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Optimizing Campus Mobility with a focus on Sustainability: A Graph Theory Approach to Intra-Campus Transportation Networks

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Optimizing Campus Mobility with a focus on Sustainability:

A Graph Theory Approach to Intra-Campus Transportation Networks

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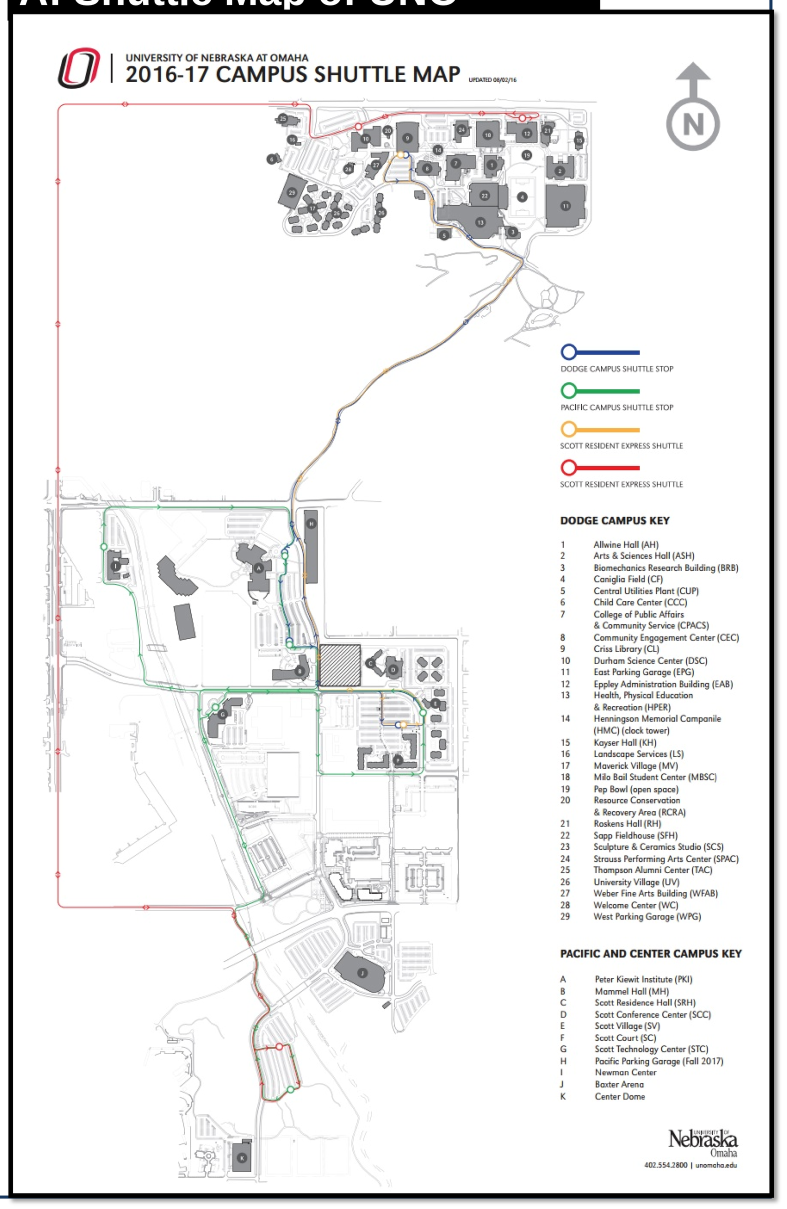
Description

The idea of public transportation is supported by most in theory but often heavily criticized by users when put into application. There are common tensions that are related to public transportation, as described by frequent users: unreliable, too crowded, and slow. The University of Nebraska-Omaha (UNO) is a growing metropolitan institution that uses a shuttle system to transport students among their three campuses daily. As of 2015, the current total student enrollment is approximately 16,000; UNO plans to enroll 20,000 students by 2020. The expected student growth is also reflected by the current construction of new buildings and expansion of UNO's campus. Like most metropolitan universities, space and parking on a college campus is a limited resource, and UNO's shuttle transportation system plays a vital role in ensuring student mobility between campuses.

