending school in Boxborough put a strain on the existing transportation system.

Existing Start Times

The school schedule as of the 2016-2017 school year is as follows:

Table 1. Existing School Start Times

TIER	School	Start Time	End Time
1	Acton-Boxborough Regional High School	7:23 AM	2:18 PM
	RJ Grey Junior High School	7:30 AM	2:06 PM
2	Douglas Elementary School	8:40 AM	2:50 PM
	Gates Elementary School	8:40 AM	2:50 PM
	Blanchard Elementary School	8:40 AM	2:50 PM
3	Conant Elementary School	9:20 AM	3:30 PM
	Merriam Elementary School	9:20 AM	3:30 PM
	McCarthy-Towne Elementary School	9:20 AM	3:30 PM

In the existing scenario, the school start times do not compensate for teen physiology, the driving force behind this study. High school students are being picked up as early as 6:36 AM. In comparison to other schools in nearby communities, the Acton-Boxborough Regional High School is one of the earliest to start. Research shows that school districts across the country as well as local cohorts are adapting to a later high school start time schedule and seeing beneficial results both in and out of the classroom.

Existing Transportation Practices

The ABRSD operates a three-tier start time/routing system and uses up to 33 buses daily for regular bus service. Existing route and driver logistics are presented in Table 2 for each tier. Buses are deployed early in the morning from either the Conant bus Lot or the Auction Lot and are regionally dispersed to service high school and middle school students which ride together during the first tier.

Table 2. Existing Route and Driver Logistics

TIER	School	# Students*	# Routes (AM/PM)	# Drivers (AM/PM)
1	Acton-Boxborough Regional High School	2694	32/32	32/32
	RJ Grey Junior High School			
2	Douglas Elementary School	1243	33/33	33/33
	Gates Elementary School			
	Blanchard Elementary School			
3	Conant Elementary School	1444	33/33	33/33
	Merriam Elementary School			
	McCarthy-Towne Elementary School			

* Number of students obtained from Student List in Transfinder Acton-Boxborough 2016-2017 Production Data Source

As one can depict from Table 2, Tier 1 utilizes 32 buses in each operating window (AM and PM) to service approximately 2694 students. Tier 2 utilizes 33 buses to service 1243 students and Tier 3 utilizes 33 buses to service 1444 students. **So why does it take the same amount of buses to service half the amount of students in Tier 2 and Tier 3?** The current time and deployment structure of the ABRSD transportation system, doubled with the school choice philosophy, results in a "breathing" in and out network which results in long travel times. Therefore, ridership must be balanced with trip length in order to provide an acceptable level of service and to ensure that trips are completed safely and within the operating windows which leads to underutilization of transportation services.

There are several constraining factors that currently influence the optimization of bus routes within the ABRSD.

- School Choice – Students are not regionally assigned to a school meaning that an incoming student or transfer has a potential to significantly alter a route. School choice results in multiple outliers which require significantly long trips with small amounts of students resulting in the underutilization of the bus fleet.

- Geography and Topography – Acton and Boxborough combine for 30.7 square miles (20.3 square miles and 10.4 square miles in Acton and Boxborough, respectively). Both towns are relatively rural in nature, Boxborough more so. Both have a significant number of cul-de-sac and dead end roadways as well as narrow, windy roads which compromise school bus maneuverability and decrease the potential for safe walking routes due to sight distance restrictions and lack of available sidewalk network.

- Practiced District Policies – District practices such as door-to-door service make it difficult to plan reasonable length trips for elementary tiers and therefore, it uses more buses than it needs, as over 50% of tier 2 buses are less than half full. Currently, there is no district policy that states students are entitled to door-to-door pick up. Massachusetts state law limits the distance from a student's place of residence to his/her assigned bus stop to one mile.

- Every Student Required Transportation - Currently, the ABRSD provides a transportation option to every student. There are no non-eligible zone policies in place.

- Fiscal and Storage Constraints – Although ideal to have all students on one tier system, the district's budget does not allow for such a scenario. Merging to a two-tier system will still require additional buses and

operators as well as additional bus storage. Buses must be maintained over time and drivers must be obtained and retained, posing a significant challenge moving forward.

- Every Student Guaranteed a Seat – Since every child is guaranteed a seat on the bus, the Acton-Boxborough Regional School District has to plan for the day that every student rides the bus, and therefore, requires more buses than necessary to service the actual ridership numbers.

- Athletics - School dismissal times need to accommodate after school athletics travel and practice schedules.

- Drop-off/ Pick-Up Window and Physical Drop-off/ Pick-Up Space - Currently, buses must drop students off within 15 minutes of the bell time. This results in non-flexible routes and also results in a high demand of vehicles requiring space in front of the school. The existing bus driveways cannot accommodate all trips arriving in such a short window resulting in queuing and potentially unsafe conditions at school drop-off and pick-up.

- Lack of Neighborhood School Locations – All of the schools are generally centrally located resulting in very long trips for those students residing on the outskirts of town. Four schools are located adjacent to Kelley's Corner right in the middle of Acton, which is a well-known traffic congestion spot, adding time to trips.

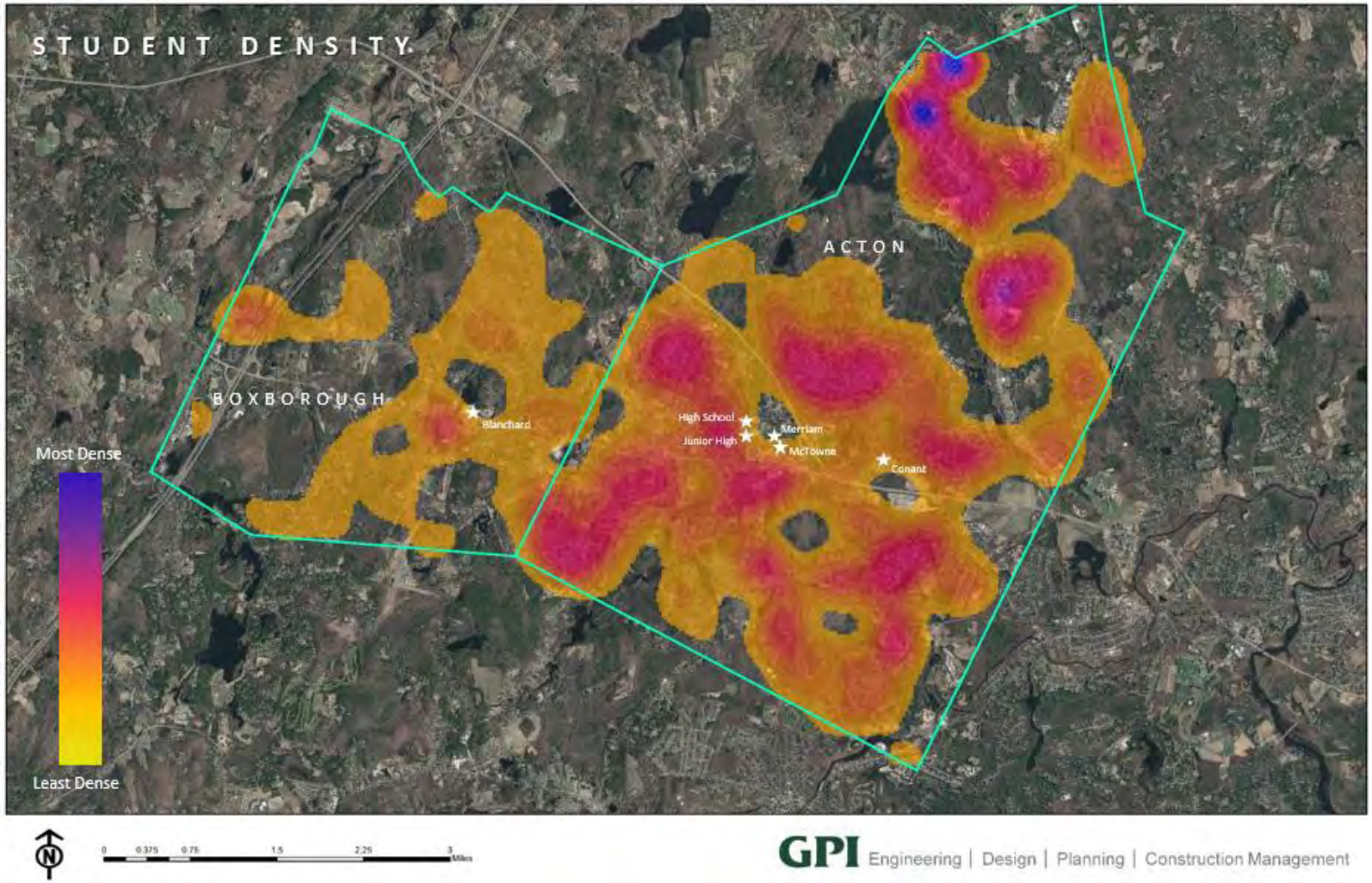
- District Target Rates (# Students on Bus): The ABRSD has a target rate of 55 students per bus for high school students and 60 students per bus for elementary students. More elementary students can safely ride the bus due to their physical size.

Although some of these are uncontrollable constraints, such as the geographical layout of the district, state policy and existing school locations, most can be addressed in order to maximize capacity while providing acceptable levels of service and safety.

Existing Student Density

Prior to routing students, it is critical to know where they are located. Utilizing the existing student database provided, GPI was able to import the students' existing addresses and geocode (convert addresses to geographic coordinates) these locations to display the data spatially. Figure 1 illustrates a density map of all the transported students. Darker areas indicate areas with a high student population within a square mile. The student population density of the regional school district is a critical determining factor in transportation planning. Areas with a denser student population will require more bus routes and will generally require less stops. On the other hand, less dense areas may not require as many buses but will likely require more stops. Figure 1 clearly indicated that a majority of the student population resides in Acton. Boxborough is certainly more rural and students are spread out more. Heavily populated areas include the Nonset Path area and Avalon Acton, both of which are in the northwestern portion of Acton. Sparse population areas are typically located in Boxborough.

