CMU Shuttle Rerouting Problem

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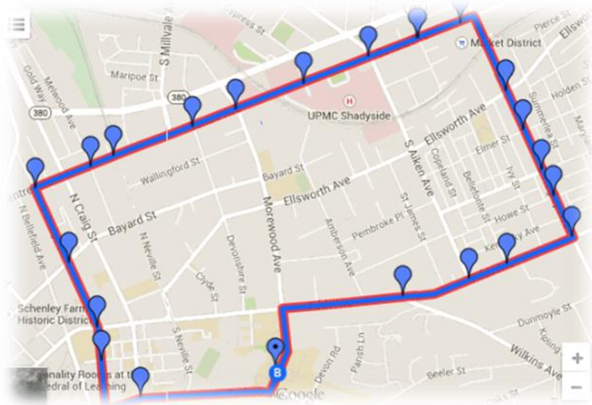
Introduction

The CMU Shuttle Bus service has been quite an important part of Carnegie Mellon University's campus service for years. Together with the Escort service, the Shuttle offers students the convenience of transportation between campus and various locations, mainly off campus apartments. The current shuttle service offers a fixed-route, fixed-stop transportation option that is available to all CMU students, faculty, and staff. Shuttle buses are assigned to different geographical areas, which surround Carnegie Mellon. The current routes are the following: A Route for North Oakland/Lower Shadyside; B Route for Upper Shadyside; AB Route for North Oakland/Shadyside when route A and B are not operating; Bakery Square (Long and Short), and PTC - Pittsburgh Technology Council. The service has been quite trustworthy and has become more and more recognized by the CMU community. After doing research on the current system and experiencing the service in person, our group found it interesting to solve some of the current issues the shuttle service is facing.

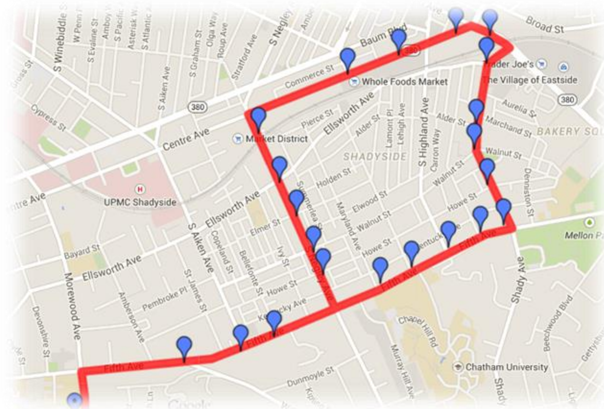
Understanding the current problems

Let us first take a look at the current routes. Each map represents a shuttle route of the shuttle service. Each route contains around 25 stops, and it takes 30 minutes for the bus to cover each of routes A and B, 45 min to cover route AB, and an hour for the bakery long route. The shuttle buses have regular operation hours as the following: route A and route B come every 30 min from 7:15 – 10:35am and 4:30 – 6:00pm; route AB comes every 45 min from 11:15am – 3:45pm; and Bakery Long route every hour at 8:30am, 9:30am, 4:30pm and 5:30pm. Note that route PTC is an independent route which does not have much intersection with the other routes, so we are not considering changing it in our project. And as for Bakery short route, it is essentially just the upper part of the Bakery long route, and we do not consider changing this route as part of our project.