With growing pressure from the UNO community to improve kinesis there is a need to optimize intra-campus transportation in an environmentally sustainable manner. To alleviate the tensions involved with the UNO shuttle system, we have created an algorithm to model shuttle routes using graph theory. Once modeled, our program chooses an optimized route based on various conditions: time, volume of students anticipated to use the shuttle, and fuel cost. The algorithm created can be used to optimize transportation routes, alleviate user tension, and decrease the carbon footprint of transportation networks. Our project thus charts the future by improving student transportation methods and people movement between urban campuses in an environmentally friendly and efficient way.

A: Shuttle Map of UNO



Problem Definition & Terminology

The University of Nebraska-Omaha (UNO) is a growing metropolitan university. The UNO campus stretches across three major streets in Omaha: Dodge, Pacific, and Center. This distance is roughly 2 miles wide. According to UNO 2013 Factbook, the UNO campus has a weekday population of over 17,702 making the university larger than the population of La Vista, NE (17,562) (Verdis Group 34). Each school day, students need to be able to move among the three campuses for classes, meals, parking, etc. The major way UNO student's move between campuses is the UNO Shuttle system. The shuttle system currently moves between all three campuses with three different routes, as shown in diagram A.

Some basic terminology for this project includes the following:

Graph = (V,E), V is set of vertices and E is set of edges between vertices.

Weighted Graphs – graphs for which each edge has an associated weight, represented by a weight function $w : E \rightarrow R$.

Adjacency-matrix Representation - of a graph G = (V,E), vertices are numbered in an arbitrary manner composing a matrix of |V| x |V|.

Proposed Solution

The graph theory approach was chosen for two reasons. First, the graph theory approach is scalable to a high degree: which in the event of an extreme data set or matrix size, the problem can be handled with our proposed implementation. Secondly, the solution can be implemented in a generic sense in the programming, so that different matrices can be handled with the same solution. This makes for a "one size fits all" solution that can be run as-is for all use cases. The code itself is written in Java and is based around the standard implementation of Dijkstra's famous shortest-path algorithm. This algorithm finds the shortest path, lowest cost, and least effort through a set of given nodes in a graph. Using this, we are able to read in a set of nodes in a graph and determine which path is the best based on a variety of factors that can be distinguished between.

D

```
8:39, true, false, true, true
verts=5
startPT=0, endPT=4
0, 11.58, 0, 11.58, 0
0, 0, 1.72, 0, 0
0, 0, 0, 0, 2.58
0, 0, 0, 0, 2.72
12.68, 0, 0, 0, 0
```

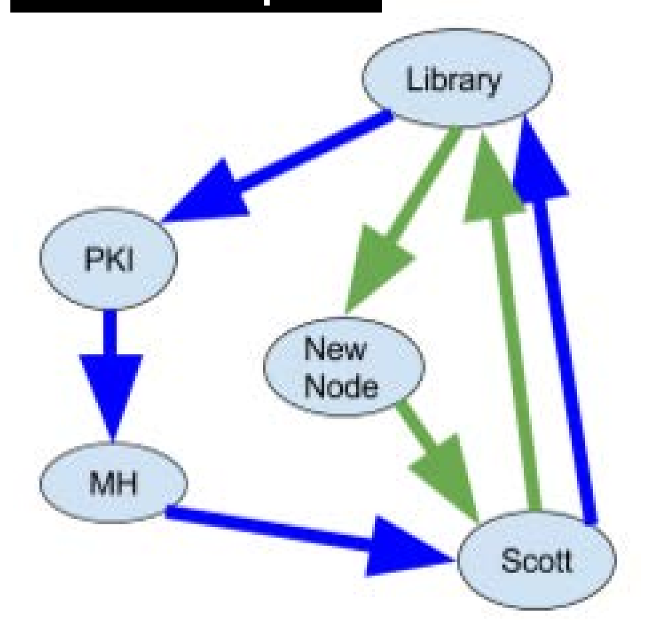
C

Make arrays (dist, parent, shortest path...)
Initialize arrays
Loop through all nodes
- Set each node to false in shortest path
- Set each node distance to infinity

