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Clemson Football Parking Optimization Using the Hitchcock Algorithm and Validation with Bluetooth Sensors

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CLEMSON FOOTBALL PARKING OPTIMIZATION USING THE HITCHCOCK ALGORITHM AND VALIDATION WITH BLUETOOTH SENSORS

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by
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Accepted by:
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ABSTRACT

The City of Clemson has a population of approximately 14,000 residents and the university has 22,700 enrolled students. However, for seven weekends during the fall, the roadways are pushed beyond capacity during home football games on Clemson University's campus. Typical attendance for these home games is 80,000+ Clemson fans. These home games generate non-recurring congestion and typically require special mitigations measures, such as police officer-control of intersections.

With this substantial increase in demand during football game days, the mobility around the Clemson area is severely constrained both before and after games. In an effort to alleviate traffic congestion, researchers at Clemson employed the Hitchcock Algorithm to optimize where ticketholders from particular origins park. By optimizing where ticketholders park and the routes they take into campus, unnecessary link flows can be reduced. Furthermore, demand for games is high enough to cause links to reach capacity, so this research also considers link capacity when optimizing lot and route assignments. Additionally results from a Bluetooth study collected by a third party were used to calibrate the existing probable routes and link flows. The data also showed that where these vehicles park is not typically a function of where they enter the network. The added travel time of these vehicles through the campus network negatively impacts the traffic congestion of the overall system.

This research revisits the problem of optimizing football parking analyzed by Malisetty in 2004 but incorporates the use of Bluetooth sensor data and the concept of capacity-restraint. Likely link flows through campus resulting from existing lot

assignments are compared to those predicted by the Hitchcock optimization, and recommendations for new parking assignments (both lots and routes into campus) are proposed for ticketholders based upon the region of the Southeast US where they originate.

DEDICATION

To my parents for working so tirelessly so I can be where I am today.

ACKNOWLEDGMENTS

First and foremost, I would like to thank Dr. Wayne Sarasua allowing me this incredible opportunity to have him as an advisor and mentor during my time in graduate school. It has been a privilege to be one of his students in Geomatics, Introduction to Transportation, and Travel Demand Forecasting. During my last two years in graduate school, I have grown both professionally and personally, and it is due to his unwavering support and the influence from his passion for the transportation engineering field.

I would also like to thank Dr. Mashrur Chowdhury and Dr. Jennifer Ogle for their support in my graduate school journey. Thank you for serving on my committee as well as being mentors for me. The Transportation Engineering faculty at Clemson is phenomenal.

Stephen Fry deserves recognition for the dedication he has put into our transportation department here and tackling the graduate course work alongside me. We started this journey back in fall 2011 in General Engineering as acquaintances and now will walk the stage together with Master's in a couple weeks as friends. He has been a plethora of transportation engineering knowledge and always willing to drop everything to help a fellow classmate. Our time as Traffic Bowl team members and conducting football traffic study work has been memorable. Thank you for being a very much needed asset in all we worked on together.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Clemson University is located in Clemson, South Carolina. The City of Clemson has a population of approximately 14,000 residents and the university has 22,700 enrolled students. However, for seven weekends during the fall, the roadways are pushed beyond capacity during home football games on Clemson University's campus. Typical attendance for these home games is 80,000+ Clemson fans. Events that draw large crowds like football games or concerts are referred to as planned special events by the FHWA (Latoski, 2003). These special events generate non-recurring congestion and typically require special mitigations measures, such as police officer-control of intersections..

With this substantial increase in demand during football game days, the mobility around the Clemson area is severely constrained both before and after games. In an effort to alleviate traffic congestion, a traffic study was performed at key intersections around the campus on two games days during the 2015 season. Additionally, Bluetooth tracking was conducted by Stantec (2015) for one of these games to determine the routes of vehicles that use the various parking facilities. While the Bluetooth study gave important data for how traffic comes into campus, there were findings of intra-campus mobility as well. The data shows that where these vehicles park is not typically a function of where they enter the network. For example, a vehicle approaching from the south is just as likely to park on the north side of campus as the south side. The added travel time of these vehicles through the campus network negatively impacts the traffic congestion of the overall system.

1.2 Problem Statement

In 2004, Clemson M.S. student Prashant Malisetty did a study that optimized football parking allocation using a network analysis algorithm called the Hitchcock Transportation Problem. By optimizing the parking assignment, it was hypothesized that there would be improved mobility during football game days. The quicker a vehicle is able to get to its lot before games and leave the region after games, the less demand there would be on the roads. This research revisits the problem of optimizing football parking but incorporates the use of Bluetooth sensor data and the concept of capacity-restraint. Malisetty ran an all-or-nothing traffic assignment to assign lots and routes to his origin zones. All-or-nothing does not consider congestion. However, Clemson's network is highly congested on game days. Thus, it is desirable to apply the Hitchcock Algorithm for parking optimization while using capacity-restraint during route assignment. The allocation would then be guided by link capacity, preventing links from being disproportionately overloaded. This thesis presents a methodology for parking optimization that takes congestion into consideration and calibrates link capacities using Bluetooth data.

1.3 Research Objectives:

- Provide an enhanced parking optimization methodology that calibrates by considering congestion and using Bluetooth data to more accurately model routes to campus.
- Demonstrate the usefulness of the Hitchcock Transshipment Problem to planned special event parking.

1.4 Outline of Thesis

First, the current chapter gives an Introduction to the project and a general overview of Prashant Malisetty's previous thesis on the Clemson University Football Traffic Improvement Study in 2004. Chapter 2 provides background information on the topics of research presented in this thesis. Chapter 3 Reviews relevant Literature, presenting other case studies that both have been completed and are planned for the future.

The Methodology behind the research is discussed in detail in Chapter 4. In Chapter 5 the Data are presented, and the procedures are demonstrated. The results and deliverables to the athletic department are also discussed in detail in Chapter 5. The Conclusions reached from the research are discussed in Chapter 6. This chapter also compares Prishant's methodology to the methodology presented in this research. The applicability of the Hitchcock transportation problem toward other planned special events is discussed as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Clemson Football Traffic Study

Parking Reallocation for Football Game Traffic at Clemson University written by Prashant Malisetty is a thesis published in 2004 which first addressed parking reallocation for Clemson football games. Overall, Prashant's study improved the conditions for the infrastructure for some years; however, the Clemson football team has been improving their program in the past decade and been making headlines, even winning the National Championship for the 2016 season and this in turn has made Clemson University a larger attraction than in years prior. Major home games can bring in crowds larger than 100,000 people (City of Clemson), and while most of those people attend the game, a large number come for the atmosphere in the small college town.

Managing the traffic demand is a daunting task. The Federal Highway Administration (FHWA) published *Managing Travel for Planned Special Events* (2017) to help event coordinators better understand and plan for traffic congestion. In it states that there are two sources of congestion: recurring and unrecurring. Recurring congestion is predictable, the best example of this is workday commuter traffic; while on the other hand, unrecurring congestion is the result of an event. These planned or unplanned events generate new trips and increases the travel demand on the infrastructure surrounding the event.

The FHWA comprised three goals for managing travel for planned special events. The first goal describes achieving predictability of the impact of the increased congestion. This is about identifying the major impact zones and performing analyzes of parking demand and traffic demand. The second goal is ensuring safety. This encompasses both pedestrian safety and preventing congestion-induced secondary incidents. The last and arguably most important goal is maximizing efficiency. This goal entails using all the available resources and excess transportation system capacity. The work in this thesis helps with the accomplishment of the first goal and Clemson utilizes their and surrounding police departments in order to have the man power to help satisfy the last two goals.

Since his thesis was published in 2004, Clemson University has seen a considerable growth with the student population and construction of new facilities in addition to the football team's success. In order to accommodate the demand for ticket holders, every available space on the west side of campus has been utilized. This led to extending parking to the outskirts of campus and even off campus. The latest additions of parking lots are at the Newspring Church at the intersection of Highways 123 and 93 and a new lot behind the First Citizens bank on Old Greenville Highway which will be implemented in the upcoming season.

Malisetty focused on the assignment of 4 area lots back in 2004 while now there is a focus on 11 smaller lots spread around the Clemson area. Malisetty also focused on grouping the vehicles based on their most preferred route. From this groups, he ran the Hitchcock algorithm to assign which the vehicles to the area lots. This was the best approach in 2004 but in the present day, the use of Bluetooth data can be beneficial. By utilizing the Bluetooth data from a study that Stantec completed, calibration of the data was completed to enhance the model by breaking down the multiple paths people can take to get to campus. Malisetty's thesis was more uniformed by implementing an all-or-nothing traffic assignment in the way that each group he created followed the same route while in reality that wasn't the case. The research in this thesis used an equilibrium approach which considered congestion.