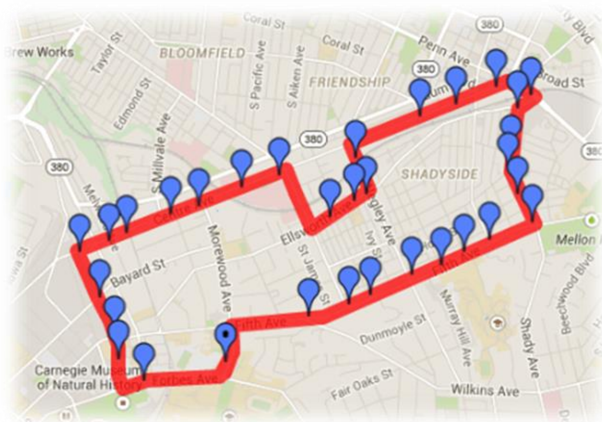
Route A — North Oakland/Lower Shadyside



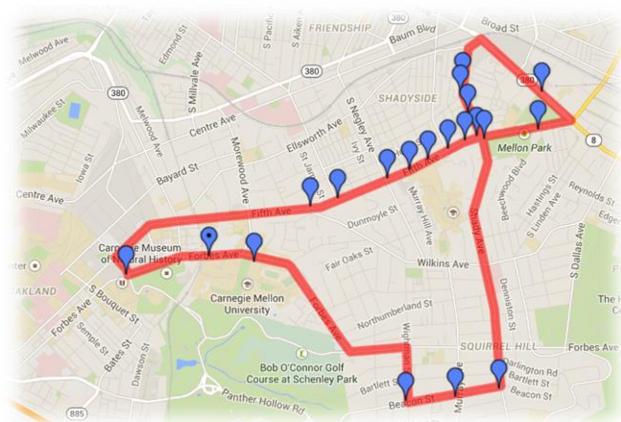
Route B — Upper Shadyside



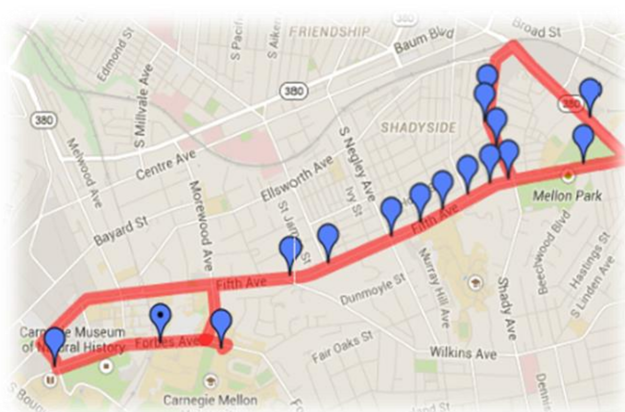
Route AB — North Oakland/Shadyside



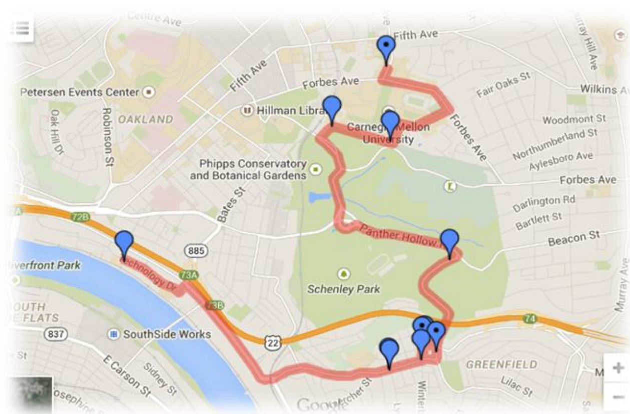
Bakery Square (Long)



Bakery Square (Short)



PTC



Route A	Route B
Morewood Gardens Turn-around**(Start)** Forbes Avenue at South Craig Street South Dithridge Street at Winthrop Street North Dithridge Street at Fifth Avenue (Across the street from Webster Hall entrance) North Dithridge at Bayard Street North Dithridge at Centre Avenue Centre Avenue at Melwood Avenue Centre Avenue at North Neville Street Centre Avenue at Devonshire Street Centre Avenue at Morewood Avenue Centre Avenue at Cypress Street Centre Avenue at South Aiken Avenue Centre Avenue at S. Graham Steet Centre Avenue at South Negley Avenue South Negley Avenue at Ellsworth Avenue South Negley Avenue at Elmer Street South Negley Avenue at Walnut Street South Negley Avenue at Howe Street South Negley Avenue at Fifth Avenue Fifth Avenue at Bellfonte Street Fifth Avenue at South Aiken Avenue Fifth Avenue at Wilkins Avenue Morewood Gardens Turn-around **(End)**	Morewood Gardens Turn Around **(Start)** Fifth Avenue at Wilkins Avenue Fifth Avenue at South Aiken Avenue Fifth Avenue at Bellefonte Street South Negley at Howe Street South Negley Avenue at Walnut Street South Negley Avenue and Elmer Street South Negley Avenue at Ellsworth Avenue South Negley Avenue at East Busway Centre Avenue at South Euclid Avenue Penn Circle South at Trade Street Penn Circle South at Shakespeare Street Penn Avenue at old Busway Entrance (across from Target) Shady Avenue at Ellsworth Avenue Shady Avenue at Alder Street Shady Avenue at Walnut Street Shady Avenue at Howe Street Shady Avenue at Fifth Avenue Fifth Avenue at Emerson Street Fifth Avenue at South Highland Street Fifth Avenue at College Street Fifth Avenue at Maryland Avenue Fifth Avenue at South Negley Avenue Fifth Avenue at South Aiken Avenue Fifth Avenue at Bellefonte Street Fifth Avenue at Wilkins Avenue Morewood Gardens Turn-around **(End)**