Figure 1. Student Population Density Map



Existing Utilization Rates and Performance Measures

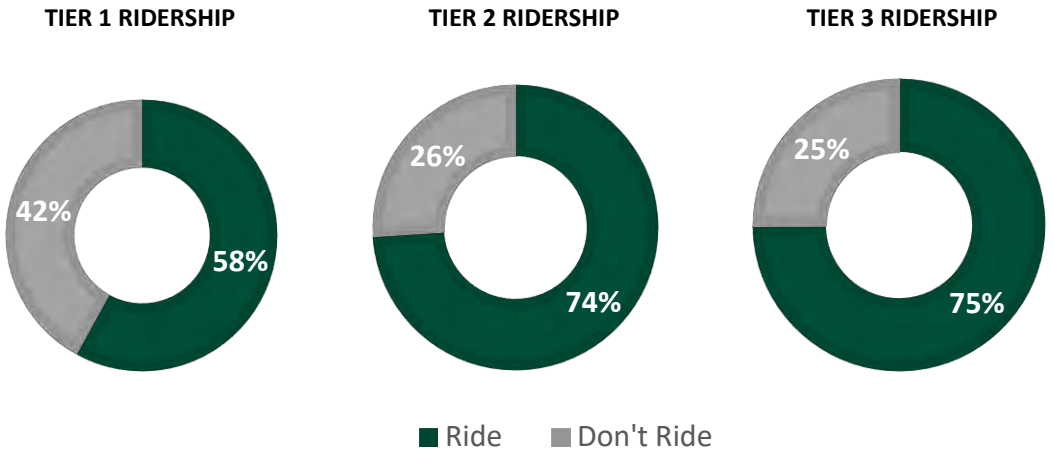
Analyzing existing utilization rates is critical prior to a change in the school start time/routing system. It is important to analyze how the system is currently working in order to identify areas where improvements could be made or policy changes necessary to minimize cost implications and improve level of service.

The transportation department routinely conducts ridership surveys every season in order to collect a more accurate number of students who actually ride the bus. The ridership information provided indicates that approximately 60% of students in tier 1 (high school and middle school students) actually ride the bus and approximately 75% of tier 2 and tier 3 students (elementary) ride the bus compared to enrollment data numbers as depicted in Table 3. It should be noted that these numbers can fluctuate throughout the year depending on weather and family circumstances and therefore any planning efforts should account for a daily fluctuation in ridership.

Table 3. Enrollment and Ridership Data

School	# Students *	# Students Riding the Bus**	Percent Riding Bus
Acton-Boxborough Regional High School	1807	1559	57.87%
RJ Grey Junior High School	887		
TIER 1 TOTAL	**2694**	**1559**	**57.87%**
Douglas Elementary School	455	636	74.74%
Gates Elementary School	396		
Blanchard Elementary School	392	295	75.25%
TIER 2 TOTAL	**1243**	**931**	**74.89%**
Conant Elementary School	511	394	77.10%
Merriam Elementary School	450	696	74.59%
McCarthy-Towne Elementary School	483		
TIER 3 TOTAL	**1444**	**1090**	**75.48%**
TOTAL	**5381**	**3,580**	**66.5%**

* Number of students per school obtained from Student List in Transfinder Acton-Boxborough 2016-2017 Production Data Source
** Ridership Data provided by Acton-Boxborough School District Transportation Department



What do these numbers tell us? Approximately 60% of tier 1 students (high school and middle school students) ride the bus while 75% of elementary students ride the bus.

Table 4. Existing Capacity Utilization

Tier	# of Bus Runs AM/PM	# Students Transported in Tier*	Maximum Bus Capacity	Utilization based on maximum capacity of each bus**	District Target Rate	Utilization based on district target rates***	# of buses less than half full (<40) assigned*	Average # of Riders Assigned****	Largest # of Riders Assigned*
AM									
Tier 1	32	2694	83	**101.4%**	55	**153.1%**	0	79	113
Tier 2	33	1243	83	45.4%	60	62.8%	21	32	55
Tier 3	33	1444	83	52.7%	60	72.9%	21	34	56
Total	98								
PM									
Tier 1	32	2694	83	**101.4%**	55	**153.1%**	0	79	113
Tier 2	33	1243	83	45.4%	60	62.8%	20	31	54
Tier 3	33	1444	83	52.7%	60	72.9%	21	35	56
Total	98								

* Number of students assigned/geocoded and assigned ridership per trip numbers obtained from Student List in Transfinder Acton-Boxborough 2016-2017 Production Data Source
** Utilization based on maximum bus capacity of each bus (83) = # Students Transported in Tier / (# bus runs * 83 seats per bus) x 100
*** Utilization based on district target rate (55 HS/JH) or 60 (Elemen)) = # Students Transported in Tier / (# bus runs * 50 or 60 seats per bus) x 100
**** Average # of Riders Assigned per bus = # Students Transported in Tier / # of Bus runs

Table 5. Existing Time Performance Measures

Tier	# of Bus Runs AM/PM	Earliest Pick-Up	Latest Drop-Off	Average Total Trip Time	Longest Total Trip Time	Average Distance	Longest Distance	Average Dead Head Distance	Longest Dead Head Distance
AM									
Tier 1	32	6:36 A.M.	7:17 A.M.	32.09	50	9.7	17.15	3.35	5.79
Tier 2	33	7:51 A.M.	8:28 A.M.	27.18	36	7.9	13.22	0.02	0.32
Tier 3	33	8:36 A.M.	9:17 A.M.	26.70	37	7.2	10.63	0.28	8.34
Total	98								
PM									
Tier 1	32	2:13 P.M.	2:59 P.M.	34.31	46	6.3	10.86	0.26	5.49
Tier 2	33	3:00 P.M.	3:41 P.M.	26.55	41	7.5	14.64	0.35	11.45
Tier 3	33	3:40 P.M.	4:18 P.M.	29.03	41	7.9	12.49	0.03	0.56
Total	98								

* All performance data obtained from Student List in Transfinder Acton-Boxborough 2016-2017 Production Data Source

When analyzing existing capacity utilization, data from the Acton-Boxborough 2016-2017 Production Data Source was used. Tables 4 and 5 summarize the existing operational parameters of the existing three-tier routing system As Table 4 suggests, transportation resources are currently over utilized in tier 1 and underutilized in tiers 2 and 3. Currently, if every enrolled high school and junior high school student were to ride the bus, there would not be enough seats to service every student and every bus would be servicing greater than 55 students, the district target rate for high school/junior high school students. This indicates that there are currently not enough buses to safely service all of the students enrolled in the high school and junior high school. Since utilization rates are above 100%, additional buses will be required to service high school/junior high school tier at a healthy utilization rate.

Table 4 also indicates a significant underutilization of the existing fleet in the elementary tiers. As one can depict from both Table 2 and Table 4, both Tier 2 and Tier 3 require a greater number of buses to service half of the students than that of Tier 1. Once again, this is due to the existing "breathing" structure of transportation routing network as well as the need to balance both ridership and trip length. Over 60% of the elementary morning runs are assigned less than 40 students, suggesting that there are more buses than necessary to service elementary children and that these trips need to be optimized to gain greater efficiency.

Currently, the ABRSD provides 196 daily trips: 98 in the morning and 98 in the afternoon. By merging to two-tier routing system, this number is likely to decrease.

Time performance measures were reported from the existing 2016-2017 Acton-Boxborough Production Transfinder Data Source and are highlighted in Table 5. Currently, high school/junior high school students are being picked up as early as 6:36 AM and being dropped off as late as 2:59 PM. Elementary students are picked up as early as 7:51 AM and dropped off as late as 4:18 PM.

Average trip length for the high school tier is 32 minutes in the morning run and 34 minutes in the afternoon. Elementary tier trip lengths are generally shorter and range from 26 minutes to 29 minutes. The large number of buses with many empty seats in the elementary tier, as well as the majority of buses with routes under 40 minutes suggests an opportunity to combine fewer routes to achieve greater efficiency.

ABRSD PROPOSED TRANSPORTATION PRACTICES Merging to a 2-Tier System

The purpose of this portion of the study is to assess the fiscal and operational constraints a two-tier start time/routing system would have on students, staff, and the community to determine whether or not such an option is viable prior to an overhaul change of the school schedules. As it is understood, the two-tier system has been a desired option by families and the ABRSD as it would standardize elementary start and dismissal times but also facilitate cross-school collaboration between teachers and staff. Converting to a two-tier system will have implications, both fiscal and operational, including an increase in equipment and personnel as well as some practice/policy changes which will most likely affect families' schedules.

If the ABRSD were to maintain the current practices, routes and stops currently in place within a two-tier structure, a total of 66 buses would be required. At this capacity, the school district would be almost doubling their existing fleet and operating budget to maintain the current practices of door-to-door service, no walk zones, and poor bus assignment levels. **Therefore, new policies and transportation approaches need to be introduced to minimize the number of buses required for a two tier merge while balancing ridership and trip length. These potential modifications include the following:**

1. Planning based on actual ridership
2. Removal of Cul-de-sac Service
3. Walk zones
4. "Cluster" stop approach
5. Maximum # of students assigned per bus
6. Trip Length and Pick-up/Drop-off Window

Prior to establishing certain inputs for route planning, it was important to research Massachusetts State Law in regards to public school transportation policies. Massachusetts State Law requires that all children residing in regional school districts in grades kindergarten through twelve be entitled to transportation, regardless of the distance of their home to their school of attendance. Bus stop locations shall be placed as to minimize distance from the residence and be limited to 1 mile, granted that safe access is available.

By modifying existing practices, the district can minimize the number of buses required to service all students within the regional district while yielding positive results in terms of capacity and efficiency in their fleet.

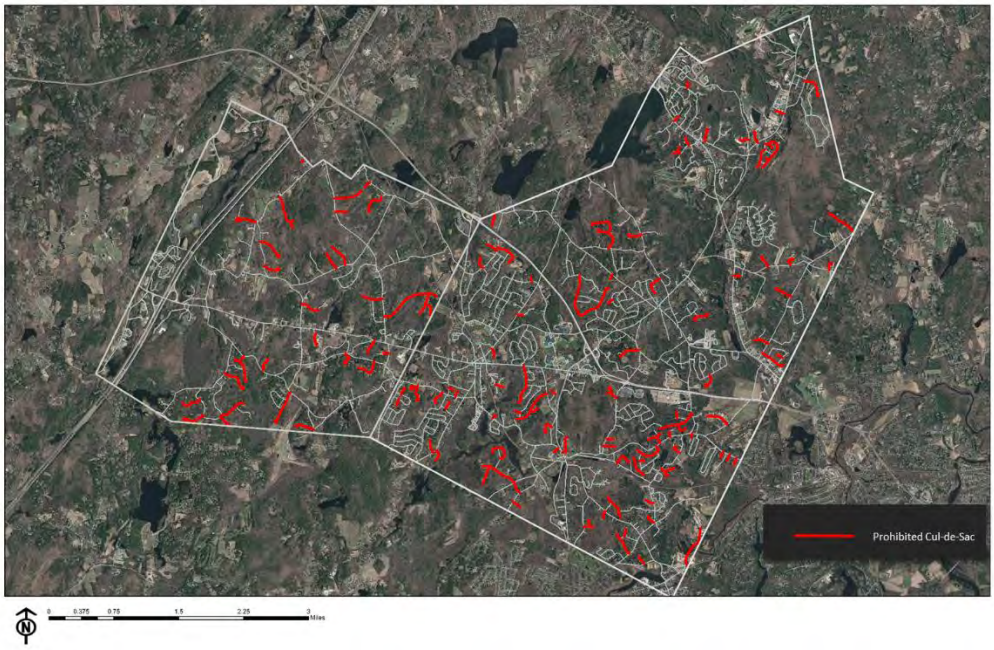
Planning Based on Actual Ridership

As Table 3 indicated, approximately 60% of high school and junior high school students ride the bus and approximately 75% of elementary students ride the bus. In an effort to further increase efficiency, the ABRSD should plan routes based on actual ridership and the assumption that not all students will ride the bus each day. This will ultimately reduce the required amount of buses needed to convert to a two-tier model rather than assuming full ridership. In this scenario it is important to plan for a healthy fluctuation in ridership and therefore, a 10% buffer should be implemented. Therefore maximum number of riders assigned should be based on a projected 70% ridership in the high school/middle school tier and 85% in the elementary tier. Therefore if 70% of the assigned riders in the high school tier actually rode the bus and 85% of the assigned students in the elementary tier actually rode the bus, safety district target rates would still be achieved. However, on the day that every student rode the bus, safety capacity rates would be exceeded but maximum bus capacity rates would not- ensuring that every student was serviced.