Set dist of first node to 0 and parent to -1
Loop through all instances
- Set min dist var to infinity and index -1
- Loop through all nodes
  - Find min dist and index of next not in path
- Add index to shortest path set
- Loop through neighbors
  - Update shortest dist to each
  - Set parent of each

Figure B shows a graphical representation of the UNO Shuttle system with our proposed augmented node. We chose to place the augmented node between PKI and MH because our observations showed a significant traffic delay between these two nodes. Figure C shows the pseudocode representing our algorithm used for data modelling. Figure D represents the test case format: time stamp, T/F penalty, T/F weather, T/F Elmwood, T/F traffic, number of vertices, start and end vertices, and a matrix of values depicting the edges. Figure E is a table containing the time ranges for each edge in our graph. The time variance was based on data collected by Molly Pavlik from UNO's Transportation department. Her data influenced the range of values as well as the penalties for weather and traffic. Each penalty adds 60 seconds to the overall run time.

B: Node Graph



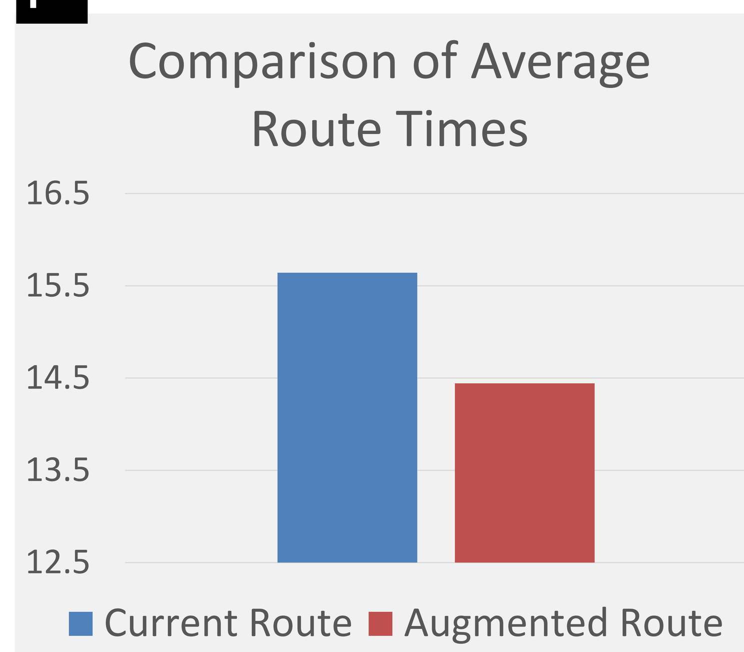
E

Start Node	End Node	Time Variance
Library	PKI	4-8 mins
PKI	MH	0.5-2 mins
MH	Scott	0.5-2.5 mins
Scott	Library	4-8 mins
Library	New Node	4-8 mins
New Node	Scott	0.5-2 mins