Route AB	Bakery Square(Long)
Morewood Gardens Turn-around Forbes Avenue at South Craig Street South Dithridge Street at Filmore Street North Dithridge Street at Bayard Street North Dithridge Street at Center Avenue Centre Avenue at Devonshire Street Centre Avenue at Morewood Avenue Centre Avenue at Cypress Street Centre Avenue at South Aiken Avenue Ellsworth Avenue at Bellefonte Street Ellsworth Avenue at Ivy Street Ellsworth Avenue at South Negley Street South Negley Avenue at East Busway Centre Avenue at South Euclid Avenue Penn Circle South at Trade Street Penn Circle South at Shakespeare Street Penn Avenue at old Busway Entrance (across from	Filmore Street (across from CMU Police Station) CIC Escort Stop on Forbes Ave in Front of CUC Forbes at Murdoch Wightman at Bartlett Beacon Street at Wightman Beacon Street at Murray Avenue Shady Avenue at Beacon Street Shady Avenue at Fifth Avenue Fifth Avenue at Beechwood Blvd. Google at Bakery Square Shady Avenue at Alder Street Shady Avenue at Walnut Street Shady Avenue at Howe Street Shady Avenue at Fifth Avenue Fifth Avenue at Emerson Street

Target) Shady Avenue at Ellsworth Avenue Shady Avenue at Alder Street Shady Avenue at Walnut Street Shady Avenue at Howe Street Shady Avenue at Fifth Avenue Fifth Avenue at South Highland Avenue Fifth Avenue at College Street Fifth Avenue at Maryland Avenue Fifth Avenue at South Negley Avenue Fifth Avenue at Bellefonte Street Fifth Avenue at South Aiken Avenue Fifth Avenue at Wilkins Avenue	Fifth Avenue at South Highland Avenue Fifth Avenue at College Avenue Fifth Avenue at Maryland Avenue Fifth Avenue at South Negley Avenue Fifth Avenue at South Aiken Avenue Fifth Avenue at Wilkins Avenue Bigelow Blvd at Pitt Union Shelters

Bakery Square (Short)	PTC
Filmore Street (across from CMU Police Station) CIC Escort Stop on Forbes Ave in Front of CUC Fifth Avenue at Beechwood Blvd. Google at Bakery Square Shady Avenue at Alder Street Shady Avenue at Walnut Street Shady Avenue at Howe Street Shady Avenue at Fifth Avenue Fifth Avenue at Emerson Street Fifth Avenue at South Highland Avenue Fifth Avenue at College Avenue Fifth Avenue at Maryland Avenue Fifth Avenue at South Negley Avenue Fifth Avenue at South Aiken Avenue Fifth Avenue at Amberson Avenue Bigelow Blvd at Pitt Union Shelters	Morewood Turn-around Frew St. at Tech St. Frew St. (Scaife Hall) Greenfield Rd. at Overlook Dr. Alger St. at Winterburn Ave. Greenfield Ave. at Winterburn Ave. Greenfield Ave. at Lydia St. PTC-Pittsburgh Technology Center

Current Issues

One major issue is about the capacity and utilization rate of the shuttle buses. On one hand, there are concerns on punctuality of the service. Though it is supposed to be a fixed-time service, and the shuttle bus drivers are trying their best to save time on the road, the buses are almost guaranteed to be late at rush hours around 9:30 – 10:30am and 4:30 – 6:00pm. On the other hand, there are time slots when the utilization rate is quite low, yet buses still operate at their normal schedules.

Another major issue is the fact that riding the shuttle buses can actually be more time-consuming than walking, especially for someone whose home is close to campus but towards the end of shuttle routes. As we proceeded with the project, we decided to treat this issue as our main focus. Thus, our research question is the following: How can we rearrange the shuttle bus stops, schedules, and routes to minimize the total time students spend on the shuttle to and from school. In order to be more realistic, we added some cost constraints, as discussed in "constraints" section later. We also made some simplifying assumptions, as discussed in "assumptions" section.