2.2 Special Event Case Study: Madison, Wisconsin

In his literature review, Malisetty referenced Phansak and Robert's paper Development of Parking Choice Models for Special Events, a case study at a University of Wisconsin mens' basketball game for parking choice at the Kohl's Center in Madison. In that case study the main parameters measured for driver choice of a parking lot was driving time, parking cost, and walking time. Assignment of people based on their address was done on the main gateways around the center and the gravity model was then analyzed for the altered network. The network was analyzed with User Equilibrium Assignment with the parameters mentioned earlier because it is the drivers' choice. The results of that study were alternative routes based on optimum travel cost. Malisetty focused on the differences in the studies, like how parking is essentially the drivers' choice and how traffic outside of Madison wasn't considered instead of considering that the authors used an equilibrium loading.

In a comparison of Phansak and Robert's study and the present day Clemson football traffic study, Phansak and Robert's available data is a strength. Street addresses were available for the ticket holders so those living in proximity to Kohl's Center were assigned to one of the 700 TAZs in the area for accuracy and those outside of the TAZs were assigned based on their zip codes. However, the athletic department supplied only zip codes so the parking permit holders closest to Clemson's campus are centered at a single centroid. Accurately tying in customer locations made their modified network strong.

2.3 Origin-Destination Studies: License Plate Surveys

License plate surveys are a method used to estimate origin-destination routes by recording license plate IDs as vehicles pass by checkpoints (Turner et la., 1998). The Oklahoma Department of Transportation conducted license plate surveys in Chickasha in order to determine the amount of traffic that could potentially make use of a proposed bypass (2007). A total of twenty survey sites were stake out and one or two surveyors were recording license plates from each location. While overall, the concept of reading license plates along different locations to understand vehicle paths is easy enough, there are factors that affected data collection.

Surveyors had to read at least three characters for the license plate to be considered viable data and conditions made it harder at times. Dirty license plates or poorly lit vehicles with burnt out license plate illuminations made data collections difficult. Speeding platoons of vehicles were another factor that impacted data collection. Human surveyors limit the data collection while Bluetooth data collection is done passively, no matter the speed or condition of the vehicle.

2.4 Origin-Destination Studies: Mobile Phone Location Data

Estimating Origin-Destination Flows Using Mobile Phone Location Data (Calabrese, 2011) describes another method origins and destinations have been estimated is by tracking mobile phone location data. It was similar to using the Bluetooth sensors which pick up passively but, location measurements from mobile phones could only be picked up actively, when a mobile phone receives or makes a call or short message and when the internet is being used. A case study involving the tracking the origin and destinations was done at Fenway Park a day prior to and of a baseball game. Their findings, as shown in Figure 2.1, were that they were able to capture the additional volume flows that were created by the baseball game.

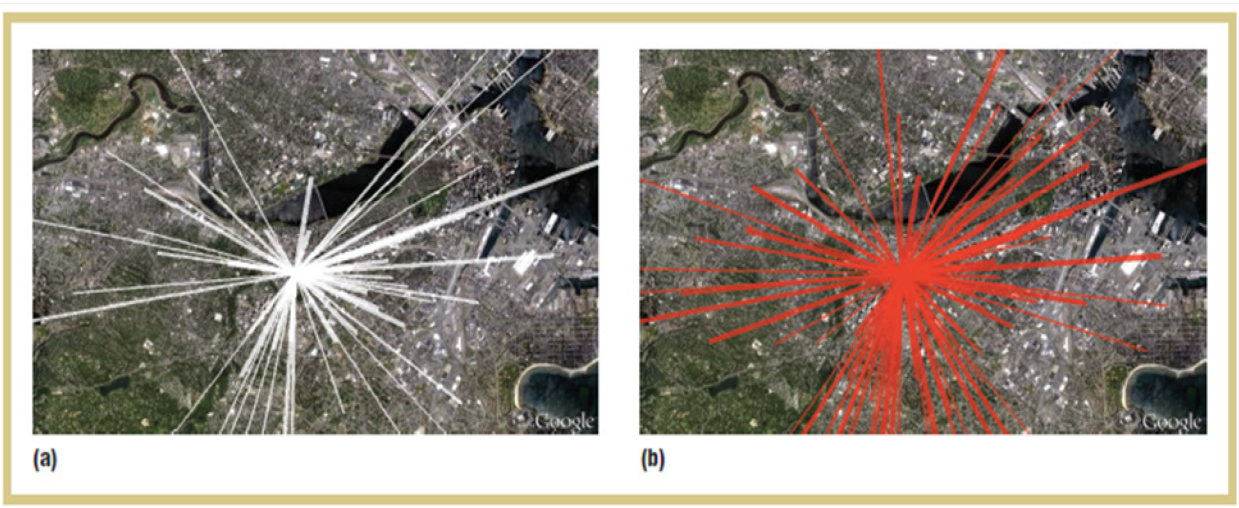

Figure 6. Incoming trips in the Fenway Park area. Each line connects a detected trip origin area to the Fenway Park: (a) normal Sunday, and (b) day of a Red Sox game. Flow volume is represented by the line's thickness.

Figure 2.1: Comparison of Trips in Fenway Park Area on a Normal Sunday vs. Day of a Red Sox Game. Reprinted from Calabrese, et al., 2011, *PERVASIVE Computing, 10*(4), 36.

2.5 Future Research

Another way that parking allocation is being done is by the use of applications on smartphones. For the 2016 football season, the University of Arizona partnered up with a Tucson-based company, Metropia, to develop an application which basically brings a Traffic Management Center to the campus. The application displays a map with road closures and live traffic and parking information. "Information about driver origins, on-campus traffic flow, fan arrival and departure times, and parking preferences and capacity levels were analyzed and allow for a greater understanding of game day patterns and the planning of enhanced traffic mitigation strategies in the future" (Metropia.com, 2016) One tool for analysis is in Figure 2.2 displays a heat map that shows where the traffic was congested on the campus during game day. Since this application was used in the 2016 football season, studies on its impact haven't been completed but from Metropia's website, the events were successful and the application's use was implemented into the basketball season. More research on emerging applications that can be applied toward planned special events would be beneficial for similar traffic studies in the future.

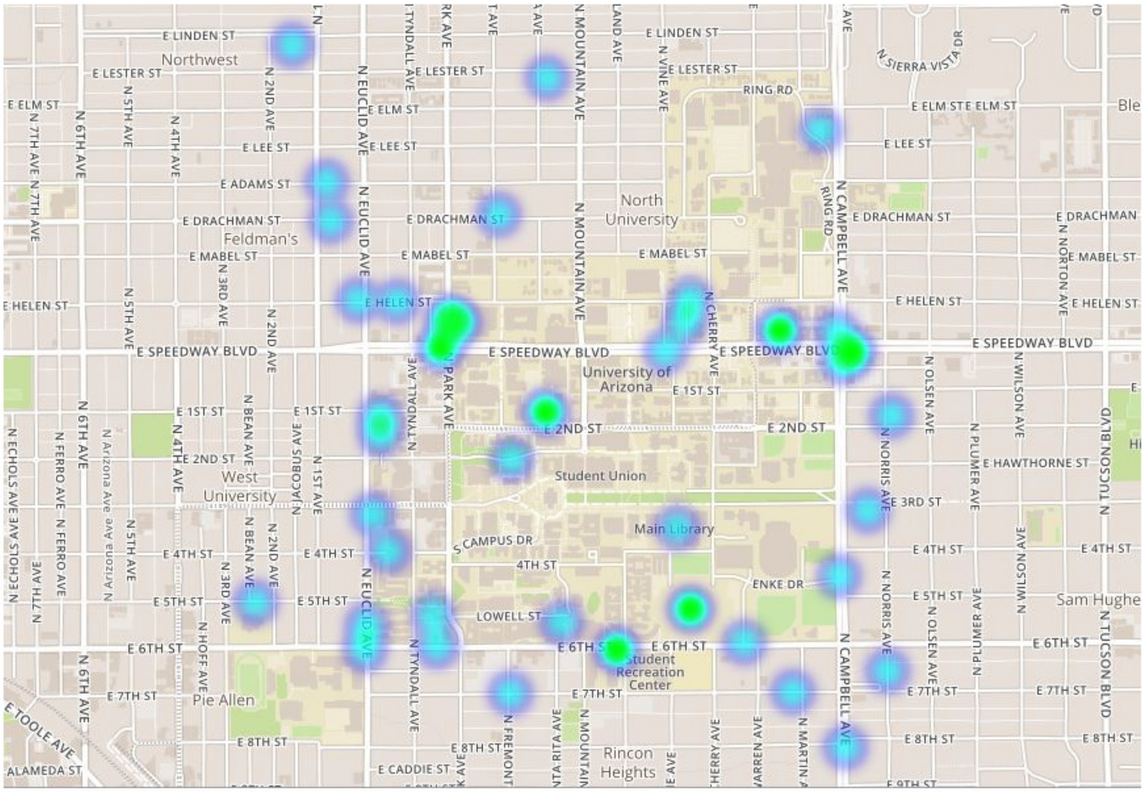

Figure 2.2: Heat Map Produced From Congestion On Arizona University Campus Before A Football Game. Reprinted from Metropia*,* 2016.

CHAPTER 3

BACKGROUND

3.1 Introduction

The Clemson Tigers football team has been steadily improving their performance in the past decade and attention has been growing. Thus, the number of football attendees has increased to the point that the stadium is at or near capacity nearly every game. Furthermore, many fans flock to Clemson for some of the more popular games to experience the game day atmosphere or just to tailgate or watch the game downtown. So the City of Clemson could easily host over 100,000 people for many games.