Removal of Cul-de-Sac Service

In order to cut down on overall travel time, cul-de-sac roadways will be removed from the routing analysis, meaning no bus routes will travel down cul-de-sac roads. The geometry of cul-de-sac roadways does not facilitate the maneuverability of school buses due to tight radii. As a result, buses are often required to back down cul-de-sac roadways which adds inefficient travel time and poses a significant safety hazard. Students residing on cul-de-sac roadways while be serviced at the end of the roadway. Figure 2 illustrates all the cul-de-sac roadways in Acton and Boxborough. The roadway GIS layer was obtained from MassGIS.

Figure 2. Prohibited Cul-de-Sac Roadways



Walk Zones

Massachusetts State Law indicates that all children residing in regional district in grades K-12 are entitled to transportation. However, the school district can heavily encourage high school and junior high school students residing less than one mile from school to walk to school. The district may also decide to implement some sort of reimbursement program for families within this walk service area that waive the transportation requirement. Figures 3 and 4 illustrate 1 mile walk service areas for both the high school and junior high school. It is important that any walk zone established be equipped with a safe sidewalk and crosswalk network to ensure student safety to and from school. Therefore, GPI requested the Acton sidewalk GIS layer which plots all existing sidewalk in the town. All walking routes from students to the school within the mile service area have sidewalk available for the high school and junior high school. **It should be noted that a walk zone was not established in the full modeling efforts but rather discuss as a possible opportunity to cut down required buses in the future. This parameter would require policy change.** However, if the 124 high school students and 71 junior high school students within the 1 mile service area were to waive the transportation requirement that would result in 195 students that would no longer be assigned to buses, minimizing number of buses required to service high school and junior high school students by three.

Figure 3. High School Walk Service Area

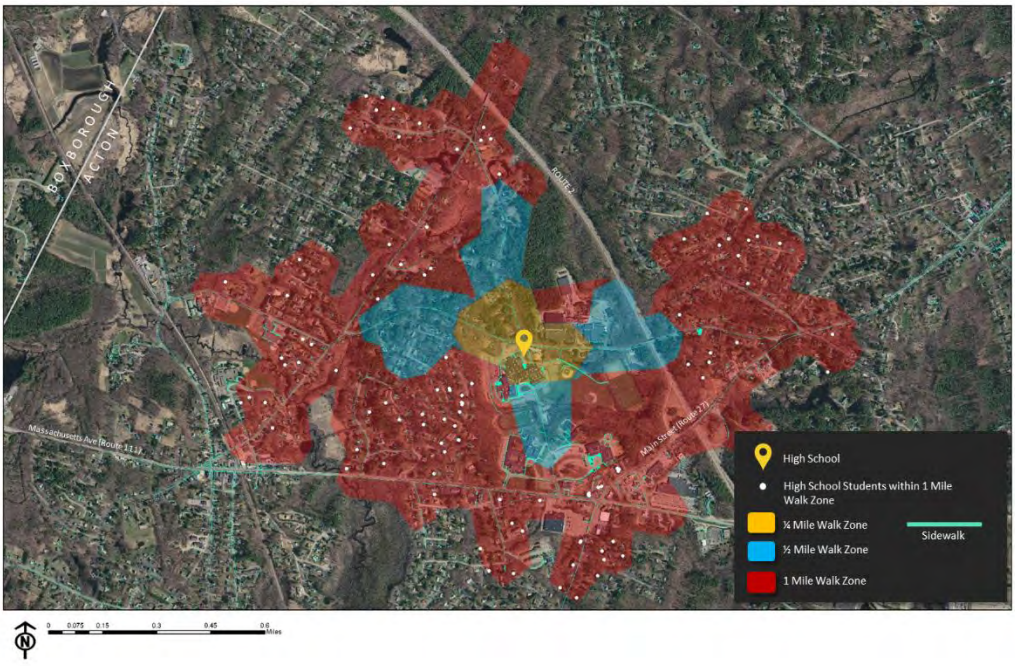
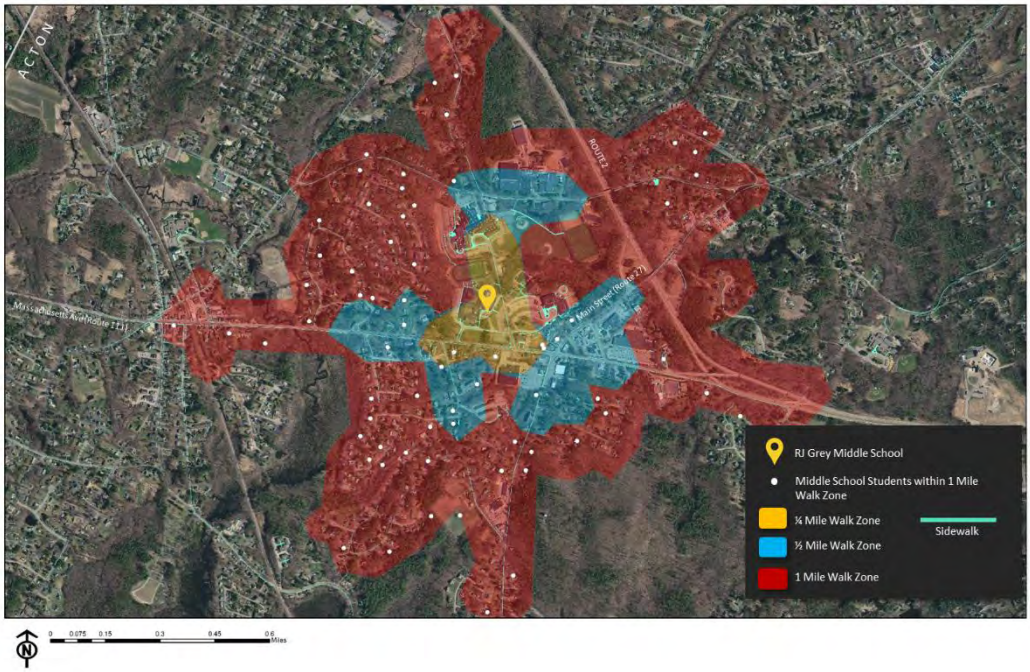


Figure 4. Junior High School Walk Service Area

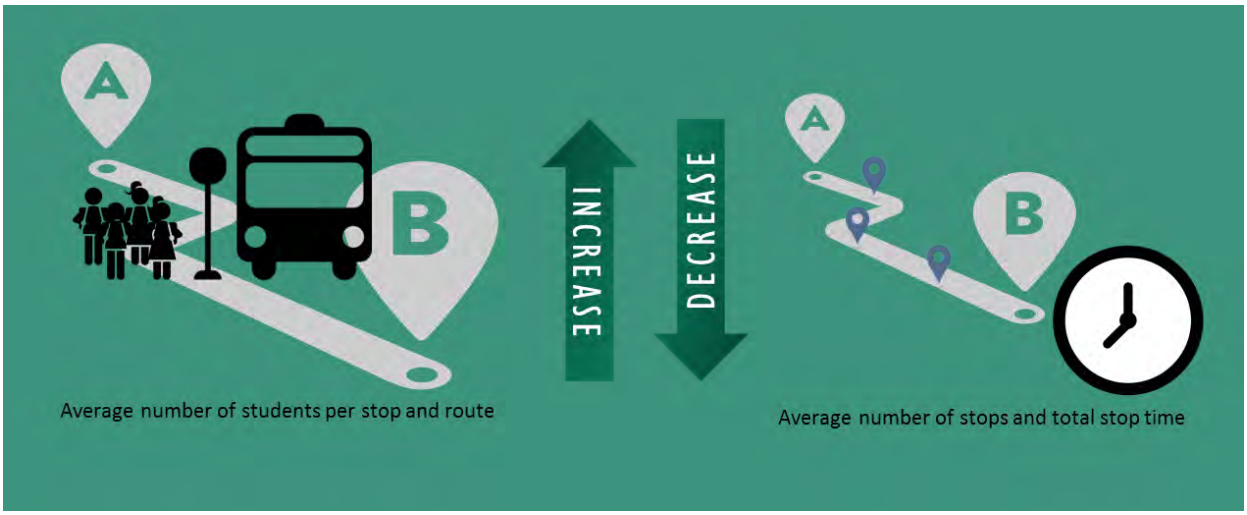


The walk zone philosophy was also initially applied to the elementary schools but given the existing nature of the location of these schools, very limited sidewalk is available and therefore no walk zones have been recommended or modeled for grades K-6.

Walk to Stop – Moving Towards a "Cluster" Stop Approach

The Acton Boxborough Regional School District often provides door-to-door service to its students which makes it difficult to provide acceptable level of service trips while filling buses to their safety capacity. Shifting towards a cluster stop approach would provide the district the ability to service more students within a shorter amount of time.