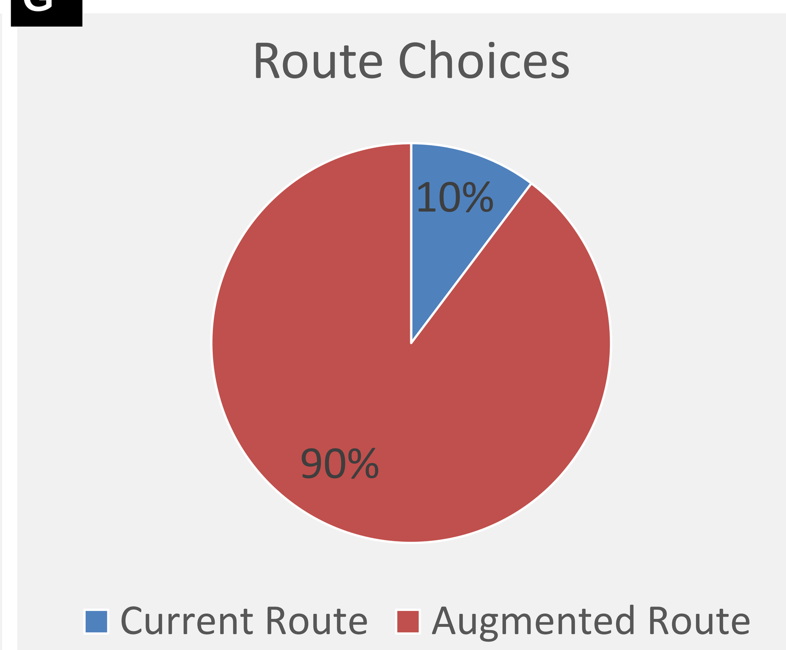
Implementation and Results

From our model of 257 shuttle runs per day, we generated 5 sets of shuttle runs to model a regular school week. With a total of 1285 total shuttle runs per week, we were able to generate graphs that demonstrate the differences between the current shuttle route and our proposed route. Figure G shows counts of each route chosen by Dijkstra's algorithm in our graph theory model. In total, our algorithm chose the augmented graph 1057 out of 1285 times, resulting in an 90% choice rate rather than 228 out of 1280 choices for the current route, a mere 10% choice rate as shown in Figure G. Moreover, through a 5 day average, our model depicts an average savings of 1.20 minutes per shuttle run. This can be translated to a savings of 308.4 minutes per day and 1542 minutes per week. With 2 semesters that each run 17 weeks long within a typical university fiscal year, this savings can then be extended to a total of 52,428 minutes (or 873.8 hours) over the duration. In addition to this, the shuttle system runs at about half rate during the summer sessions. This then adds another 10,794 minutes, or 179.9 hours. Let's project that each shuttle costs the university 38 dollars per hour of operation. At this rate, the new shuttle node would save an average of 40,040.6 dollars per year. Over the course of a year, it can be estimated that the entire shuttle fleet is operating at 25 mph for 75% of the time and sitting idle for the other 25%. To operate the shuttle at 25 mph for a period of 750.77 extra hours requires 1,681,724.80 grams of CO_2. To let the fleet sit idle for the other 25% of the time requires an extra 259,264.18 grams of CO_2. These numbers are extremely large and it would be a great service to both our civilization and our planet to reduce and optimize them, not just for our university, but for all around the US and abroad (Environmental Protection Agency, 2008).

F



G



Conclusions

Our graph theory model of the UNO shuttle system has produced a sound model that demonstrates areas where the system can be improved and optimized for future users. This project compares the current blue shuttle route to an augmented route proposed in this project. The augmented route contains a new node between PKI and Mammel Hall on 67th street. The implementation of this new node in our augmented graph is shown by our model to save an average of 1.2 minutes per shuttle run, which translates to a savings of 308.4 minutes per day, and 1542 minutes per week - based on 257 shuttle runs per day. Overall, the augmented route with a new node in the graph alleviates tensions associated with the shuttles being too slow - and does this in a sustainable manner. In the long run, a savings like this can pay off substantially in terms of fuel consumption, cost, and CO_2 emissions.

References:

1. Environmental Protection Agency. (2008, October). Average In-Use Emissions from Urban Buses and School Buses. Retrieved from www.epa.gov: https://www3.epa.gov/otaq/consumer/420f08026.pdf
2. Verdis Group. (2014, November). *UNO Sustainability Master Plan.* Retrieved from www.unomaha.edu: http://www.unomaha.edu/news/docs/UNO-Sustainability-Master-Plan.pdf