The Clemson campus has been changing significantly as well. Large-scale construction projects such as Douthit Hills, Core Campus, and the new soccer practice fields have impacted parking for games tremendously. For example, addition of new soccer practice fields alone took away 2,000 parking spaces.

A common approach to alleviating traffic congestion is to add capacity by building new roads or adding lanes to existing roads. This solution would add a sea of pavement to Clemson that is undesirable and impractical. On the other hand, a practical and cost-effective solution is to optimize where they park. If fans are assigned to parking spaces closer to their origins and in a manner which reduces conflicting movements, they can leave the network (park their vehicles) at a faster rate.

Parking Allocation had been proposed once before for Clemson University by Prashant Malisetty. This was successful for the system at the time; however, Clemson's campus has changed over the years and so has the parking plan. The approaches for conducting parking allocation have changed as well due to technological advances that have happened in the last decade. For example Bluetooth data set a new precedent for creating routing decisions in modeling software. (Cragg, 2013)

3.2 System Equilibrium vs User Equilibrium

User Equilibrium, also known as Wardrop Equilibrium (Wardrop, 1952), is equilibrium in which the user of the system does what is best for him or her. The driver is only interested in getting out the quickest way possible and is not worried about the rest of the drivers in the system. User equilibrium can lead to dramatically different travel times through the overall system as compared to System Equilibrium. Meanwhile, System Equilibrium has a “Robin Hood” approach (Sarasua, 2011). The fictitious character Robin Hood would steal from the rich and give to the poor, and System Equilibrium shares that same concept, only with travel time. System equilibrium assigns trips to routes with the goal of reducing the average travel time over the whole population of vehicles. The assignment is done iteratively until the sum of all vehicles’ travel times is the absolute minimum. Some drivers will not have routes as fast as previously, but the average travel time of the whole system will decrease.

One of the goals of parking allocation is to force system equilibrium. Forcing system equilibrium during route assignment allows the average travel time of the system as a whole to be lower. For example, at the Seneca Creek Meadow Lot, drivers are forced to make a right turn, away from campus, after games. This quickly takes people out of the Clemson network, and, by allocating parking in that lot to ticketholders who live in that direction, hopefully drivers will find the forced system equilibrium agreeable, even though it is not user equilibrium.

3.3 Bluetooth

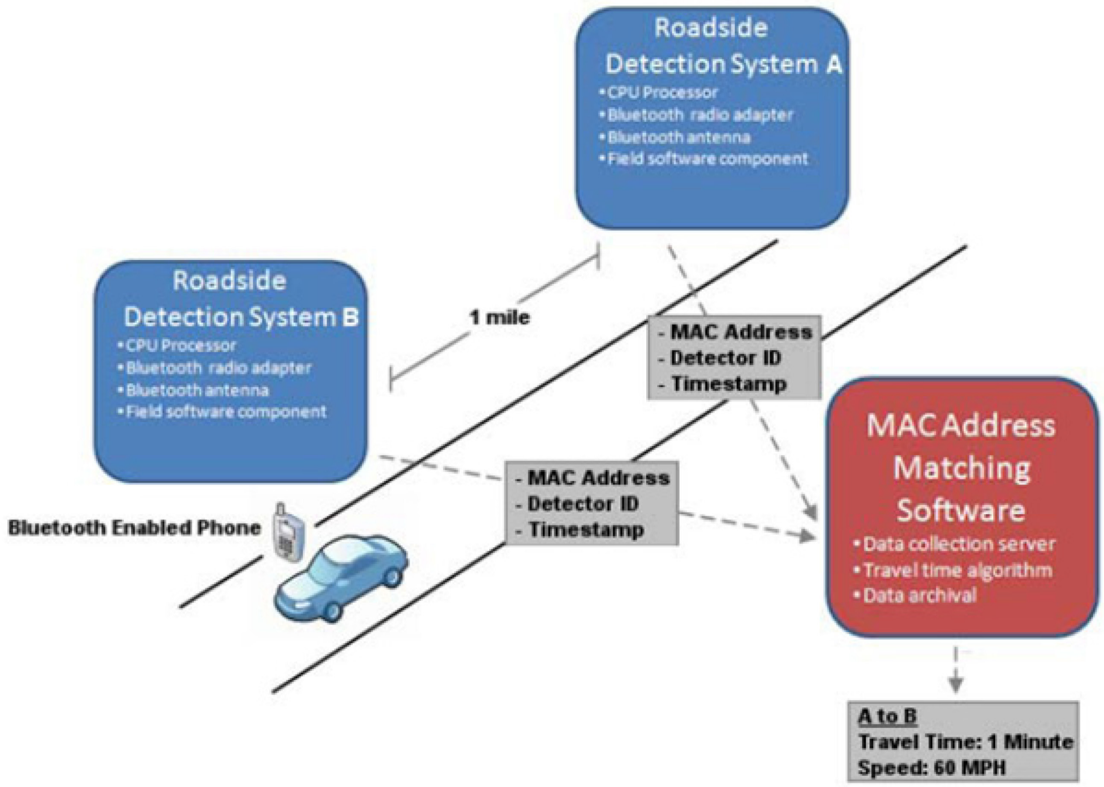

Figure 3.1: Concept of how Bluetooth data are collected. Reprinted from *Federal Highway Administration,* 2017; U.S. Department of Transportation.

Blue tooth recorders such as Bluetoad are data collection devices which are placed around an area of interest to estimate Origin/Destination data. This can be accomplished by collecting a large sample of the network's vehicles by detecting the Bluetooth-enabled devices passing through the network over a period of hours. Each Bluetooth-enabled device has its own unique MAC address. When a vehicle passes by a Bluetooth device, the device detects the MAC address and issues a time stamp.

As the vehicle passes other strategically placed Bluetooth devices, the time and path of the vehicle can be identified. MAC addresses which pass only one sensor are removed from the sample, so only vehicles which take a route through the network are considered. Figure 3.1 from the Federal Highway Association illustrates the data collection process

Figure 3.2: Example of Bluetooth Sensor Device. Reprinted from Stantec, 2015.

Not all of the data collected by Bluetooth receivers are perfect. For example, it is possible for a vehicle to be counted at least twice. Some vehicles are equipped with hands-free Bluetooth and the driver or a passenger could have their phone in Bluetooth mode, both of which would be picked up by Bluetooth sensors. Filtering of the data must be done in order to make the data reliable. To aid in filtering out multiple Bluetooth devices from one vehicle, a couple of criteria must be met. In Cragg's *Bluetooth Detection--Cheap But Challenging* report (2013), he noted that the filtering of differing MAC addresses from the same vehicle require that detections must be within four seconds of each other at three different locations. Furthermore, a minimum gap of 15 minutes must occur between the first and last detection to ensure they aren't two vehicles closely following each other. Cragg gathered Bluetooth data along a Scottish corridor with little curvature, so the 15 minute minimum gap between detections is viable there. On the other hand, Clemson University on game days is a smaller, more congested network, so that much of a gap would not be viable. The filtering of the data needs to fit the context of the specific network it is covering.

3.4 Hitchcock Algorithm

The Hitchcock Transshipment Problem, also known as the Hitchcock Algorithm, identifies the most efficient way to service a set of destinations from a set of origins. Hitchcock minimizes the sum over all origins and destinations of the product of route cost and route usage for all possible routes (TransCAD, 2002) . There can be many routes between many origins and many destinations, each of which may be used by multiple vehicles (usage). Furthermore, the total number of supplied trips (at the origins) must equal the total number of demanded trips (at the destinations). (Gass, 1990). The Hitchcock algorithm is typically used to find the minimum-cost route between pairs of truck supply centers and customers. For the majority of application, the costs that are being optimized are either distances or travel times. The solution output is a map like the one shown in the figure below and an OD matrix and a set of attributes for each network link containing assigned volumes. TransCAD (cite) implements the Hitchcock algorithm in its GIS environment. The TransCAD Routing and Logistics Guide (2002) directly explains how the algorithm works: "[It] starts with an initial feasible solution with this minimum number of flow carrying nodes, then checks whether the solution can be improved by using a currently empty link . If such a link is found, the algorithm determines the amount of flow that can be assigned to the new link without violating any constraint, adjusts the flow on all other flow carrying links, and updates the network. The process repeats itself until no further improvement can be found by switching links" (Malisetty, 2004).

The following figure was the output of the sample problem provided by TransCAD in the typical application. The blue icons are the warehouses where the supplies are located and the customers are represented by the red stars. Time was the cost field in this example, so the solution is the set of routes and trips assigned to them that would cost the minimum time to deliver the products from the warehouses to the customers. In this sample problem, the Warehouse represented the origin (supply) and the Customer represented the destination, the units available for delivery at each warehouse constituted the supply while, the number of units required for delivery to each customer constituted the demand. The results showed which warehouses should tend to which customers to minimize vehicle time in the network.