Figure 5. Benefits of Cluster Stops



When shifting towards a cluster stop approach, it is critical to assess the safety concerns of each walking route (home to stop and vice versa). All stops must consider the existing sidewalk network specifically on heavily travelled roadways and high speed roadways, ensure adequate sight distance from both approaches, and address speed limits and narrow roadways. It is expected that cul-de-sac and dead end roadways with residing students will receive a cluster stop along the service roadway as to eliminate the need for buses to execute the difficult maneuverability of turning around or backing up which poses a potential safety hazard. Based on discussion with the ABRSD Superintendent, Deputy Superintendent and Director of Transportation Department, walk distances of 0.15 miles for grades K-6 and 0.25 miles for grades 7-12 were applied. These distances are measured from the sidewalk or public way in front or nearest to the student's home of residence to the nearest bus stop utilizing the existing street network. Although it would be ideal to maximize these distances, the existing sidewalk network is limited and therefore cluster stops are not readily available in every neighborhood. Acton and Boxborough's rural nature results in windy, narrow roadways which in many instances do not provide safe walking access routes for students. Therefore, when placing cluster stops in the future to service new student populations, it is highly suggested that walking road safety audits be performed as to ensure all stops are safe and appealing. It is recommended that the Acton Boxborough Regional School District implement Walking School Buses to ensure safety along the walking route stop to home while promoting healthy transportation options and community building.

The benefits of cluster stops is evident in the reduction of total bus stop time as it relates to the number of students serviced. Bus stop time is measured by the following:

Bus Stop Time (K-6) = 30 + S(5)

where 30 =time the bus is stopped (seconds), and S = number of students at stop, and 5= student boarding time(seconds)

Bus Stop Time (G7-12) = 30 + S(3)

where 30 =time the bus is stopped (seconds), and S = number of students at stop, and 3= student boarding time(seconds)

Table 6. Cluster Stop Performance Measures

Tier	Measure	Existing	Proposed
High School/Junior High	Average # Stops per Route	19.3	10
	Average # Students per Bus	51	55
	Average # Students per Stop	2.61	5.5
	Total Stop Time	9 minutes 52 seconds	5 minutes 17 seconds
Elementary	Average # Stops per Route	21.65	18
	Average # Students per Bus	30.62	54
	Average # Students per Stop	1.413	3.33
	Total Stop Time	10 minutes 57 seconds	9 minutes 16 seconds

Students in grades 7-12 are expected to travel further distances and therefore, the average number of stops per route is decreased by half, resulting in a 46% reduction in bus stop time. Cluster stops allow for the average number of stops in the elementary tier to be decreased from 20 to 18 but also accounts for a greater number of average students on each bus. Therefore, the bus has the ability to service more students within a shorter amount of time. Table 6 illustrates the potential reduction in total stop time for each tier when cluster stopping is introduced.

Implementing cluster stops may be a significant change for some families and may result in public concern. It should be noted that the cluster stops examined during the modeling phase are expected to change each year as students graduate, enrollment numbers change, and infrastructure such as sidewalk, bicycle lanes and other multimodal accommodations are improved.

Maximum Number of Students Assigned to a Bus

As previously stated, the ABRSD has set target rates for the number of students on each bus. For elementary routes, the target is 60 students on a bus. For high school and junior high school routes, the target is 55 students on a bus. Elementary routes can service more students due to their physical size in comparison to the older students. GPI has assessed this district target rate and feels as though it is appropriate in regards to transportation safety.

As Table 7 indicates, the capacity of the buses is 83 students. Approximately 60% of existing tier 1 buses exceed this limit based on the number of students assigned –in other words, 60% of the buses have over 83 students assigned to them. In addition based on actual ridership counts, over 35% of HS/JRHS buses are transporting more than the 55 students established as the district target rate. Conversely, over 50% of elementary routes have less than 30 students assigned to them resulting in significant underutilization. In an effort in increase efficiency, the amount of assigned riders should be dispersed in a way that takes advantage of student density areas while not exceeding the maximum capacity of the bus while aiming for district target rates. Utilizing the location-allocation spatial analysis tools in the ArcGIS environment, GPI was able to achieve district target capacities and assign students to a bus based on actual ridership, student density areas and geographical constraints. Figure 6 illustrates the location-allocation tool at work which allows one to see potential bus route areas based on student density areas.

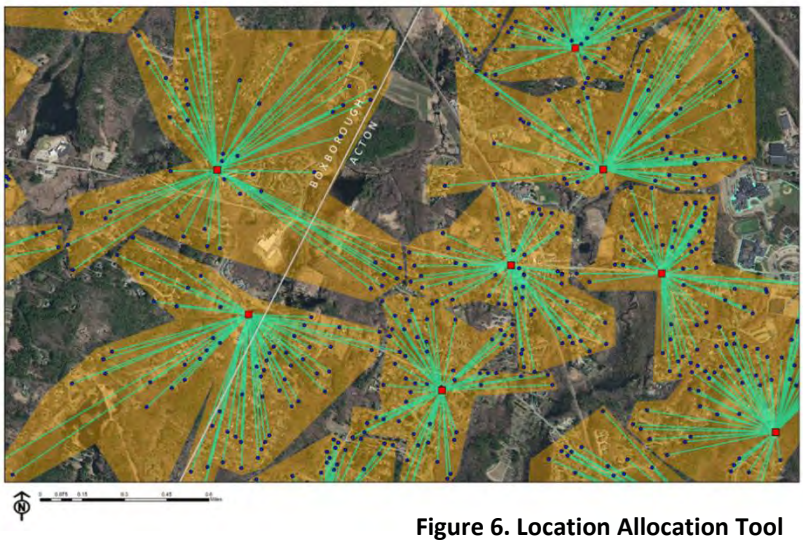


Figure 6. Location Allocation Tool

Table 7. Bus Capacity Rates

Tier	Max. Bus Capacity	District Target Capacity	Max. Students Assigned per Bus
Elementary: K-6	83	60	70
High School/JR: 7-12	83	55	75

Table 7 highlights the maximum number of students that should be assigned per bus. For the elementary tier, it should be limited to 70 students and for the high school/junior high school tier it should be limited to 75. As Table 8 indicates, the maximum number of students assigned per bus is less than the maximum capacity of the bus but larger than the district target capacity. Maximum assigned student is based off of the actual ridership numbers, including a 10% buffer to account for ridership fluctuation throughout the year. Let's look at the elementary tier as an example. If we assign a maximum 70 students to the bus and we can expect a conservative 85% ridership that would result in 60 students riding the bus, exactly at the district target rate. However, if there were a day that all 70 assigned students rode the bus, each would be guaranteed a seat because it is less than the bus capacity. The same ideal holds true for the high school/junior high school tier. It should be noted that the amount of assigned riders for the high school/junior high school tier is greater than that of the elementary tier due to projected lower ridership levels.

Trip Length and Pick-Up/Drop-Off Window

In the two tier scenario, maximum time spent on the bus will be governed by the morning and afternoon operating windows as well as geographical constraints. In the proposed two-tier system, there will be a 40 minute gap between tiers in both the morning and afternoon window in which students must be serviced and travel between schools must be factored in. In order to maximize bus route lengths and allow for some flexibility within the system, it is recommended that the ABRSD look into extending the pick-up/drop-off window by 15 minutes to allow for transportation routes to be serviced within a half hour to bell start and dismissal times. This will allow for routes to run a bit longer while still ensuring students make it to school on-time. It will also grant drivers more time to enter/exit school driveways without queuing since the existing window limits capacity given physical space constraints when the demand is too big within a short time frame. As the district has voiced, it is ideal to limit the time a student is on the bus to 40 minutes. Within two tier model, some students may be on a bus greater than 40 minutes due to the school choice option.

When analyzing maximum time spent on the bus, it's also important to consider the method of routing to deploy. With the two tier merge, all elementary students will need to be serviced within a 40 minute window. Consideration as to whether a bus should be deployed regionally to service more than one school on a given trip or buses should be allocated on a per school basis. The concern with routing buses on a regional basis at the elementary tier is that the travel time between schools must be factored into the operational analysis. For the purpose of maximizing student capacity on each bus, it is suggested that buses be allocated on a per school basis as to reduce travel time between schools. In this scenario, more students can be serviced with the time it would take to travel between schools.

Figures 7- 11 represent the service drive time areas for each of the schools serviced. In each figure, the blue area represents travel 0-5 minutes away from the school, the green area represents travel 5-10 minutes from the school and the red area represents travel 10-20 minutes away from the school. Each service area utilizes the existing street network and factors in historical traffic data experienced in the region at 8:00 AM on a Thursday.

