A Simple Approach for Sustainable Transportation Systems in Smart Cities: A Graph Theory Model

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Abstract - 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.

Keywords – graph theory, metropolitan universities, transportation networks, environmental sustainability, urban planning

I. INTRODUCTION

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) [1].

Each school day, students need to move among the three campuses for classes, meals, parking, etc. The growth of UNO’s students, accompanied by the expansion of the UNO campus creates a situation where campus mobility can be a serious problem.

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 the following diagram.

Figure 1: UNO Campus Shuttle Routes
The growth of UNO’s student enrollment and campus expansion puts pressure on UNO to improve the UNO shuttle system to adequately transport students between campuses. This research project focuses on creating an algorithm that represents the UNO shuttle system in a graph theory approach, while finding an optimized shuttle route for the UNO transportation network.

II. BASIC TERMINOLOGY AND PROBLEM DEFINITION

As previously described, UNO is a metropolitan campus surrounded by businesses, parks, and residential developments. The interoperability of UNO’s campus mobility is highly dependent on the subsequent traffic from various high volume areas (i.e. Aksarben, Elmwood Park, Pacific Street). Such campus mobility is critical to the livelihood of UNO’s students, faculty, and visitors. A major component of campus mobility is parking. A large demographic of UNO’s students are commuters to campus: meaning they drive to campus on a daily basis for classes, meetings, studying, etc.

A shuttle system that currently runs on diesel operated buses presents a situation where advances in sustainability can be made. If there are ways to limit the amount of fuel burned, decrease the carbon-footprint, and increase the sustainability of the UNO shuttle system - then a proposed change satisfying these requirements would be widely accepted.

To provide more momentum for our project, UNO has specifically detailed their commitment to improving the shuttle system in a sustainable manner. For example, in the UNO Sustainability Master Plan, their top six priorities are detailed. One of the six priorities relate to the improvement of the shuttle system: “Adjust campus shuttle contract to favor cleaner burning fuels to improve campus air quality and image” [1]. This specific commitment to enhance the sustainability of UNO’s shuttle system is profound and well-received. From an administrative level, UNO has acknowledged the importance of a sustainable shuttle system - providing relevance and support for various efforts reflecting UNO’s priorities.

There are several terms that will be used throughout the remainder of the project. It is essential to understand these in order to understand the overarching concepts that are used in the solution to the stated problem. In the field of computer science and graph theory, the two primary definitions are those of a node and an edge. A node is simply a data point on a larger network. These networks can consist of hundreds or even thousands of nodes, but for the current purposes, will not exceed more than a few that gives an adequate solution to the problem. An edge is simply an association between two nodes that can be visualized as a connecting line, and computed as a two element subset of the nodes that it respectfully connects.

The term graph, as it is used currently, is referring to the network of nodes that is connected by edges, and representing, in this case, the UNO shuttle system. This system can be altered, as has been done to accommodate a fluctuating number of students. When another node is added to the graph along with its corresponding edges to accompany it, the graph is said to be augmented, or added to.

Mathematically, there is a need to represent the edge data that is present outside of a graphical form. This is especially important when creating software representations for simulation. This is done using an adjacency matrix. This is a \(|V|\) x \(|V|\) two-dimensional array of length and depth equal to the number of nodes, or vertices represented as \(V\), that are present in the corresponding graph. In the current implementation, the row represents the starting node, and the column represents the ending node. The value at this location in the array is the edge value that can be mapped on the corresponding graph.

III. PROPOSED SOLUTION

The approach we chose is based on Graph Theory as classic scheduling-based problem and uses a software implementation to autonomously take in collected or simulated data and make recommendations based on it [11][12][13][14]. The graph theory approach was chosen for two reasons. First, it is scalable to a high degree, which in the event of an extreme data set or matrix size, the problem can be handled with the implementation. Secondly, the solution can be implemented in a generic sense in the coding, so that different matrices can be handled with the same

![Figure 2: Pseudo Code for proposed algorithm](image_url)
solution. This makes for a “one size fits all” solution that can be run as-is for all use cases.

<table>
<thead>
<tr>
<th>Start Node</th>
<th>End Node</th>
<th>Time Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Library</td>
<td>PKI</td>
<td>4-8 mins</td>
</tr>
<tr>
<td>PKI</td>
<td>MH</td>
<td>0.5-2 mins</td>
</tr>
<tr>
<td>MH</td>
<td>Scott</td>
<td>0.5-2.5 mins</td>
</tr>
<tr>
<td>Scott</td>
<td>Library</td>
<td>4-8 mins</td>
</tr>
<tr>
<td>Library</td>
<td>New Node</td>
<td>4-8 mins</td>
</tr>
<tr>
<td>New Node</td>
<td>Scott</td>
<td>0.5-2 mins</td>
</tr>
</tbody>
</table>

Table 1: Edge time variances

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.