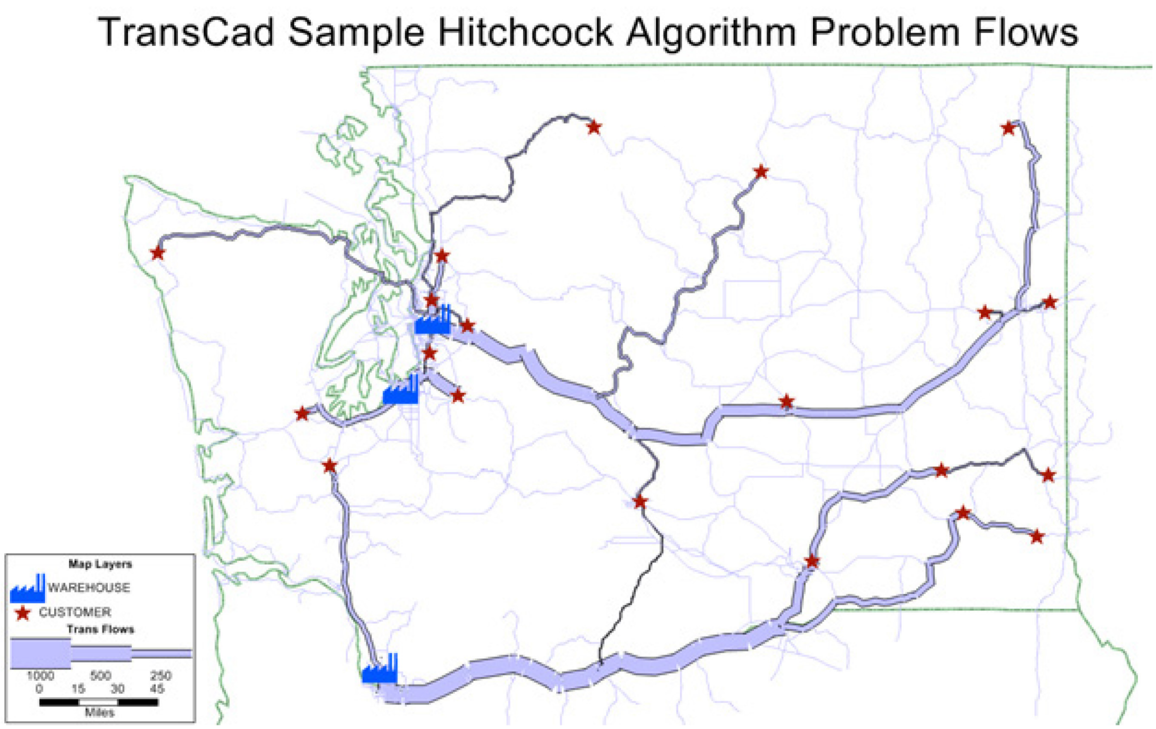

Figure 3.3: Solution of Flows from Sample Transshipment Problem. TransCAD, 2015.

For the application of the transshipment problem in this thesis, the origins were the ticketholders' zip code centroids, and the destinations were the parking lots to which the ticketholders' were assigned. The destinations in this case have a capacity, i.e. the limited number of spaces in the parking lot. The solution to this application of the Hitchcock Algorithm was the reallocation of area lot parking spaces to area lot parking permit holders that would render the minimum total network travel time between the zip code centroids and area parking lots.

CHAPTER 4

METHODOLOGY

4.1 Introduction

Clemson University football parking has two different parking arrangements for season ticket holders during football games: numbered lots and area lots. Numbered lots are parking lots in which fans are assigned a specific space to park and tailgate. These differ from area lots, in which fans assigned to a lot may park anywhere in their assigned area. With football games, there are many traditions and for many Clemson football fans, their parking spot is a part of their tradition. Out of respect for them, the ticket holders assigned to numbered lots were excluded from reallocation.

4.2 Data

TransCAD was chosen to implement the Hitchcock Algorithm due to its GIS and matrix operations capabilities. The athletic department provided an Excel spreadsheet which included season ticket holders' zip code of residence and their parking assignment. The existing condition for the TransCAD model was based on the data provided in this spreadsheet. The spreadsheet was imported into TransCAD as a dataview. A dataview is a window in the TransCAD software that displays data in rows and columns. By using the Locate By Zip Code function, each parking permit was represented on the map by a point via a newly created point layer as shown in Figure 4.1. The number of ticket holders from each zip code was generated by an overlay (also referred to as a spatial join) of the ticket holders' point layer with the zip code area layer. The zip centroid was extracted from the boundaries so each ticket holder address in a zip code was then represented by a point the zip code's centroid.

Figure 4.1: Origin Locations of All Permit Holders for the 2015 Clemson Football Season

4.3 Routing

Network partitioning, the process of creating zones from a street network, was used to break up the ticket holders into groups based on the route they would most likely drive to campus. Figure 4.2 presents the zones that were the result of the network partitioning based on routes into campus and Table 4.1 describes the probable route for each zone. These routes into campus were determined to be most efficient based on the travel time from each zip code.

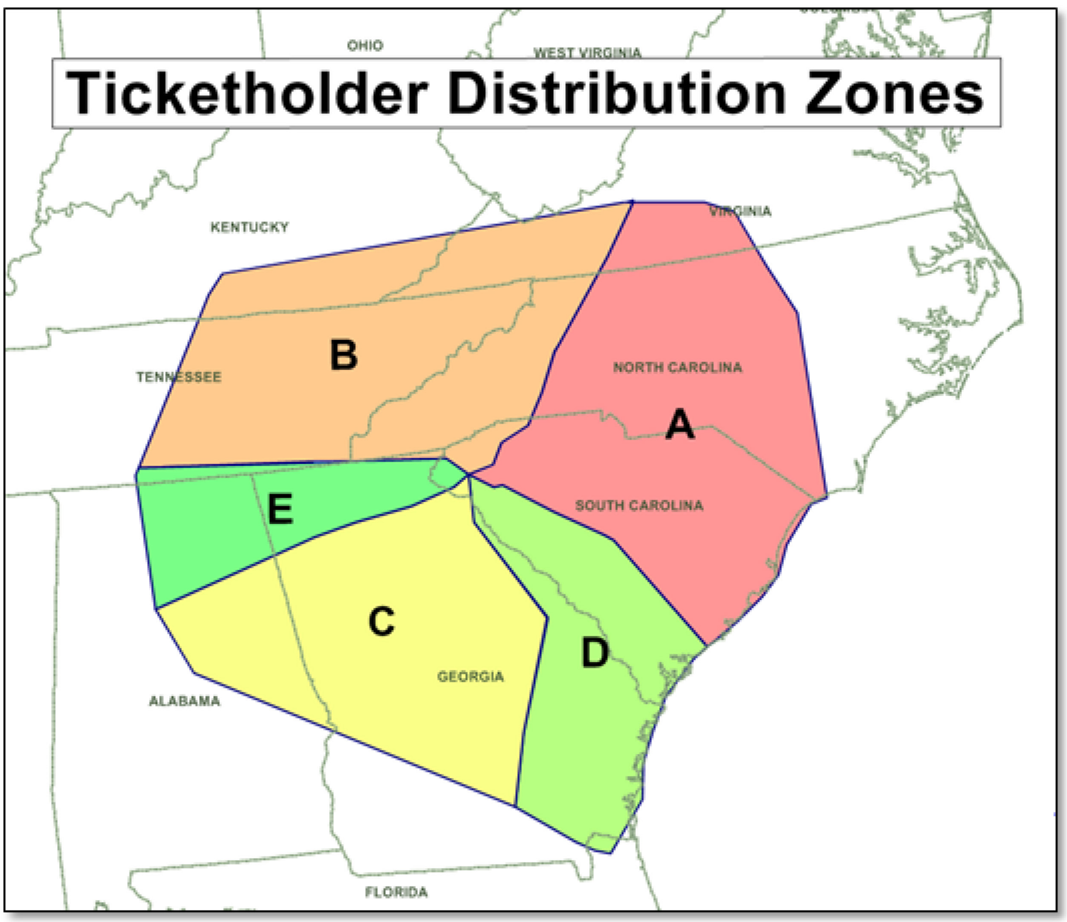

Figure 4.2: Distribution Zones Established From Network Partitioning

Table 4.1: Zones Partitioned By Route.

Zone	Route
A	I-85 South. Either Hwy 123 W or US 76 N
B	US 25 and Hwy 123 W
C	I-85 North
D	US 76 N
E	Hwy 123 E

Table 4.2: 2016 Zone Distributions by Area Lot

Zone	Distribution	C1	LOT 11	ELIB	HX	LOT16	LOT23	NSP	SCM	SNOW
Group A	60.5%	64.5%	64.0%	69.3%	63.9%	62.6%	60.2%	63.5%	51.3%	53.1%
Group B	8.5%	3.9%	6.1%	13.6%	10.5%	12.6%	7.1%	8.6%	9.9%	10.0%
Group C	6.2%	1.8%	5.5%	2.3%	3.8%	4.9%	4.6%	5.4%	13.2%	7.7%
Group D	20.1%	29.0%	22.0%	12.5%	19.5%	17.6%	21.9%	17.9%	15.9%	23.1%
Group E	4.6%	0.8%	2.4%	2.3%	2.2%	2.2%	6.1%	4.6%	9.7%	6.2%
Sum	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 4.2 displays the non-optimized distributions among the different zones and their allocations in the studied 2016 area lots. Based on Zone A's parking lot and overall distribution, the assumption that the area lots are currently assigned by customer priority and not location is sound. Figure 4.3 shows the 2017 Clemson football parking map with the focused area lots circled in red.