Figure 7. Drive Time Service Areas from High School/Junior High School

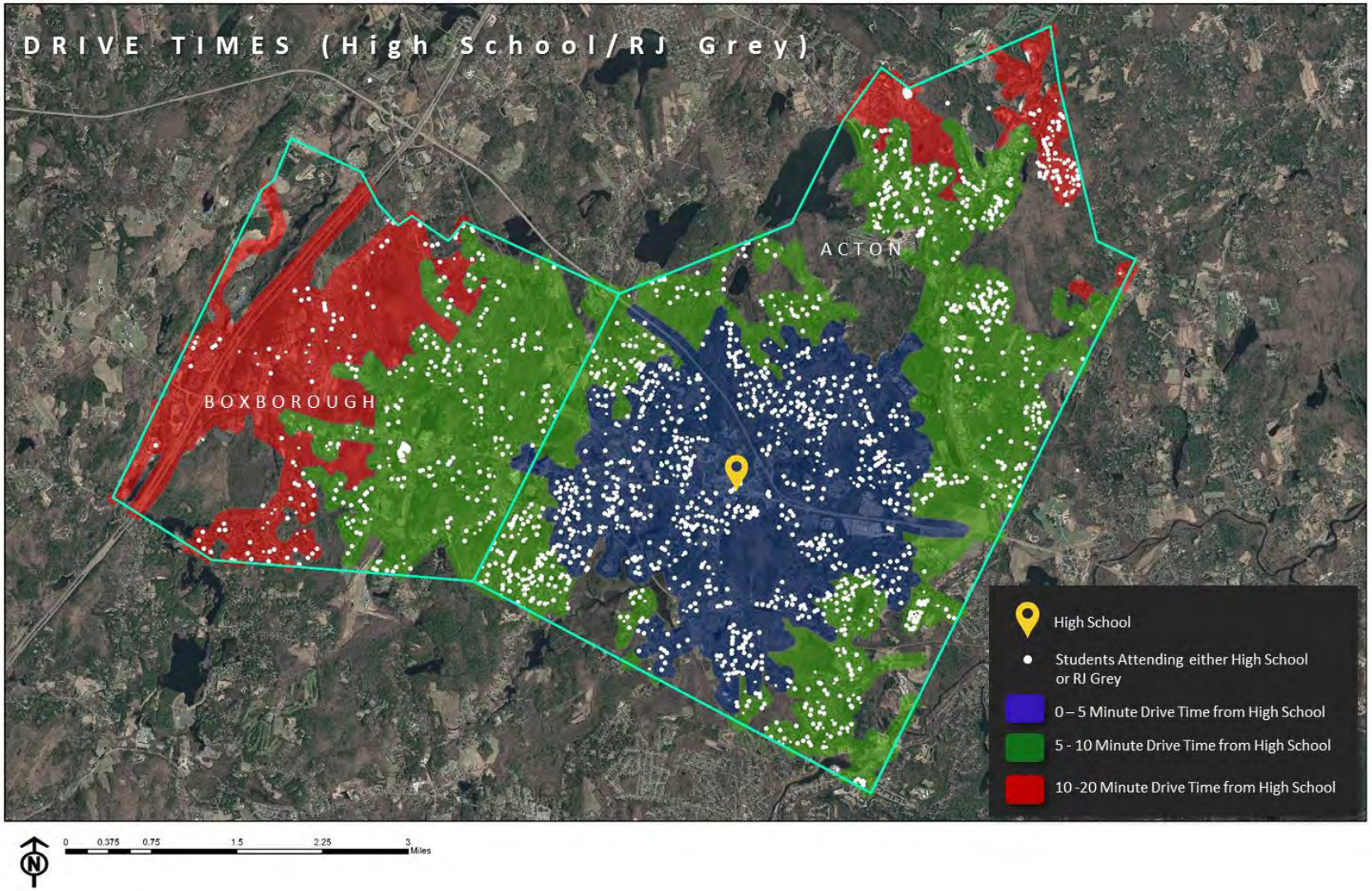


Figure 8. Drive Time Service Areas from Blanchard

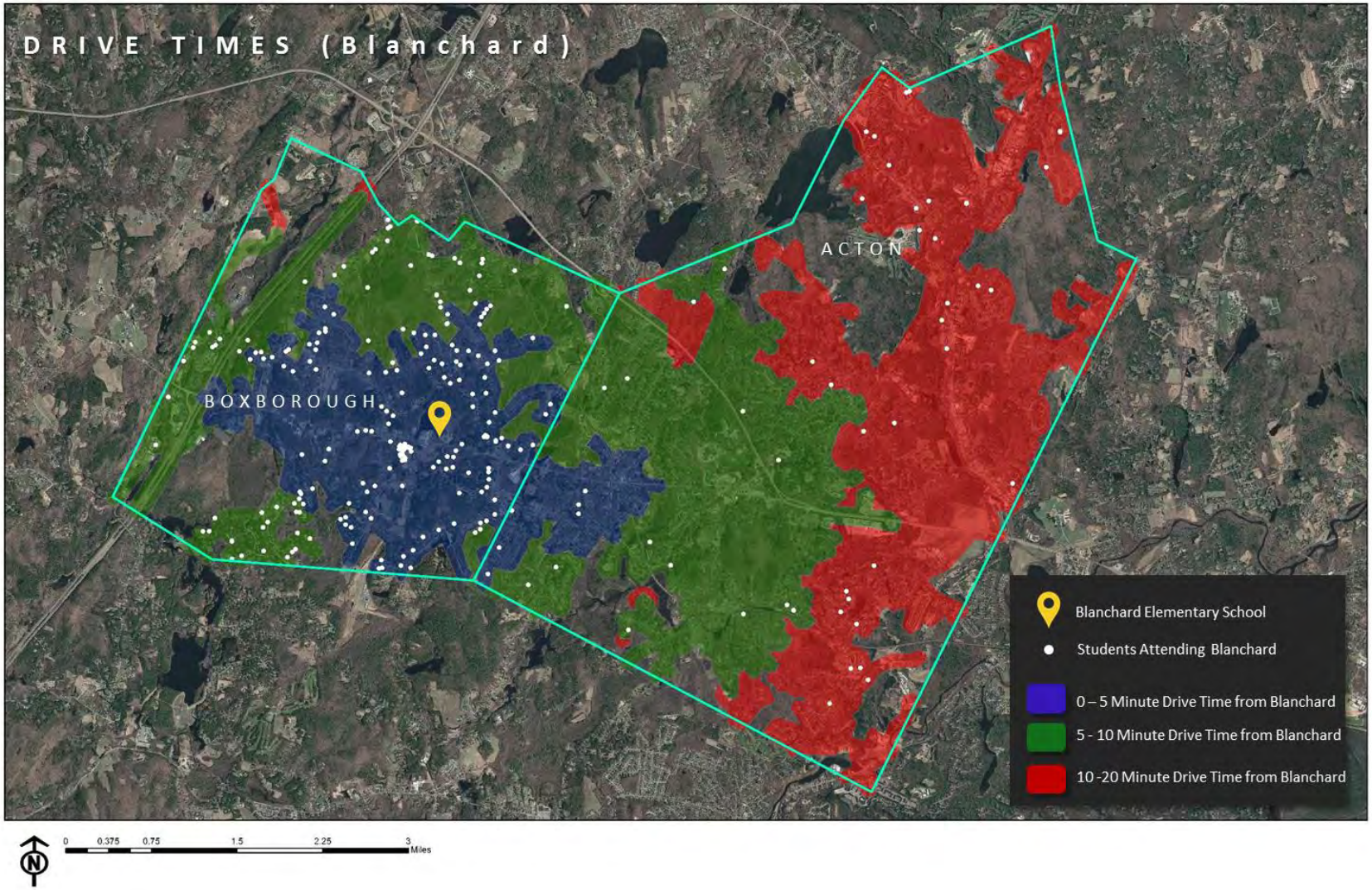


Figure 9. Drive Time Service Areas from Douglas/Gates

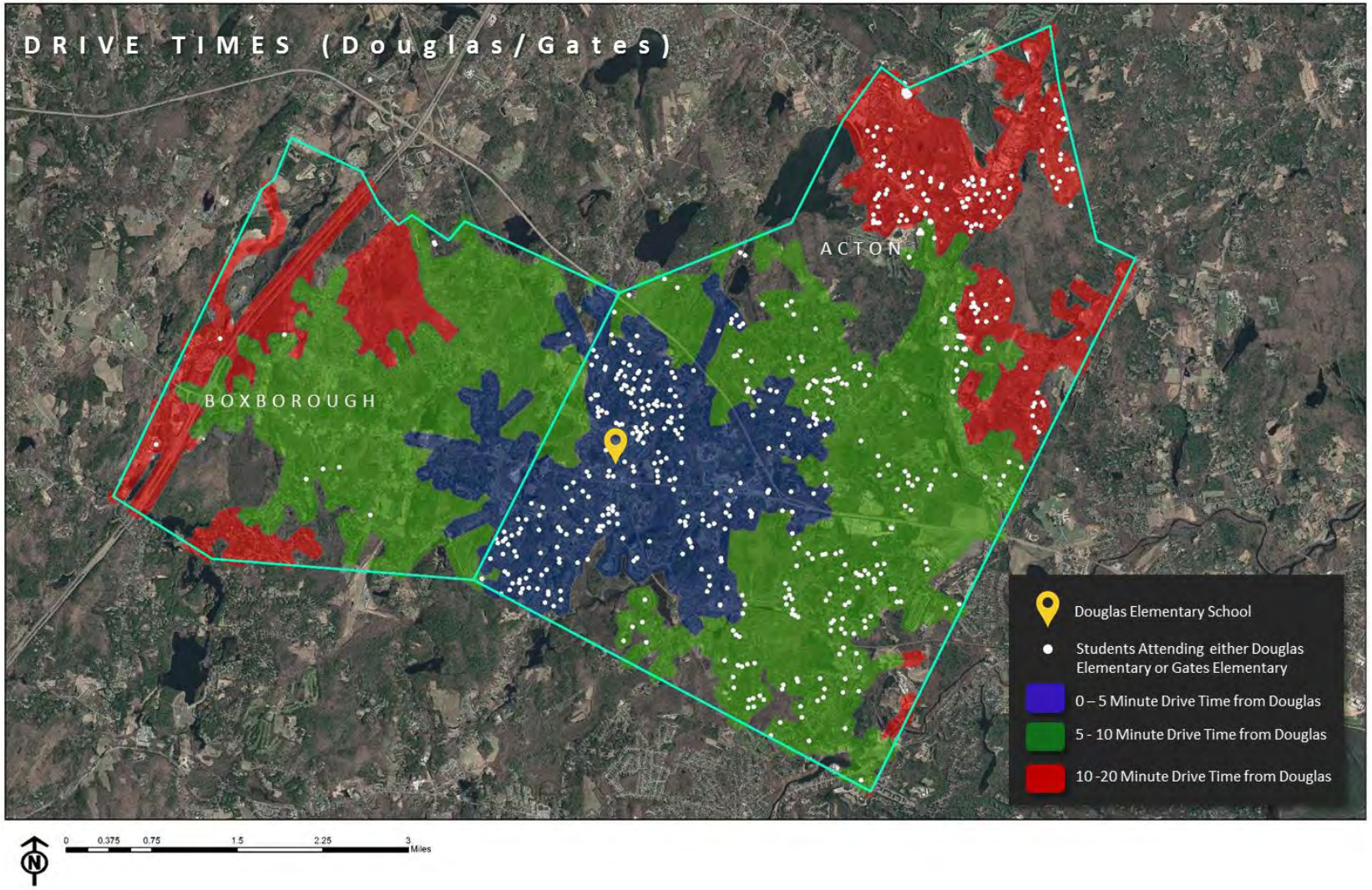


Figure 10. Drive Time Service Areas from Conant

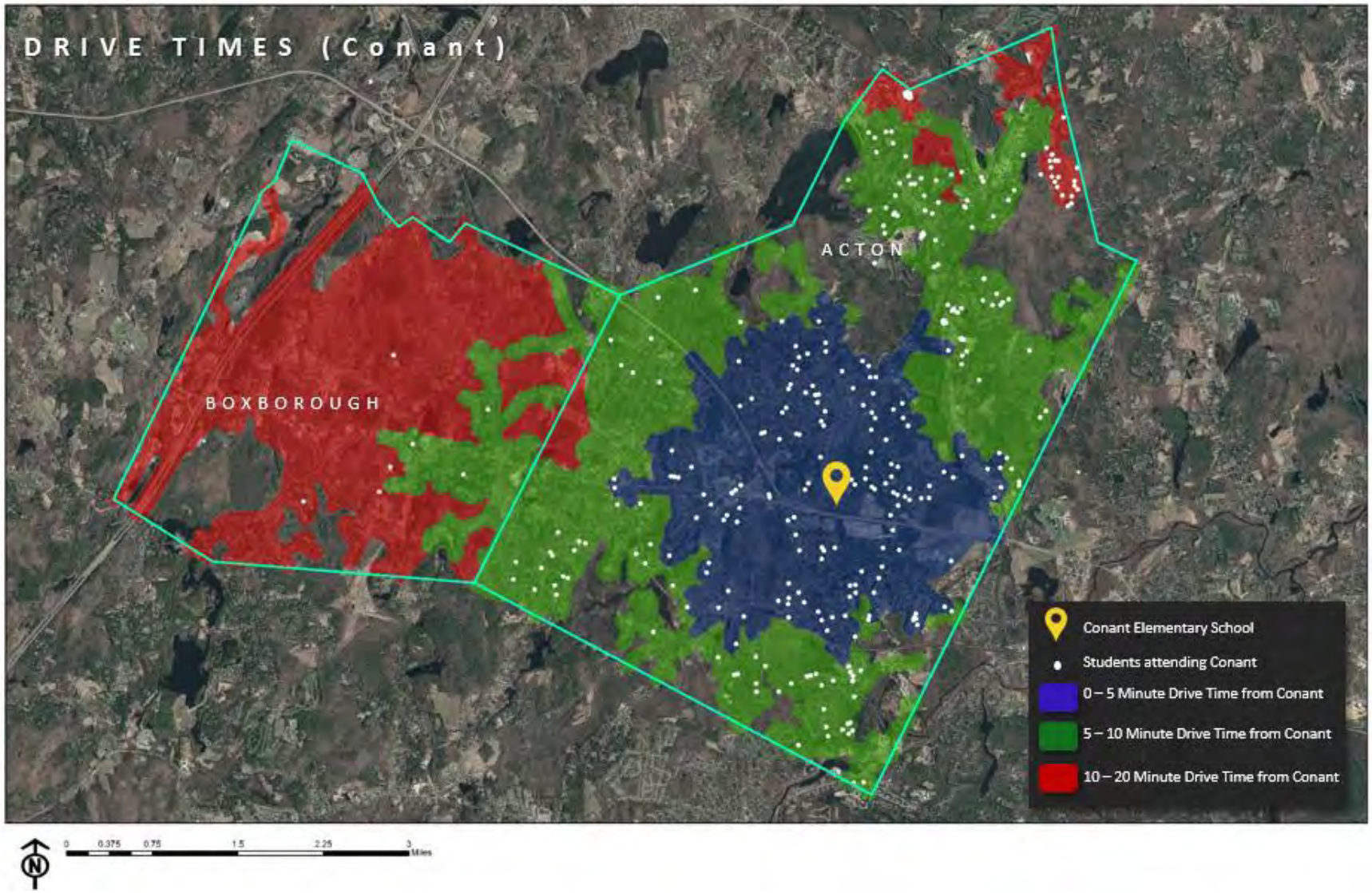
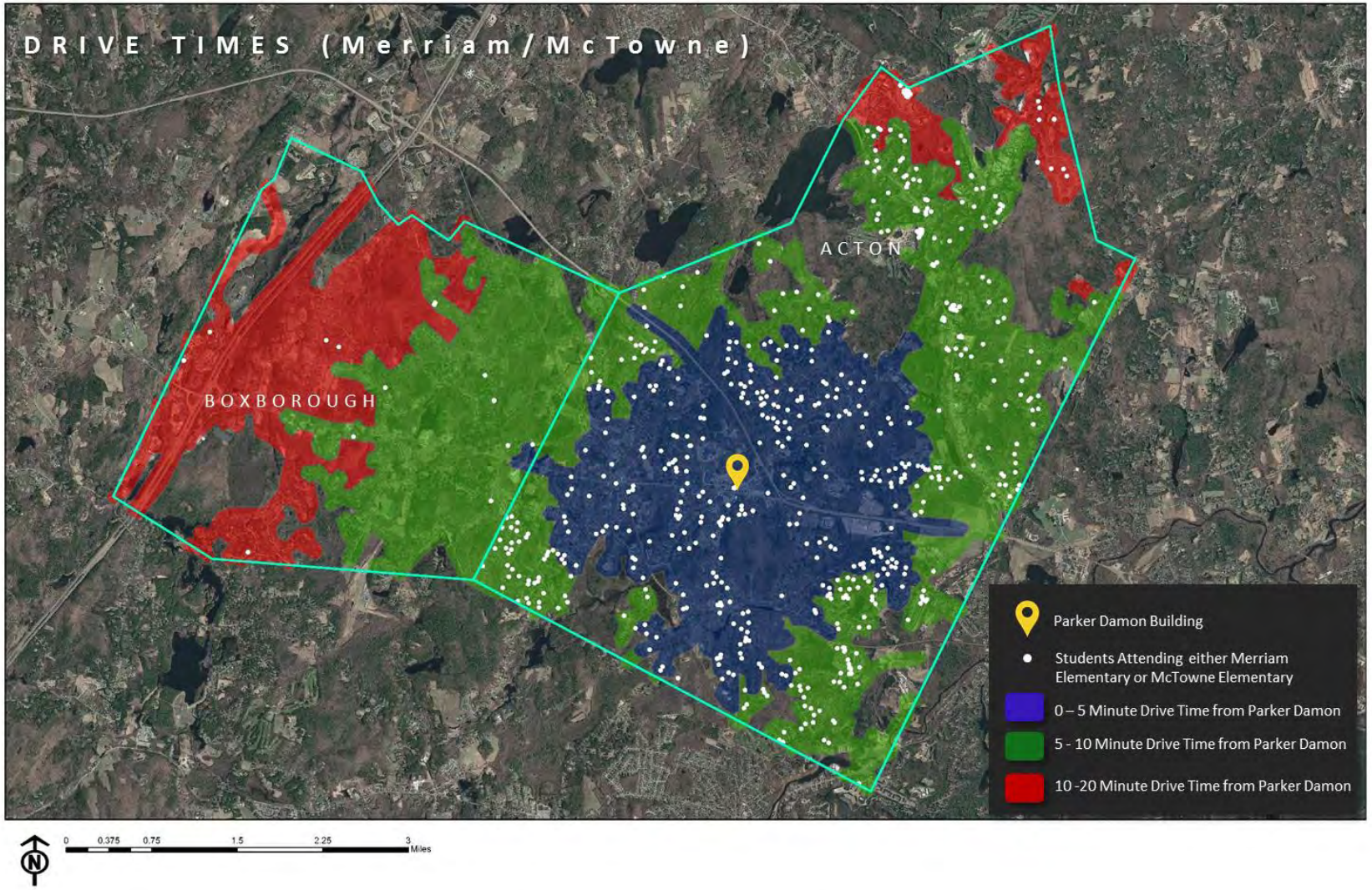


Figure 11. Drive Time Service Areas from Merriam/McTowne (Parker Damon Building)



Figures 7-11 allow for planners to visually inspect where routes need to be more direct and where routes can service more students within the time constraints. These service area graphics make it easy to pinpoint the "outliers" which will require long trip lengths and are most likely the result of "school choice". For each school, routes within the blue areas can spend more time picking up students while routes ranging out towards the red area must spend more time traveling between pick-up and drop-off area. When planning multiple trips for a single bus, these graphics are extremely beneficial. Since students must be serviced within that drop-off/pick-up window, it does not make sense for a single bus to drive similar routes for both tiers. In other words, it is ill-advised to have one bus complete a "red" route in the first tier and a similar "red" route in the second tier. Trip time would be extremely tight and not as many students would be able to be serviced. It is recommended, however, that one bus may complete a "red" route in the first tier and a "blue" route in the second tier to balance trip length between tiers and thus adhering the drop-off/pick-up window as well as minimizing time spent on the bus.

ABRSD PROPOSED FLEET REQUIRMENTS Merging to a 2-Tier System

Proposed Fleet Requirements

As previously mentioned, if the ABRSD were to merge to a two-tier routing system utilizing the existing transportation practices in use today, a total of 66 buses would be required to service all students, leading to greater inefficiency and underutilization. However, if the transportation practices introduced previously in this document were implemented, including the planning for actual ridership numbers, the