Possible Solutions

First, our team discussed the possibility of reducing the number of stops, in order to decrease the buses' travel times. We thought about combining close stops and removing stops from a route if they are covered by another route during the same time period. Then, we considered the possibility of using additional buses to only serve close to campus. Furthermore, we considered arranging interviews or doing a survey with students, in order to understand the current major concerns of the users of the service. Last but not least, our team looked into the possibility of upgrading the phone app for the shuttle service to provide people with more information regards to expected arrival time, current traffic conditions, seat availability, etc.

Assumptions

In order to simplify the problem given, we made some assumptions. The first such assumption was that people only use the shuttle to travel from school to home, or vice-versa. Since the routes cover a vast amount of space when combined, we realized that some people use the service to get to other destinations that do not involve Carnegie Mellon University. For example, some people may use the shuttle to travel from their home to a local grocery store like Giant Eagle. However, the shuttle service was primarily thought of as a service for students to commute between home and school in an efficient manner with low cost. Therefore, since the problem would be much bigger without a consistent destination, we decided to assume that students use the shuttle busses for its primary use only.

The second assumption made was that the bus travels at a constant speed at all times when moving regardless of traffic or speed limit. We picked 30 miles per hour as this speed. This assumption simplified our problem quite a lot because the shuttle busses drive on many different roads with different speed limits and traffic. This assumption also entailed that stop times were consistent. In other words, the time between stopping to let passengers off the bus and getting on the road again was the same for all stops. To keep this previous assumption true, it was assumed that the same number of passengers would get off at each stop. If these assumptions were not made, further research would need to be completed which was not possible because of the time constraint given in order to complete the project.

The next major assumption was that the cost of fuel was constant, and the amount of fuel used was solely dependent on miles per gallon. This assumption was made because there are many factors that come into play when dealing with fuel consumption, which would make the problem much more difficult to complete within the time constraint.

Finally, we made the assumption that for each route, the capacity of the bus was greater than or equal to the demand. Therefore, no person would have to wait at the stop for an hour and half because the capacity has reached its maximum and can't let another passenger on the bus.

Constraints

The following are constraints given to this problem, in order that the problem and its solution make sense and are economically feasible. The first of these constraints was that we would use only one bus for each route, and that buying more busses was infeasible. If we did not add this constraint, then we could continue purchasing more busses could be bought until the problem would be solved by turning the service into a taxi service or something similar to Uber or Lyft.

Our next constraint was that we would increase the cost of the service by no more than 10 percent of current cost. Costs include fuel, paying the driver, and maintenance of buses.