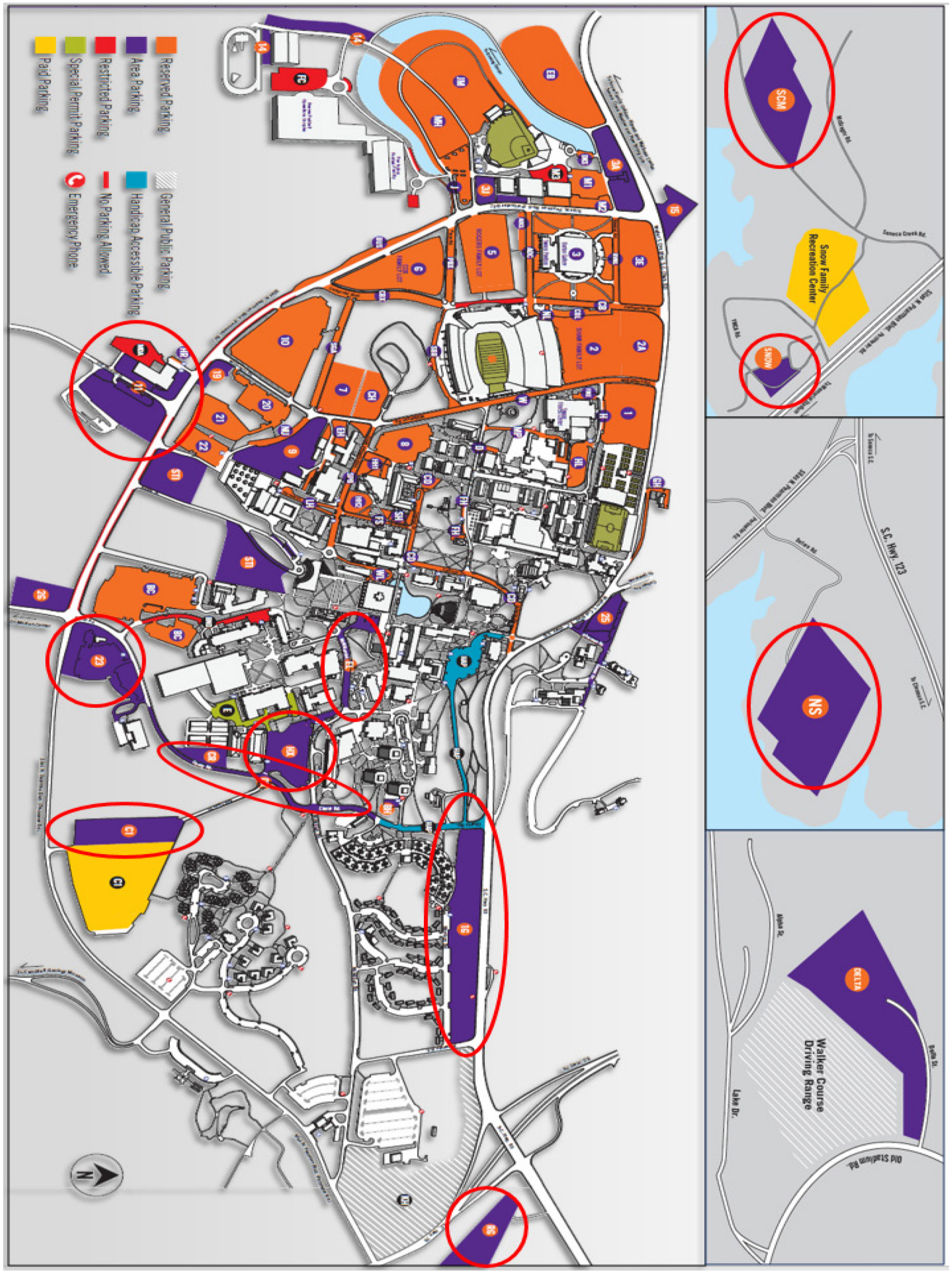

Figure 4.3: 2017 Clemson Football Parking Map. Based from IPTAY, 2017

4.4 4-Step Model: Traffic Assignment

The data supplied by the athletic department covered the traffic generation and distribution steps while modal choice did not need consideration since this is a parking assignment problem. Traffic assignment application requires two things: a virtual road network comprised of nodes and links and associated attributes (e.g. travel time and capacity) and an origin-destination trip table typically developed from the trip distribution step. The roadway network was a large region clipped from TransCAD's Streets layer which extended 115 miles from the Clemson campus. This 115-mile radius includes zip codes from Atlanta, GA, Charlotte, NC, and Columbia, SC. Ticket holders with addresses beyond this distance were considered non-direct travelers (e.g. those staying overnight or whose known addresses were located beyond the southeast). The origin-destination trip table was created using the 2015 data provided by the athletic department. Zip codes boundaries served as origin zones, and the assigned parking lots were destination zones.

A network is comprised of links and nodes. Links are streets which carry attribute information while nodes are typically intersections. To calculate travel time costs, additional attributes were required. Speed was assigned to each link based on its functional class. A table with the functional class and typical speed was joined to the network file. The travel time was calculated by filling the field with the formula (adjusting for unit conversion): Travel time = (Length/Speed)

The traffic assignment procedure was first run by using the all-or-nothing assignment. Travel times were used as the cost parameter causing ticket holders to be assigned the quickest path from their origins to their destinations, This assignment method disregarded congestion. This assignment was done in order to understand the actual demand for each route. Figure 4.4 presents a bandwidth map of the result of the all-or-nothing assignment.

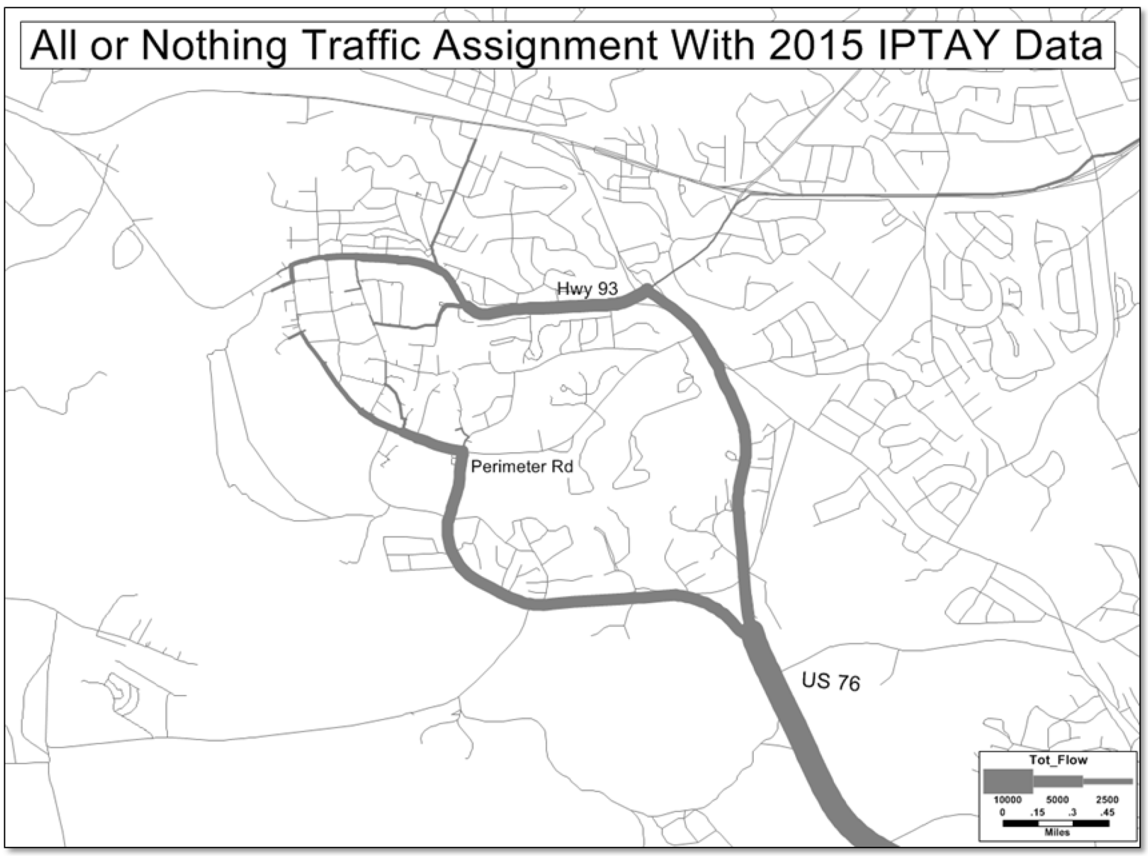

Figure 4.4: Flows Based on Actual Demand

In the modeling component of this research, trip routes to Clemson by season ticket holders were assumed to be representative of all visitors' routes. The flows in Figure 4.4 were compared to the Bluetooth data gathered before and after the Notre Dame game. The Bluetooth data indicated that there were significant differences between the modeled and actual season ticket holder traffic movement to campus.