ABRSD can dramatically decrease the amount of required drivers and buses for efficient service. Actual ridership data, depicted in Table 3, indicates a 60% ridership at the high school/junior high school tier and a 75% ridership at the elementary tier. In order to account for rider fluctuation, a 10% buffer should be added for greater flexibility. Therefore, routes should be planned to assume a 70% ridership at the high school/junior high school tier and an 85% ridership at the elementary tier.

There are currently 2,687 students enrolled in grades K-6 (elementary tier). If an 85% ridership is assumed for the elementary tier, we can expect that 2,284 students will actually be riding the bus. At this level, 33 buses would be required to guarantee a seat for every student riding and 39 buses would be required to achieve the district target rate of 60 at the elementary tier. Although ideal to minimize the number of buses to 39, this does not take into account additional buses required in order to balance ridership with trip length for students residing far from their school of choice. **Therefore the required number of operating buses for elementary service is 42.** In the event of bus malfunction, it is recommended that 5 spare buses be available for reserve – resulting in 47 total buses for the elementary tier.

There are currently 2,694 students enrolled in grades 7-12 (high school/junior high school tier). If a 70% ridership is assumed for the high school/junior high school tier, we can expect that 1,886 students will be actually riding the bus. At this level, 33 buses would be required to guarantee a seat for every student and 35 buses would be required to achieve the district target rate of 55 at the high school/ junior high school tier. Although ideal to minimize the number of buses to 35, once again this does not factor in additional buses required to balance ridership with the trip length for students residing far away from their school of choice. **Therefore the required number of operating buses for high school/junior high school service is 38.** In the event of bus malfunction, it is recommended that 5 spare buses be available for reserve – resulting in 43 total buses for the high school/junior high school tier.