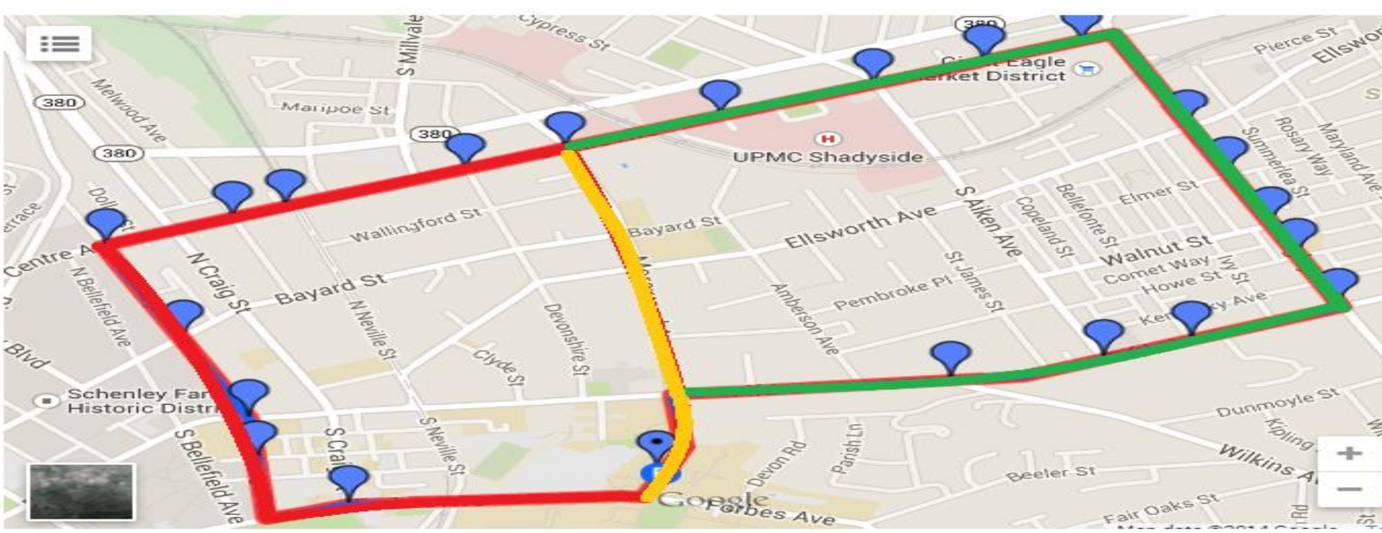
Methods

Using these assumptions and constraints, we decided to address the problem by creating shorter routes, which return to campus more frequently, thereby reducing students' time on the bus. Specifically, the method used to solve this problem involved taking each route (except PTC), cutting the route in (approximately) half, and creating two sub-routes. After finishing each of these sub-routes, the bus returns to campus, and then begins the other sub-route.

Furthermore, CMU currently has smaller buses in stock, used for the nighttime Escort service. Thus, if the shuttle routes were split roughly in half, then the busses were changed from large to small ones. For five of our new routes – both halves of current routes A and AB, and the bottom half of Bakery – we are able to use small busses.

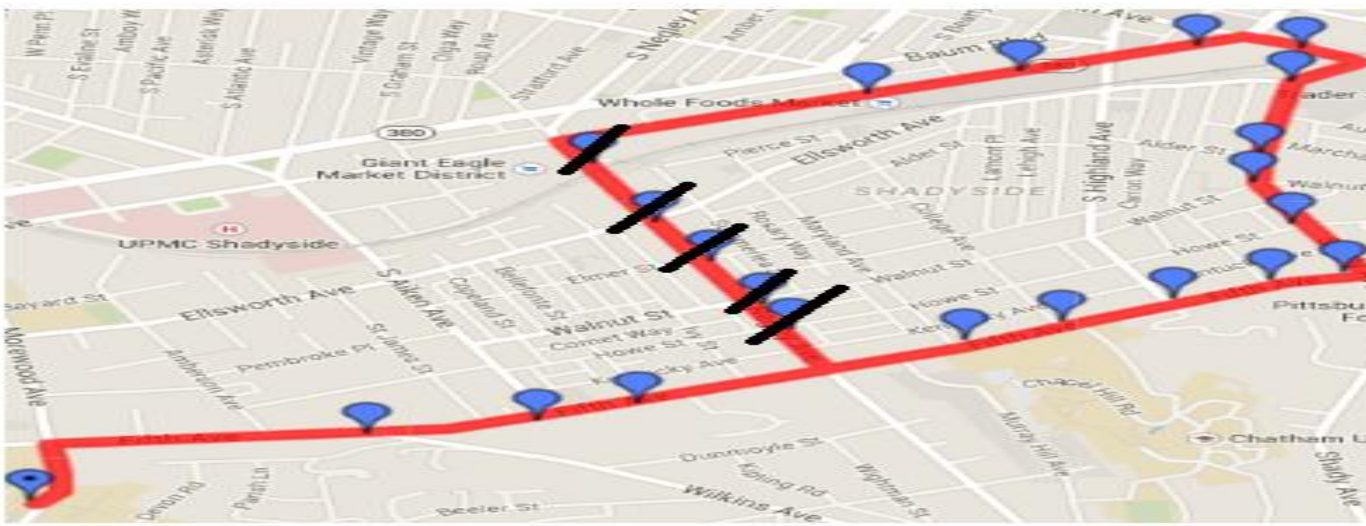
The following are the changes that were made to each route:

Route A:



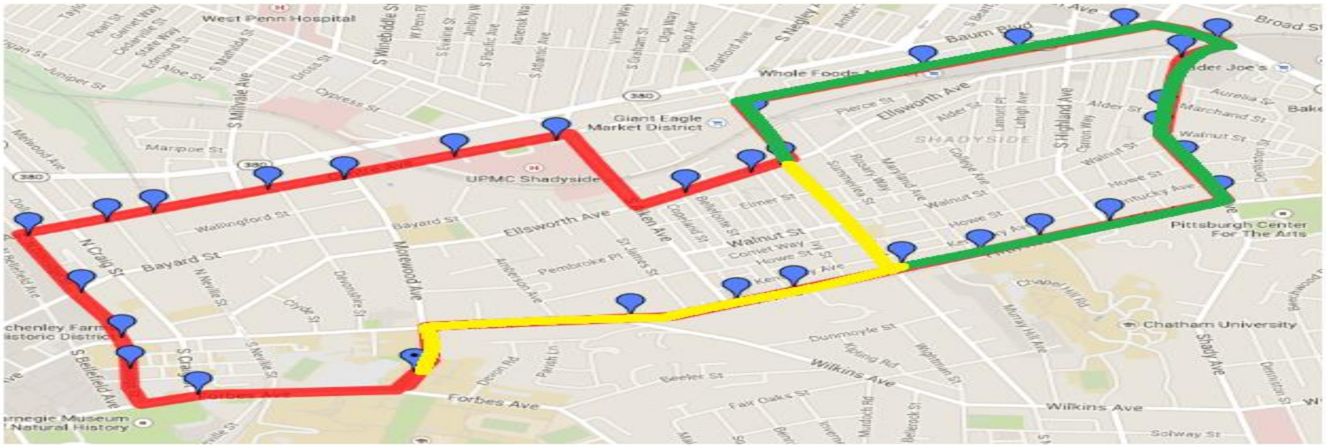
Route A was split roughly in half; therefore, the smaller busses were used for both new routes. The green route traverses the path in a clockwise pattern, whereas the red travels in a counterclockwise pattern. The yellow path is the intersection of the two new paths, and it may be useful to note that the green path has to take a left turn to get to Morewood in order to pick the students before beginning its route on the red path.

Route B:



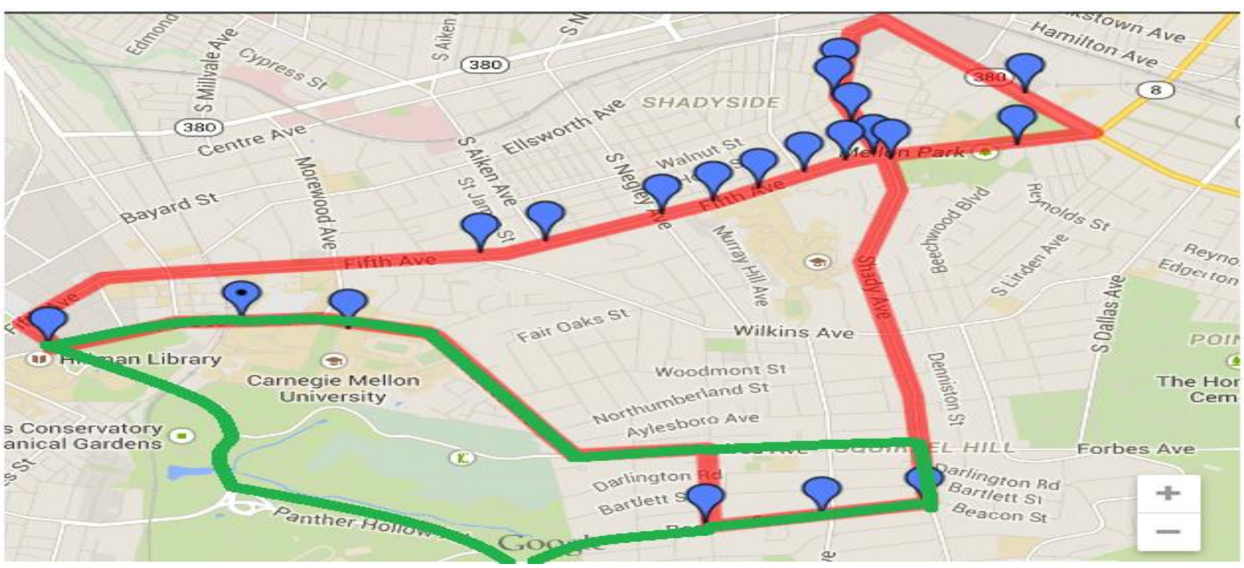
Route B was not split in half. The original route was already optimal, and there was no room for improvement by splitting the route. Instead, it was observed that there were a few stops that were shared between A and B. In order to save student’s times on the bus it was decided to remove the intersecting stops from route B, which is denoted by the black crosses in the above picture. So instead of taking time to make these stops, the bus would just drive past these stops. And since the route was not cut in half, the bus used this route would be the larger bus.

Route AB:



Route AB was split roughly in half; therefore, smaller busses were used for this route. Similar to what was done in route A, the green path will be traversed in a clockwise fashion, whereas the red is traveled in a counterclockwise pattern and the yellow is the intersection of the two paths. And the three stops on the yellow path are only stopped at when traveling along the green path.