The traffic assignment can be calibrated using the Bluetooth study findings. Since all-or-nothing was used, capacities were not taken into consideration. So, calibration began with establishing capacities for roadways like US 123 to encourage equilibrium. If the all-or-nothing traffic assignment were true, most patrons would take US 76 to get to campus. This and similar results from running all-or-nothing assignment did not match the Bluetooth data Thus, it was surmised that the model was not calibrated. A different type of loading assignment was needed, one that considered congestion.

4.5 Calibration:

Next, user equilibrium traffic assignment, which used the capacity attributes, was implemented.

To better replicate actual traffic movements into campus, two methods were used to calibrate the model. First, user equilibrium assignment was used to assign routes based upon link capacity. This is done by adjusting the speed (and travel time though a calculated field function) using a delay function. The Bureau of Public Roads Curve was the delay function used in this assignment to adjust capacity:

$$t = t_f[1 + \alpha(vc)^{\beta}].$$

Here, t is congested link travel time;

t_f is link free-flow travel time;

v is link volume;

c is link capacity, and

α and β are calibration parameters.

Adjusting the calibration parameters would slightly change the travel time resulting from the v/c ratio. In addition to changing the parameters, several path-based user equilibrium iterations of assignments were run adjusting synthetic link capacity each time at selected locations until route decisions better represented the Bluetooth data.

Actual capacities were not used in this model because background traffic was not included in our model—only season ticket holders. Thus, assigned volumes of the previous iteration were used to influence the synthetic capacities for the next iteration. The outcome of the model calibration was a set of routes determined by the model that ticket holders

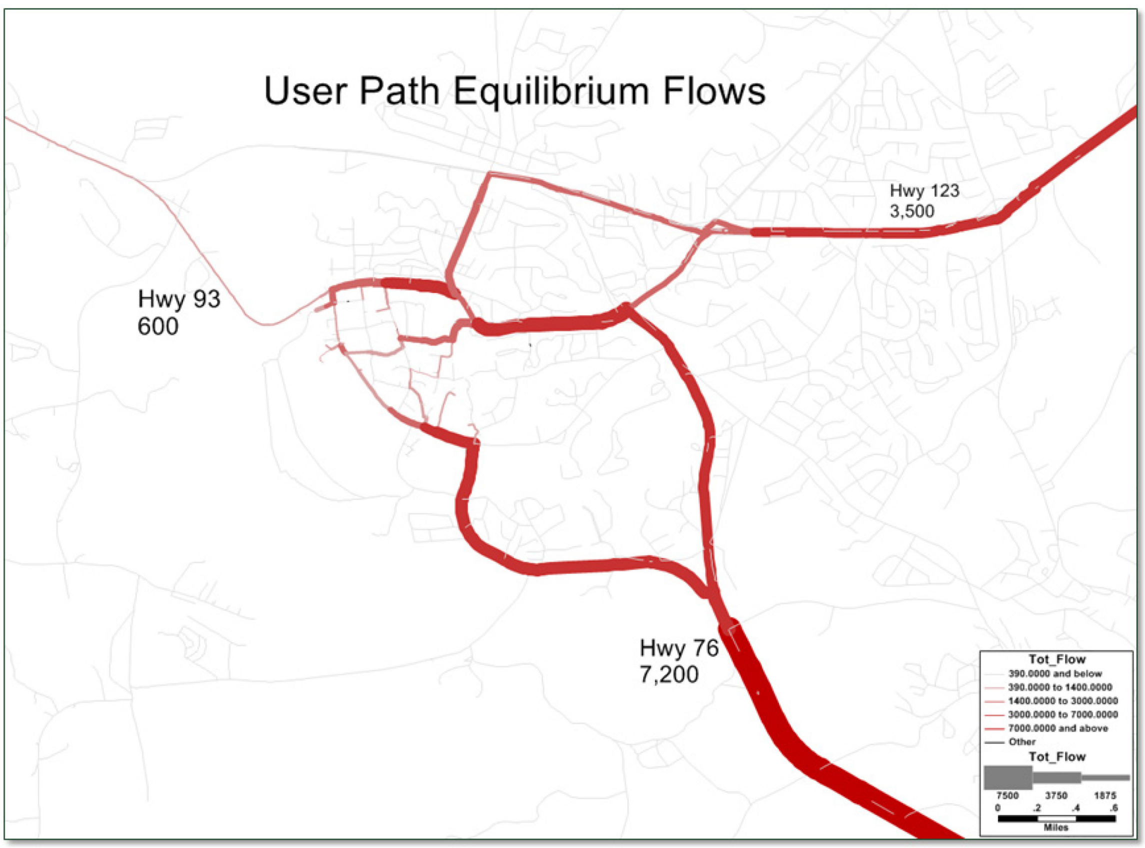

Figure 4.5: TransCAD Clemson Network Calibrated

took to get to campus. The resulting bandwidths for each traveled link are illustrated in Figure 4.5.

4.6 Existing Conditions/Current Assignment

The 2015 data, which included both area and numbered lots, were used to calibrate the model so that the actual route path would inform the modeling of existing assignments for 2016 area lot ticketholders. Only the ticket holders within a 115-mile radius of campus were used in the assignment (Figure 4.6). The transshipment problem did not function outside of that radius, and it was assumed that outside of 115 miles, a lot of fans would have trips linked through a non-campus destination (e.g. staying in a hotel in Clemson). Figure 4.7 is an overview of these area lot ticketholders' origins are.

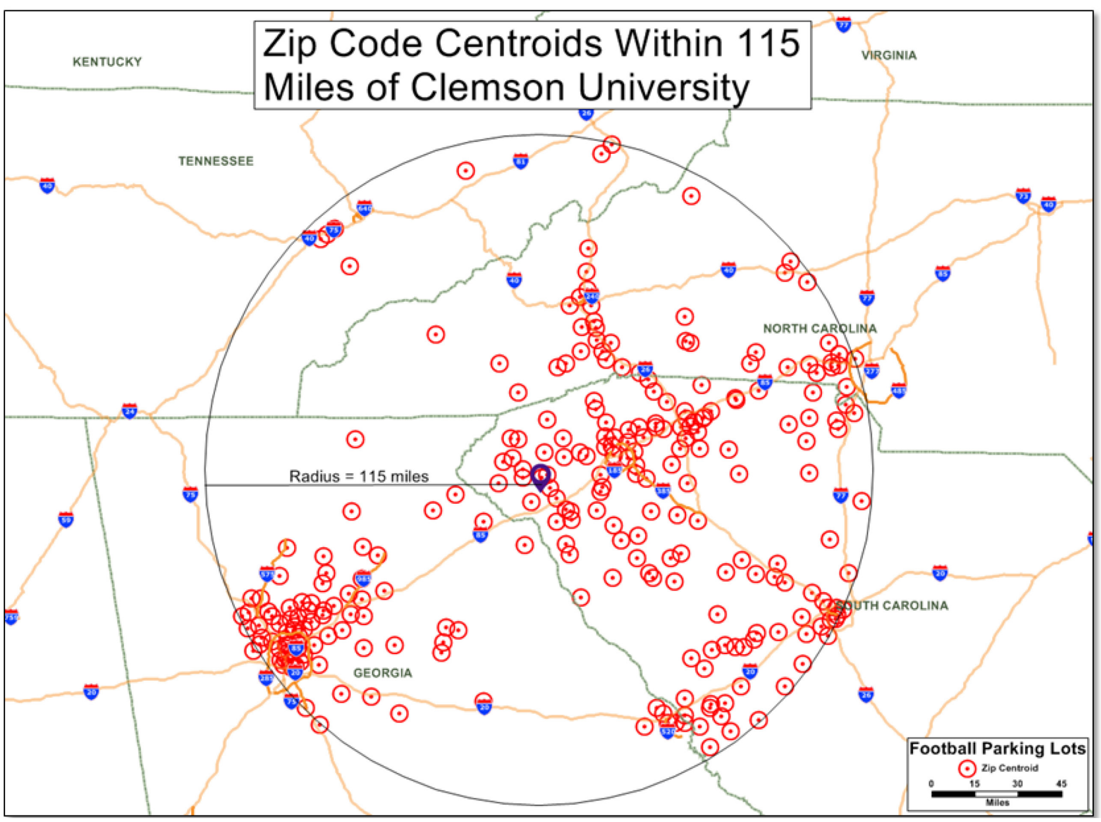

Figure 4.6: Zip Code Centroids Included in Traffic Assignment of 2016 Area Lot Data