Table 8. Minimum Number of Buses Required

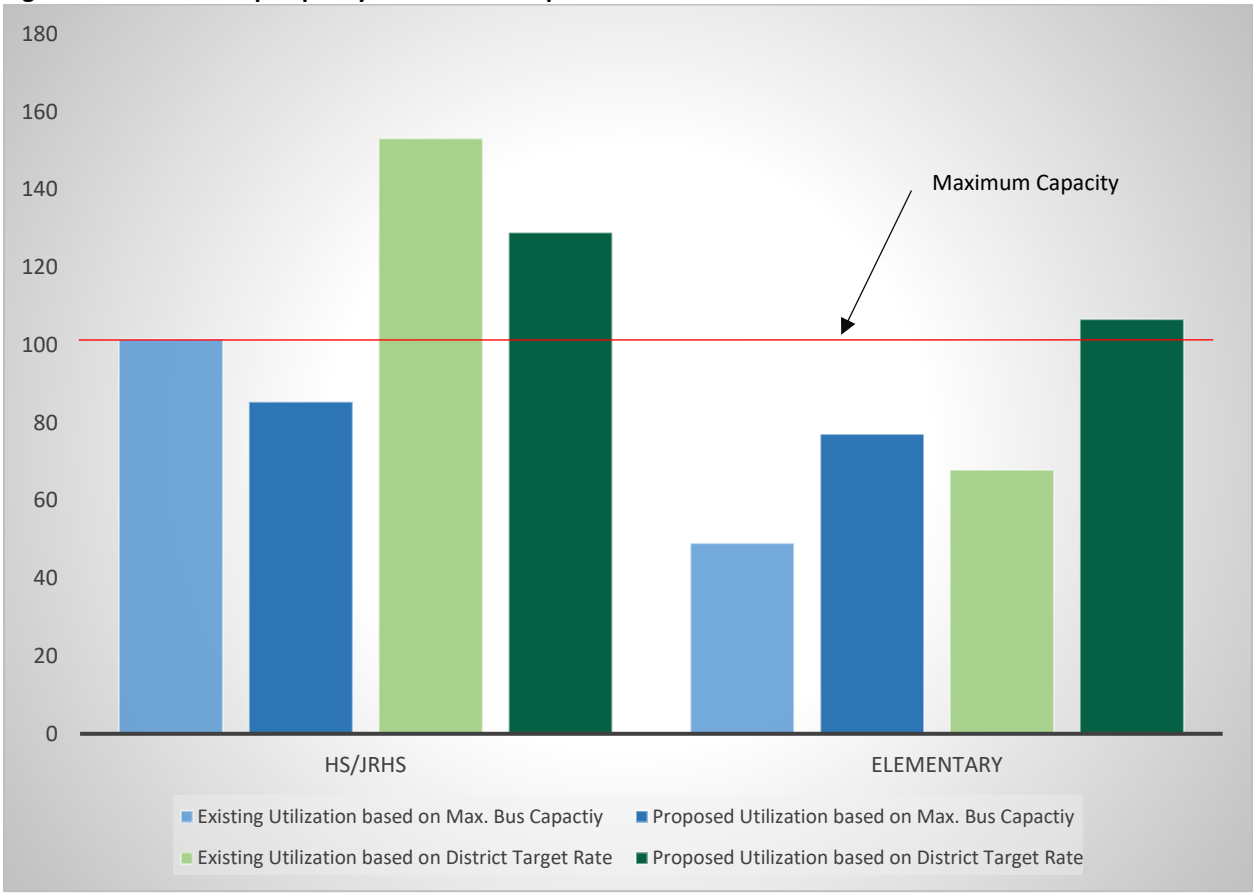
Tier	# Students in Tier	# Students Actually Riding (+10% Buffer)*	# of Buses (Limit 83 Students per Bus)**	# of Buses to Meet District Target Rates***	Required # of Buses for Efficient Service****	Recommended Spare Buses
Elementary (K-6)	2687	2284	33	39	42	5
HS/JRHS (7-12)	2694	1886	33	35	38	5

*Elementary = 2687(.85) = 2284. HS/JRHS = 2694(.7) = 1886
**On the day that every student rode the bus (doomsday scenario); Elementary = 2687/83 = 33, HS/JRHS = 2694/83 = 33
*** Students Riding Bus/District Target Rates
**** Factors in time window constraints and geographic considerations

Proposed Utilization Rates

Based on existing utilization rates depicted previously in Table 4, the intent of merging to a two-tier system is to pull down utilization rates in the high school/junior high school tier to a healthy rate and drive up utilization rates in the elementary tier to a healthy level. Table 9 illustrates the capacity utilization with full ridership, depicting the doomsday scenario when every enrolled student must be serviced. In this capacity, utilization based on maximum bus capacity for both tiers in both the AM and PM windows is under 100%, ensuring that no matter what, every student is guaranteed a seat on the bus. It also shows that most buses will be servicing more students than the district target rate at both levels resulting in possibly an uncomfortable ride. In comparison to existing utilization rates, utilization is brought down to a healthier rate in the high school tier and brought up to a healthier rate in the elementary tiers. This can be seen in Figure 12.

Figure 12. Full Ridership Capacity Utilization Comparison



As mentioned, the ABRSD has set district target rates at 55 student per bus at the high school/ junior high school level and 60 students per bus at the elementary level. Therefore, projected utilization rates based on the maximum capacity of each bus (83 seats) should be approximately 66% (55/83) for high school/junior high school tier and 73% (60/83) for elementary tier. Since we are planning to hit district target rates, projected utilization based on target rates should ideally be 100%. However, it would be acceptable, and perhaps better planning, to have a utilization rate of about 90% to account for greater flexibility and a potential growth in the student population down the line. Table 10, which illustrates proposed capacity utilization with projected ridership, hits those utilization targets, which a graphically depicted in Figure 13.

Figure 13. Actual Ridership Capacity Utilization Comparison

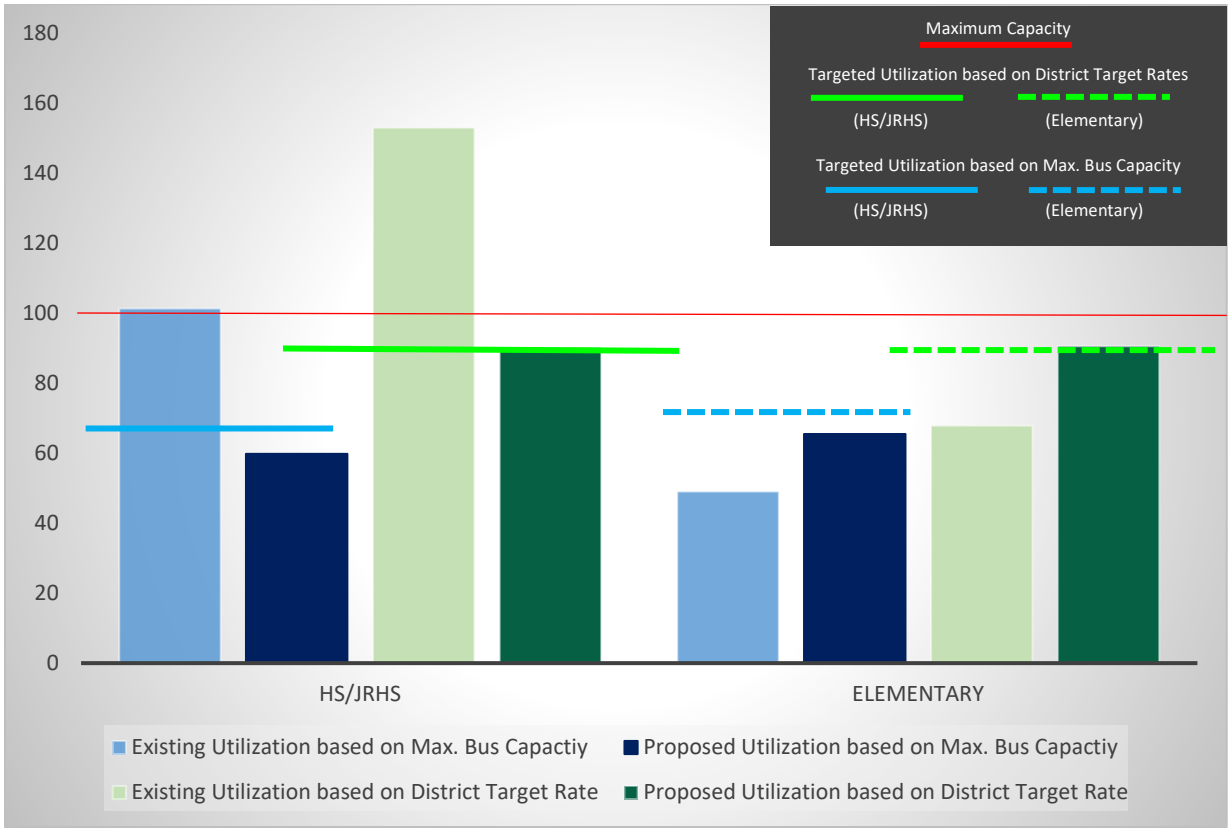


Table 9. Proposed Capacity Utilization with Full Ridership

Tier	# of Bus Runs AM/PM	# Students Transported in Tier (Full)	Maximum Bus Capacity	Utilization based on maximum capacity of each bus	District Target Rate	Utilization based on district target rates	# of buses less than half full (<40) assigned	Average # of Riders Assigned	Largest # of Riders Assigned
AM									
Elementary	42	2687	83	77.1%	60	106.6%	0	64	70
HS/JRHS	38	2694	83	85.4%	55	128.9%	0	69	75
Total	81								
PM									
Elementary	42	2687	83	77.1%	60	106.6%	0	64	70
HS/JRHS	38	2694	83	85.4%	55	128.9%	0	69	75
Total	81								

Table 10. Proposed Capacity Utilization with Projected Ridership

Tier	# of Bus Runs AM/PM	# Students Transported in Tier (Projected)	Maximum Bus Capacity	Utilization based on maximum capacity of each bus	District Target Rate	Utilization based on district target rates	# of buses less than half full (<40) assigned	Average # of Riders Assigned	Largest # of Riders Assigned
AM									
Elementary	42	2284	83	65.5%	60	90.6%	0	64	70
HS/JRHS	38	1886	83	59.8%	55	90.2%	0	69	75
Total	81								
PM									
Elementary	42	2284	83	65.5%	60	90.6%	0	64	70
HS/JRHS	38	1886	83	59.8%	55	90.2%	0	69	75
Total	81								

POTENTIAL START TIMES Merging to a 2-Tier System

When focusing on the two-tier start time/routing model, two potential scenarios were introduced by the ABRSD Superintendent, Deputy Superintendent and Director of Facilities and Transportation. Both scenarios will require the system to converge from a three-tier model to a two-tier model. **Regardless of which scenario is chosen, the number of buses required to service students stays the same, and therefore the planning is interchangeable considering a fairly well balanced number of students to service between tiers and a consistent operating window between both scenarios**. The potential start time scenarios are as follows:

Scenario A

In scenario "A" elementary students will be serviced in Tier 1 followed by high school and junior high school students in Tier 2. Scenario "A" presents the opportunity for a 67 minute delay for high school students which is more in line with teen physiology, the driving force behind the potential school schedule alteration.

Table 11. Scenario A Start Times

Proposed 2-Tier: Scenario A			
Tier 1	**Start**	**End**	**Duration**
Elementary All	7:50 AM	2:20 PM	6 hours 30 minutes
Tier 2	**Start**	**End**	**Duration**
High School	8:30 AM	3:10 PM	6 hours 40 minutes
Junior High School	8:30 AM	3:06 AM	6 hours 36 minutes

Table 12 displays target pick-up times and drop-off times for both tiers in this scenario – resulting in a maximum of 40 minutes spent on the bus for any student. It should be stated that it is possible that ride times may exceed 40 minutes for those students who reside far from the school they attend, and are most likely participating in school choice. These times are may be considered extreme but are a result of balancing ridership with trip length- governed by geographical constraints. Most students will be picked up within 40 minutes of the bell time.