Route Bakery Square:



For Bakery Square, it was observed that the three stops at the bottom right of the map were far from all the other stops. So it was discovered that it would be much more efficient if the green path would be traveled in a clockwise pattern. Also, we found that the route along Panther Hollow Road (part of the green route above) would be shorter than going back to campus on

Forbes. Since the green path only has 5 stops, not including the starting point, the smaller bus would be used for this path. The upper path would follow the Bakery Short route which can be found under "understanding the current problems."

Results Analysis

To calculate the cost effectiveness of our solution, we use the bus data and distance data as following:

Type of Buses	Capacity	Type of Fuel	MPG	Fuel Usage (gallon/mile)	Fuel Price ($/gallon)	Bus Fuel Costs ($/mile)
Small	22	Diesel	4.66	0.215	3.65	0.78
Large	45	Diesel	4.36	0.229	3.65	0.83

Table: Bus Data.

Both two types of buses use the same type of fuel, which indicates that their fuel price per gallon is the same. Due to their different capacity, small buses have less fuel usage per mile and thus lower fuel costs per mile. We will use the small bus fuel costs of $0.78/mile and large bus fuel costs of $0.83/mile in future calculations of the cost effects.

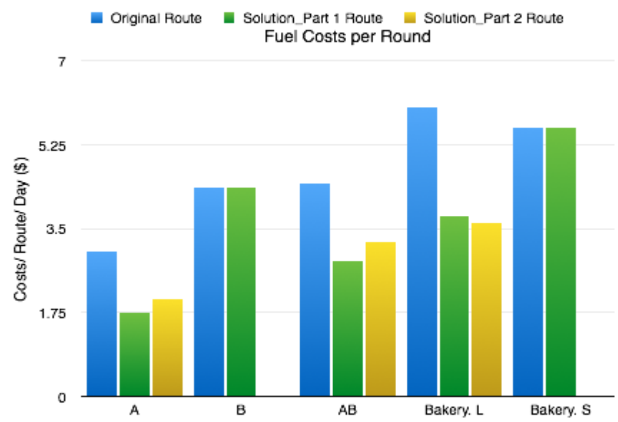
Route	Original Total Distance (mile)	Solution Part 1 Distance (mile)	Solution Part 2 Distance (mile)	Solution Total Distance (mile)	Extra Distance (mile)
A	3.6	2.2	2.6	4.8	1.2
B	4.1	4.1	N/A	4.1	0
AB	5.3	3.6	4.1	7.7	2.4
Bakery. L	7.2	4.8	4.6	9.4	2.2
Bakery. S	6.7	6.7	N/A	6.7	0

Table: Distance Data.

The original route is separated into two parts - Part 1 and Part 2, so we compare the total distance of the original shuttle route and the total distance of our solution routes as shown in the table above. Similarly for route AB and route Bakery. L. Please note that the total distance for route B and route Bakery. S. stay the same for the current shuttle system and our solution.

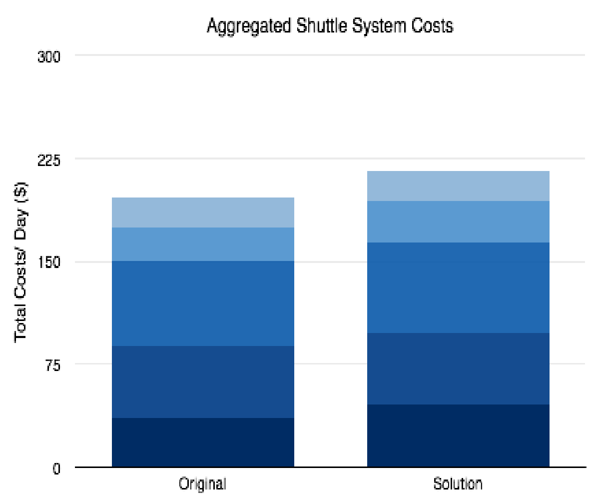
Based on the fuel costs for different bus types and the total distance for the current shuttle routes as well as our solution routes, we are able to calculate the total fuel costs per round for all routes, as shown in the graph and table below.