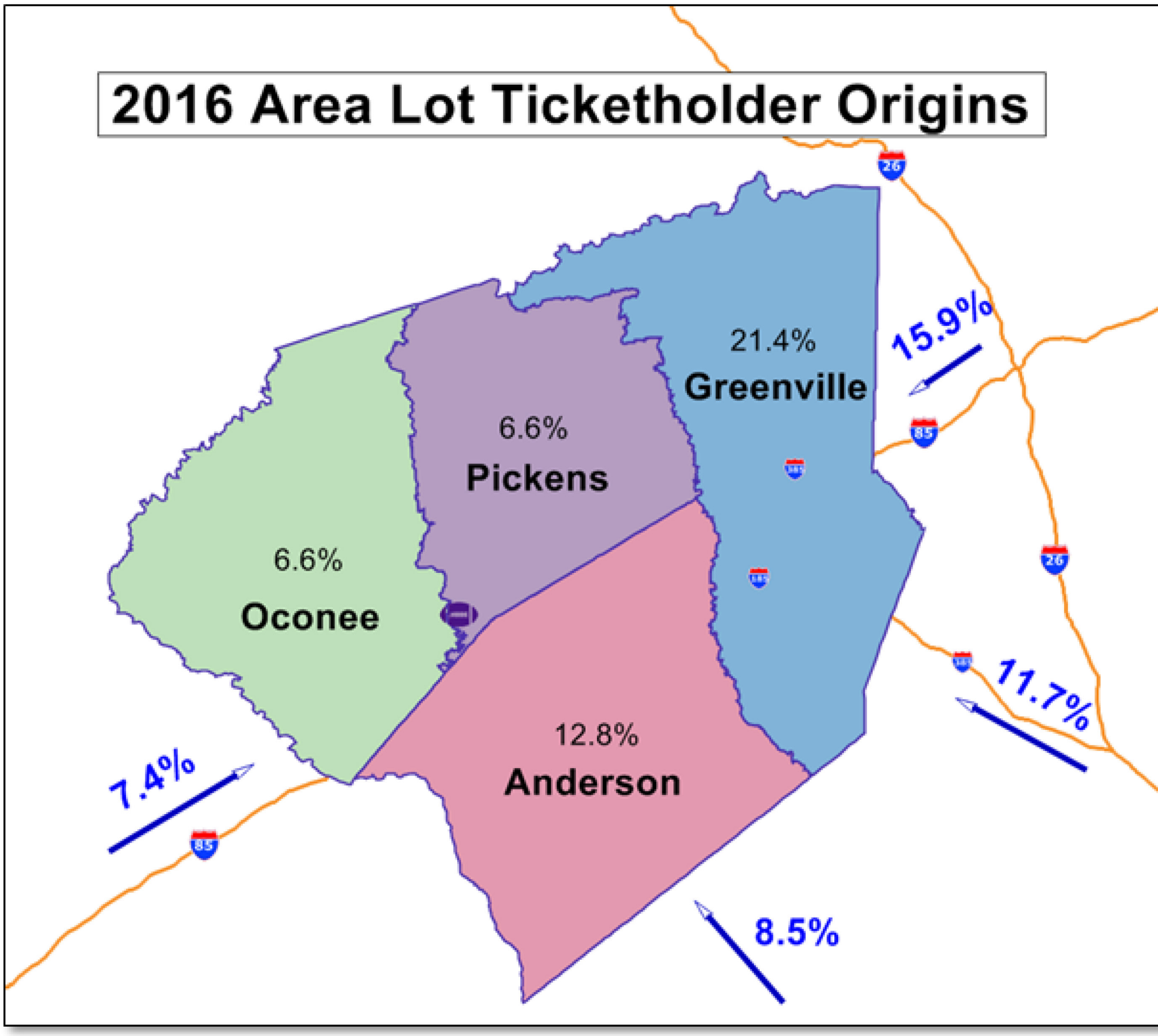

Figure 4.7: Breakdown of the Origins from Area Lot Sample

In order for the full capacity to be assigned to each lot by the Hitchcock Algorithm, the supply (number of ticketholders) needed to be adjusted. Table 4.3 shows the capacity of each lot. 3860 spaces are available in 9 area lots. The number of area lot permit holders in the 115 miles radius was 2019, so 1841 additional needed to be input. An adjustment factor for each lot was calculated as the ratio of the capacity of a lot over its assigned supply and applied to the origin-destination trips table to calibrate the number of trips to each lot. This brought the supply up to 3860 permits. The results of this assignment yielded the paths that people took from their origins to their destinations. All of the paths were summed up, and total flows are illustrated in a negative flow bandwidth map (Figure 4.8). The values represented by this map were taken away from the network.

Table 4.3: Lot Adjustment Factors Based on Their Capacity Over Supply Ratio

Lot	Capacity	Supply	Adjustment Factor
LOT16	350	139	2.5
C1	500	340	1.5
LOT23	185	146	1.3
HX	400	235	1.7
ELIB	120	66	1.8
11	250	122	2.0
SNOW	125	89	1.4
SCM	700	435	1.6
NSP	880	504	1.7

4.7 Transshipment

The Hitchcock Transshipment Problem was run, yielding a trip table of optimal origin-destination assignment. Rerunning assignment with the load used by the previous equilibrium assignment produced the positive flows illustrated by the bandwidth map in Figure 4.9. Since there are ticketholder zip codes beyond the 115 mile radius of the campus, these zip codes must be aggregated. Outside of 115 miles, the paths of these zip codes can be easily predicted.