In comparison to existing pick up and drop off measures, high school students are picked up approximately 74 minutes later in Scenario A than existing, however, they may be dropped off as late as 3:50 PM- approximately 50 minutes later than existing. This reduces the unsupervised time for teenagers in the afternoon, but also may be concerning for families who depend on high school/ junior high school siblings to watch after elementary students. The 3:10 PM release for high school students could possibly pose a hazard for athletic travel, and possibly result in athletes traveling to away games to miss schooling to do so. Also in Scenario A, elementary students are being picked up as early as 7:10 AM in which it could be dark out during the winter months.

Table 12. Scenario A Performance Measures

Tier	# of Bus Runs AM/PM	Target Pick-Up (AM)	Target Drop-Off (PM)
Tier 1 (Elementary)	42	7:10 AM	3:00 PM
Tier 2 (HS/JRHS)	38	7:50 AM	3:50 PM
Total	80		

Scenario B

In scenario "B", the order of service is flipped. High School and junior high school students are serviced in Tier 1 and elementary students are serviced in Tier 2. Scenario "B" offers a 37 minute delay for high school students. Although not as much of a delay as Scenario A, it is more in line with other school districts in the area.

Table 13. Scenario B Start Times

Proposed 2-Tier: Scenario B			
Tier 1	**Start**	**End**	**Duration**
High School	8:00 AM	2:40 PM	6 hours 40 minutes
Junior High School	8:00 AM	2:36 PM	6 hours 36 minutes
Tier 2	**Start**	**End**	**Duration**
Elementary All	8:40 AM	3:10 PM	6 hours 30 minutes

As Table 13 highlights, all elementary schools will start at 8:40 AM, the existing start time for tier 2 elementary as is. This scenario will pose less of a change for families.

Table 14. Scenario B Performance Measures

Tier	# of Bus Runs AM/PM	Target Pick-Up (AM)	Target Drop-Off (PM)
Tier 1 (HS/JRHS)	38	7:20 AM	3:20 PM
Tier 2 (Elementary)	42	8:00 AM	3:50 PM
Total	80		

Same as Scenario A, target pick-up times and drop-off times for both tiers result in a maximum of 40 minutes spent on the bus for any student. Most students will be serviced within 40 minutes prior to bell times. However, much like that in Scenario "A", there will be a handful of students, residing far from the school they attend and most likely participating in school choice, in which ride times will exceed 40 minutes. These times are may be considered extreme but are a result of balancing ridership with trip length- governed by geographical constraints.

In Scenario B, high school students may be picked up as early as 7:20 AM, approximately 44 minutes later than existing. High school students will be dropped off before elementary students which allows for them to care after elementary students in the afternoon. The 2:40 PM high school dismissal time is more in line with athletics, reducing the possibility that student athletes miss class time for travel games.

It should be noted that travel times were evaluated through means of a computer-based software program and may not reflect all operational constraints. Therefore, large-scale experimentation using actual bus operations must be deployed prior to implementation to validate theoretical findings and optimization methods to demonstrate their real-world potential.

COST IMPLICATIONS Merging to a 2-Tier System

Merging to a two tier model will reduce the total number of runs by 34 but increase the total number of buses and drivers as highlighted in Table 15. This will result in an increase in transportation budget spending as the school district will need to add to their existing fleet, hire new drivers and provide benefit packages, and increase bus storage facilities. As Table 15 indicates, merging to a two-tier model will result in the increase of 11 buses and drivers for the elementary tier and 7 buses and drivers for the high school/junior high school tier. These numbers factor in spare buses and drivers for planning purposes. In regards to calculating the required budgetary numbers for a two-tier model, the district must plan for the addition of 11 buses and 11 drivers which will cover both elementary and high school/junior high school service. Utilizing numbers from the proposed 2018 Transportation and Personnel budgets, the additional 11 buses, bus drivers, operational, and maintenance costs, will result in a total increase of $750,900 to the transportation and personnel budget in the first year of operation (2018-2019) The state provides reimbursement for regional transportation costs for all students who are more than 1.5 miles from their school. However, they reimburse based on the prior year expenses. As a result, we would expect that the district would have to fully fund the additional cost of single tier busing in the first year ($750,000), but that the reimbursement would help to offset those costs starting in the second year. The state reimbursement for these additional transportation costs are estimated to be $378,454, leaving $372,446 to be covered in the ongoing school operating budget. These costs include both operational and personnel costs and can be found in Table 16. Although this represents a significant increase in transportation spending, it should be noted that merging to a two tier system with the input parameters mentioned earlier, will result in healthy utilization rates, efficient routing, and safe trips for students. It will also allow for cross school collaboration, a consistent elementary schedule, the facilitation of athletic and extracurricular programs and most importantly achieve a delay for the high school start time.

Currently the existing 2018 budget yields a transportation cost per student of approximately $522. With the proposed transportation budget, this cost is expected to increase $140 resulting in a transportation cost per student of approximately $662. According to the National Center for Education Services, the national average expenditures for transportation per student transported in 2013-2014 was $961.00. Since 2000, average cost per student has gradually increased from $734.00 (1999-2000) to $961.00 (2013-14). **Therefore, although the budget would increase, the Acton-Boxborough Regional School District will continue to transport students at a cost significantly less than that of the national average.**

Table 15. Routes, Operating Buses, and Active Drivers Comparisons

TIER	ROUTES (AM/PM/TOTAL)			TOTAL BUSES*			TOTAL DRIVERS**		
	Existing	Proposed	Change	Existing	Proposed	Change	Existing	Proposed	Change
Elementary	66/66/132	42/42/84	-24/-24/-48	36	47	+11	34	45	+11
HS/JRHS	32/32/64	38/38/76	+6/+6/+12	36	43	+7	34	41	+7
TOTAL	**Reduction in 34 total trips**			**Increase of 11 buses**			**Increase of 11 drivers**		

* Includes 5 spare buses
** Includes 3 spare drivers

Perhaps the most difficult challenge of merging to a two tier model will be the hiring of trained, qualified school bus drivers and retaining these qualified drivers. Driver shortage is still widespread across the county. By proposing the addition of 11 additional operators, this poses a significant task ahead. Since there are four more drivers dedicated to the elementary tier than the high school tier, these four drivers may only get 4 hours of work a day, which is difficult to hire for and maintain. However, in the event that the school district move forward with Scenario “A” in which the elementary tier is serviced first, the excess number of drivers from the elementary tier can applied to the high school tier which could be utilized for athletic travel and extracurricular transportation. This would provide additional hours for these drivers and potentially make hiring an easier task.

Table 16. Cost Implications

TWO-TIER COST IMPLICATIONS			
Personnel Costs			
	Units	**Cost**	**Total**
Salary 30 Hours (Could possibly reduce to 25 hours)	11	$30,000	$330,000
Health Insurance	11	$11,000	$121,000
Workers Comp/Unemployment		$15,000	$15,000
Total Personnel Costs			**$466,000**
Bus Costs			
Bus Lease	11	$13,500	$148,500
Gas/Fuel Costs	11	$5,500	$60,500
Maintenance& Miscellaneous	11	$3,000	$33,000
Property & Liability	11	$2,800	$30,800
Bus Storage	11	$1,100	$12,100
Total Bus Costs			**$284,900**
Total Costs of Single Tier Busing (First Year 2018-2019)			
Total Personnel Costs			$466,000
Total Bus & Maint Costs			$284,900
Total Costs First Year (2018-2019)			**$750,900**
Budgetary Costs After Reimbursement (Starting in 2nd Year 2019-2020)			
Total Costs of Single Tier Busing			$750,900
Costs Eligible for Reimbursement	70%	Number of Students over 1.5 miles	$526,630
Estimated Reimbursement available 2nd year (2019-2020)	72%	Reimbursement of Eligible Costs	**$378,454**
Cost of single tier busing after reimbursement (starting in 2019-2020)			**$372,446**

CONCLUSIONS

GPI recommends that the Acton-Boxborough Regional School District continue to look into converting the existing start time/routing system from three tiers to two tiers in an effort to delay high school start times. Research continues to prove that additional sleep for high school students can have tremendous benefits in student mental and physical health. However, the decision to alter the school schedule to accommodate for a delayed start does come at a price and will require change management meaning there must be a balance of resource allocation. Adjusting bell times for high school students means that administrators must carefully allocate limited resources to operate efficiently within the budget.

As this report has indicated, in order to minimize the number of buses required to complete safe, efficient routes in the two-tier routing model, certain parameters must in introduced, which may pose significant changes for some families. These parameters include the following:

1. Planning based on actual ridership – Accounts for a 10% buffer in actual ridership numbers to plan for ridership fluctuation throughout the school year.
2. Removal of Cul-de-sac Service – Students will now be serviced at the end of the street.
3. Walk zones – The district may want to consider creating walk zones and not providing transportation for students residing within a .5 mile of the school the students attend.
4. "Cluster" stop approach – Most students will now walk to a stop rather than receiving door-to-door service. Elementary students will walk a maximum of 0.15 miles and high school/junior high school students will walk a maximum of 0.25 granted that safe, sidewalk access is available.
5. Maximum # of students assigned per bus – Elementary routes will have a maximum of 70 students assigned and high school/junior high school routes will have a maximum of 75 students assigned.
6. Trip Length and Pick-up/Drop-off Window – Trips will be designed to target a maximum 40 minutes spent on the bus. Some trips will exceed this target number, as to account for geographical and traffic constraints for cross-town trips and those participating in school choice. To accommodate for some of these longer trips, the pick-up and drop-off window for some students may be lengthened from 15 minutes to 30 minutes.

It is understood that these changes will alter family schedules and potentially induce stress on the school community. Therefore, it is critical to involve all stakeholders from the very beginning with the intent of educating the public on the trade-offs of a delayed high school start time as well as to continue to create alternate start time scenarios that are responsive to family concerns.

Given that the ABRSD assumes actual ridership at a safety capacity with the parameters introduced for more efficient service, the ABRSD will require 47 buses and 45 drivers. This results in an **addition of 11 buses and 11 drivers to the existing fleet and workforce**. The cost implications for these additional resources will result in an increase in transportation spending of **$750,900 ($372,446 after reimbursement).** Based on initial route projections, the ABRSD can expect a healthy utilization rate for both the high school/junior high school tier and the elementary tier as well as positive results in performance measures.