Our modelling system produced 257 shuttle records per day - which simulates a full run. Our graph theory model can be seen in figure 5. Each shuttle record has a various number of values: test case number, time stamp, penalties (weather, Elmwood, and traffic) Dijkstra’s choice, non-augmented route length (minutes), and augmented route length (minutes), as shown in figure 3. The time variances for our model are shown in table 1. Our model uses a random time variance generator to simulate the shuttle runs. 257 shuttle runs per day is an accurate model of an average day for the UNO shuttles running on the blue route between Dodge campus and Pacific campus. In our program, shuttle runs are generated based on a frequency, as shown in table 1. From 6:30am - 6pm, a shuttle record is generated every 3 minutes. From 6pm - 10:30pm, a shuttle record is generated every 10 minutes. The application of a frequency based modelling system adequately represents an average day for UNO shuttles. In addition, the application of penalties determined by weather, traffic, and delays in Elmwood Park add to the rigor of our modelling system.

IV. 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.

In total, our algorithm chose the augmented graph 1057 out of 1285 times, resulting in an 90% choice rate compared to 228 out of 1280 choices for the current route, a mere 10% choice rate. The augmented route is consistently shown as the better option in terms of time when compared to the current route. Moreover, through a 5 day average, our model depicts an average savings of 1.20 minutes per shuttle run, as shown in figure 4. This can be translated to a savings of 308.4 minutes per day, and 1542 minutes per week.

This then leads into the greater discussion that involves the monetary and sustainability debates that encompass the shuttle situation as a whole. 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. The university (the case in point) currently outsources its shuttle services to external companies. Let’s project that each shuttle costs the university 38 dollars per hour of operation. At this rate, the recommended new shuttle node would save an average of 40,040.6 dollars per year. This is the tip of the iceberg.

On the side of sustainability, this can have an impact on CO\textsubscript{2} emissions as well. 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% of the time. To operate the shuttle at 25 mph for a period of 750.77 extra hours requires 1,681,724.80 grams of CO\textsubscript{2} [6]. To let the fleet sit idle for the other 25% of the time requires extra 259,264.18 grams of CO. Obviously 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 [6].

V. CONCLUSIONS
The UNO shuttle system is a vital component to campus mobility and interoperability on a daily basis. With this in mind, the shuttle system needs to be optimized to the highest extent. Each day, roughly 16,000 people have the opportunity to depend on the UNO shuttle system for effective mobility between campuses. In total, the future academic years can introduce an influx of students, teachers, and faculty which will depend on the shuttle system of optimized travel and mobility each and every day.

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 in our modelling system 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\textsubscript{2} emissions.

Furthermore, our graph theory model identifies potential areas of optimization within traffic routes and transportation systems at large. Our model can be used in a wide range of applications to identify transportation systems that have routes that could be optimized – thus translating to a decrease in CO\textsubscript{2} emissions. A current example of this type of optimization can be seen in Figure 6. This figure shows a portion of Dodge Street in Omaha, NE. Dodge Street is the busiest street in Omaha – as it connects the downtown area to the suburbs. In addition, Creighton University, Midtown, the University of Nebraska Medical Center (UNMC), Children’s Hospital, and Westroads Mall are all located on Dodge Street. In short, the traffic on Dodge Street is integral to the efficiency of Omaha transportation. Figure 6 showcases a portion of Dodge Street that passes by UNMC. In this example, it is easy to see that an additional road, Farnam Street – denoted in blue – was added to alleviate the traffic on Dodge Street – denoted in red - with the need to go to UNMC. This is shown again with Harney Street – denoted in purple – which was added in a one-way fashion to alleviate traffic congestion in this area.

Overall, these types of solutions are examples of the potential impact and possible improvement gleaned from our model. When our model is put to use, different routes can be generated and optimized to enhance traffic flow in a sustainable manner. The impact of this solution is incredible and widespread. Moreover, civic institutions have limited budgets to implement widespread change that will positively benefit their constituents. Our model is the most effective application to solve this problem: it is cost effective, easy to implement, and powerful. This is a simple solution to a problem with a limited number of variables – that yields actionable data to optimize transportation systems.

With this in mind, our research project has demonstrated an increase in campus mobility and

![Figure 6: Dodge Street Re-route – Omaha, NE](image)
interoperability by decreasing the time it takes for a shuttle to complete its route. The information in this project was presented to the administration at UNO and change was put into place for the 2017-2018 school year. Our proposed model was accepted and put into action – thus alleviating tensions towards the UNO Shuttle System, increasing the sustainability, and decreasing UNO’s carbon footprint. This research project provided evidence and actionable data to make large scale changes. Our model is proof that a simple graph theory algorithm can be modified and applied to real-world challenges and produce sustainable solutions.

VI. REFERENCES