Route	Original Costs ($)	Total Solution Left Costs ($)	Total Solution Right Costs ($)
A	3.01	1.73	2.04
B	4.35	4.35	N/A
AB	4.43	2.826	3.219
Bakery. L	6.02	3.768	3.611
Bakery. S	5.60	5.60	N/A



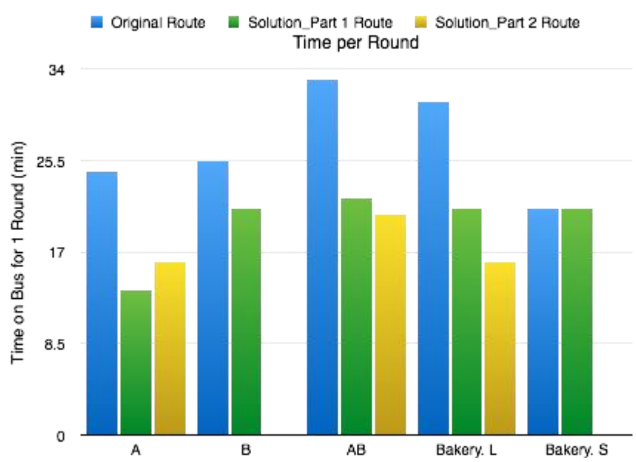
To calculate the shuttle system total fuel costs each day including all routes adjusted for the time schedule changes, we summed over fuel costs multiplied by number of rounds per day for all routes in the current system and our solution, as shown in the graph and table below. The aggregated solution costs is (215.851-196.82)/196.82 = 9.67% greater than the aggregated original costs.

Route	Original Time Interval	Total Original Costs ($)	Solution Time Interval	Total Solution Costs ($)
A	30min	36.12	30min	45.24
B	30min	52.2	30min	52.2
AB	45min	62.02	60min	66.495
Bakery. L	1hr	24.08	1hr	29.516
Bakery. S	1hr	22.4	1hr	22.4
Total		196.82		215.851



While our solution is able to keep the total solution costs increase within 10% (though just barely) as indicated in our constraints, we will examine the time effect for our solution. Due to the decrease in total distance for A – Part 1(denoted by A_1) and A – Part 2 (denoted by A_2) compared to the original route A, students living in area A_1 would experience a decrease of 44.90% in time spent on shuttle, calculated using the change of time spent to travel one round; similarly, students living in area A_2 will experience a decrease of 34.69% time decrease. Although route B is not separated into two parts, reducing its stops can help students benefit from a 18.65% decrease of time. Students living in area AB_1 and AB_2 will experience a decrease of 33.33% and 37.88% respectively, compared to the current shuttle system. Since the route Bakery. S is not changed, students taking this shuttle route will not be affected. The solution time effects for each route are shown as below:

Route	% Decrease in Solution Part1 Time (min)	% Decrease in Solution Part2 Time (min)
A	44.90%	34.69%
B	17.65%	N/A
AB	33.33%	37.88%
Bakery. L	32.26%	48.39%
Bakery. S	0	N/A



In conclusion, our solution will be able to decrease time spent on shuttle for all students taking route A, B, AB, and Bakery L. by a percentage ranging from 17.65% to 48.39%, with an increase in shuttle system total costs of less than but close to 10%. Thus, if the university would be willing to pay the extra cost, our solution could be implemented to reduce time spent on the bus.

Future Plans

Though we have a reasonable estimate of the cost of our new solution, with more time we could try to be more precise about the actual cost. For example, the bus uses more fuel when more people are on board. Therefore, on our shortened routes, the bus may actually use less fuel, since fewer people would be on board at a time. We would also look at the gas used when the bus makes a stop. Currently, we are assuming that the bus uses no gas when it is stopped, and uses a constant amount of gas while in motion. However, in reality, the process of breaking takes gas, and the bus continues to use gas while stopped. Also, the process of starting to move again after completing a stop uses additional gas.   To determine a more accurate cost, all these measurements would have to be taken into account.

Additionally, we could consider trying to find more efficient ways to cover all the stops. In particular, one approach would be to write a program to run the "Travelling Salesman" algorithm, and use it to find the most efficient way to cover all the stops. Another approach would be to use the "local optimization" method.

Finally, as mentioned earlier, we could create a survey to find out how many people currently use the shuttle service, at what times, and to what stops. Based on the responses, we could potentially cut out some stops at certain times of day. Furthermore, if there are time periods when 22 or fewer people would use a certain route, we could use the smaller escort bus to cover that route, thereby reducing gas usage.

Overall, our solution demonstrates that the shuttle system's routes can potentially be shortened without too high a cost. We hope that, if our solution and suggestions for additional improvement are implemented, the shuttle will become a more pleasant experience for its users.