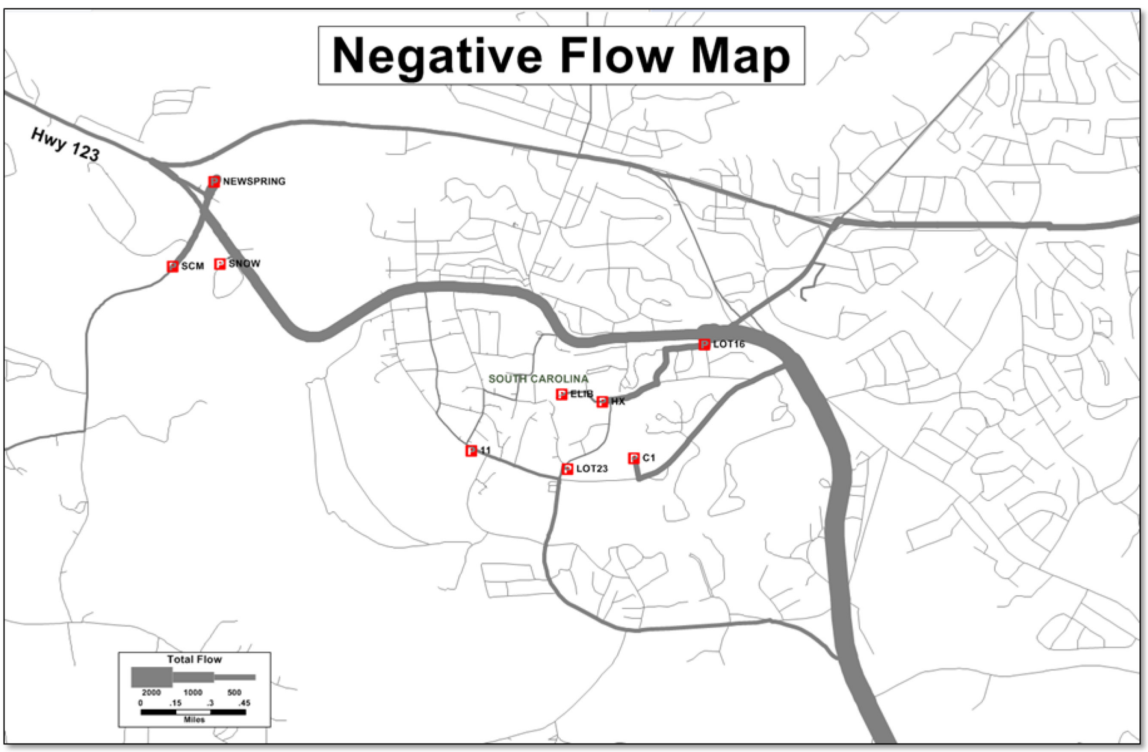

Figure 4.8: Flows Resulting From Existing Condition Equilibrium Assignment

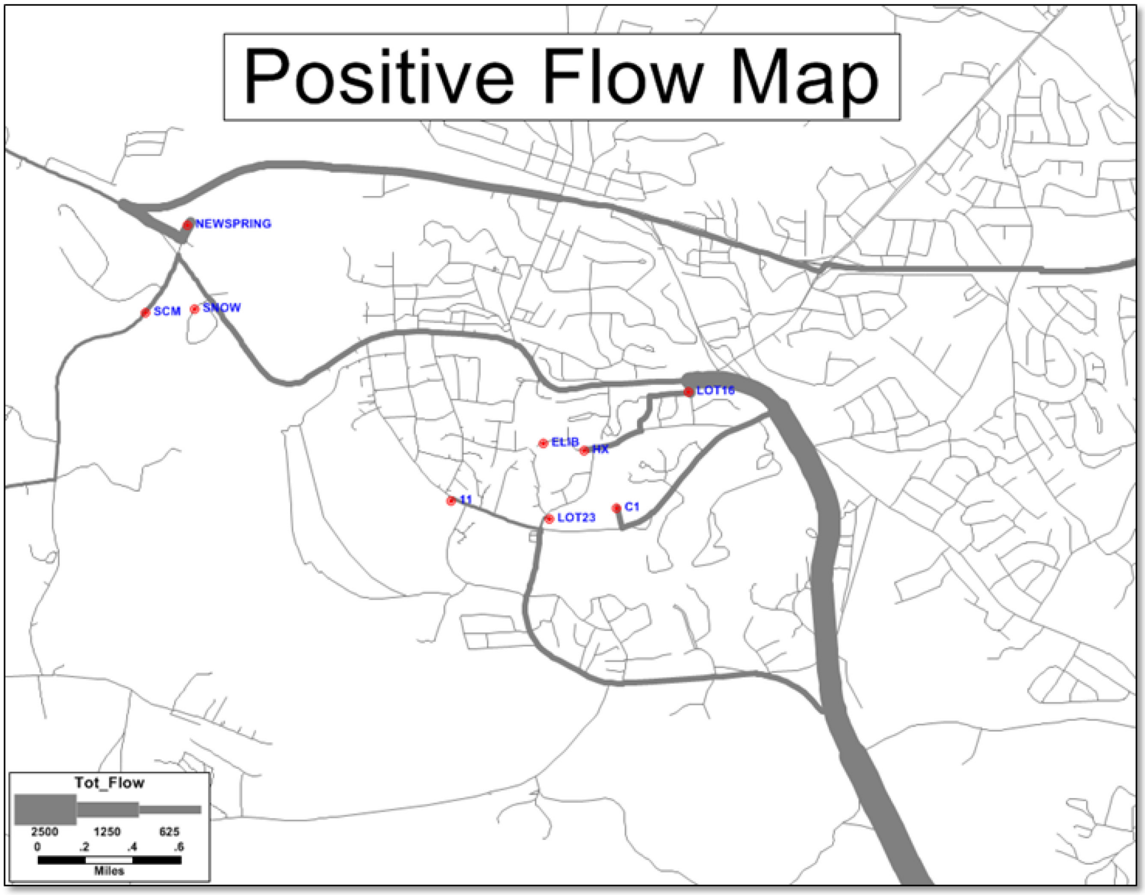

Figure 4.9: Flows Resulting From Hitchcock Transshipment Assignment

The net flow, which is the difference between the Hitchcock flow and the existing-assigned flow is shown in Figure 4.10 with contrasting colors.. Blue represents negative flow, meaning that fewer vehicles would take use those links under Hitchcock conditions than under existing conditions. Red means more vehicles would take use those links as a result of Hitchcock. As shown in the figure, the center of campus is mostly blue. This means that there are less vehicles traveling on the roads through campus. There are some red links on the outskirts of campus, but the added volumes represented by these red links quickly leave the network once they reach their respective lots.

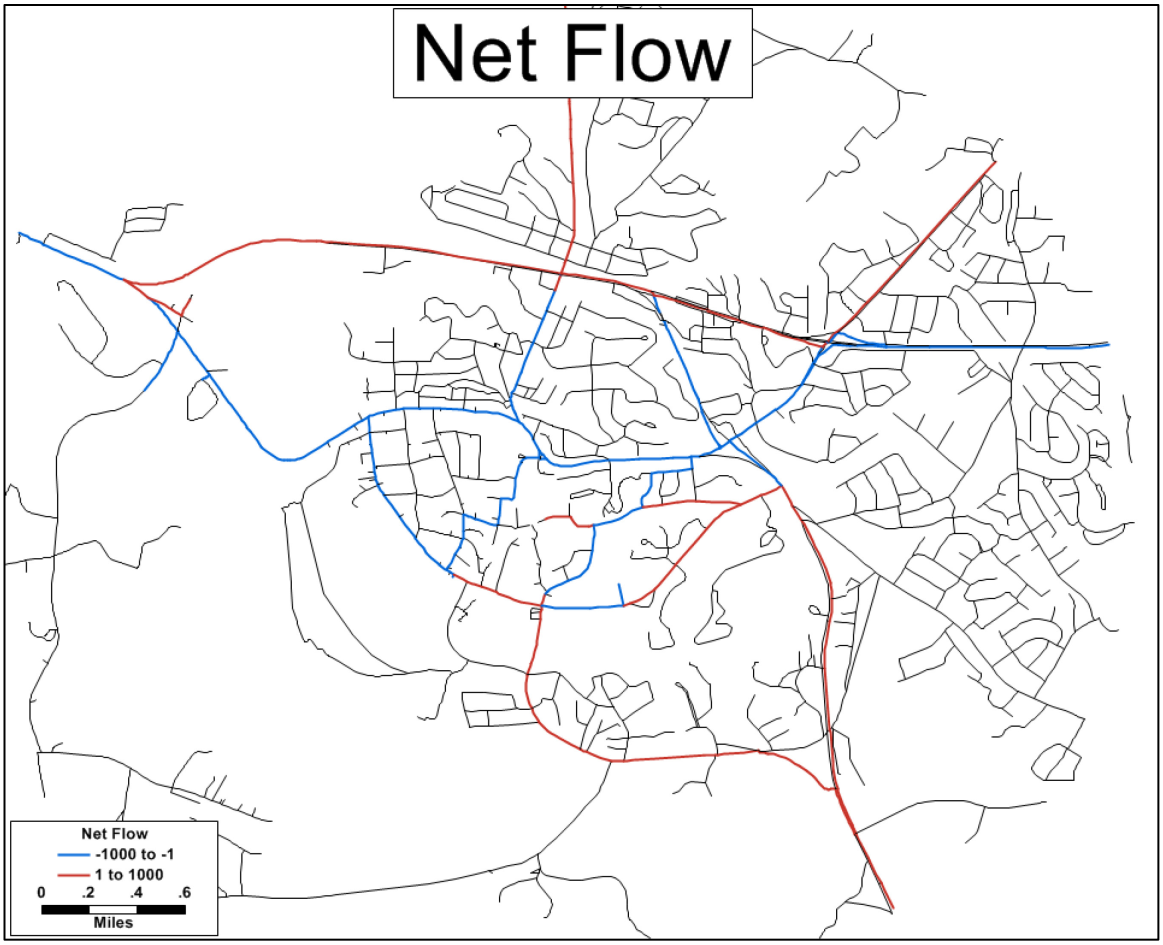

Figure 4.10: Resulting Distribution of Trips from the Implementation of the Hitchcock Transshipment Problem.

CHAPTER 5

RESULTS

The results given to the athletic department were tables listing each zip code range's assigned area lot as recommended by the researchers. This is the result of applying the Hitchcock Algorithm. In addition to the Hitchcock-preferred lot assignments, each zone is also listed with several alternative lot assignments prioritized by their desirability according to Hitchcock. This result is useful when assigning in what lot patrons should park.

Theoretically, the parking lots on the west side of the football stadium would be assigned only ticket holders approaching campus eastbound. However, based on the distribution of the zones shown in Table 4.1 in Section 4.2, the spread across all lots wasn't optimized. However, as shown in Table 5.1, it is important to note that Seneca Creek Meadow (SCM) and Newspring were the latest area lots opened for parking and their existing assignment was better than the other lots. This implies that the athletic department began the process of assigning area lots based on origin rather than trying to make each lot match the overall zonal distribution. SCM and Newspring are located on the west side of campus, so it would optimal for Zones C and E to be assigned there, and roughly 70% of those zones were assigned to one of those lots.

Table 5.2: 2016 Area Lot Assignment by Zone

Lot	A	B	C	D	E	Distribution
C1	17.5%	8.0%	3.8%	24.5%	3.1%	16.2%
LOT 11	6.5%	4.4%	4.5%	6.2%	3.1%	5.8%
ELIB	3.8%	5.3%	0.6%	2.0%	1.6%	3.2%
HX	12.2%	13.7%	5.7%	11.3%	4.7%	11.2%
LOT16	6.9%	10.2%	5.1%	6.0%	3.1%	6.6%
LOT 23	7.3%	5.8%	3.8%	7.2%	9.3%	7.0%
NSP	25.3%	25.2%	22.3%	21.5%	24.0%	24.1%
SCM	17.1%	23.0%	48.4%	16.3%	45.7%	21.6%
SNOW	3.4%	4.4%	5.7%	5.2%	5.4%	4.3%
Sum	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 5.1: Lot Assignment Based on the Hitchcock Algorithm

Lot	A	B	C	D	E	Distribution
LOT 11	4.5%	0.0%	0.0%	4.1%	0.0%	2.2%
C1	4.5%	2.2%	0.0%	49.0%	0.0%	10.8%
CR	18.0%	0.0%	0.0%	0.0%	0.0%	5.9%
ELIB	3.4%	0.0%	0.0%	4.1%	0.0%	1.9%
R6	2.2%	43.5%	0.0%	0.0%	0.0%	8.2%
HX	9.0%	2.2%	0.0%	10.2%	0.0%	5.2%
LOT 23	13.5%	0.0%	0.0%	0.0%	0.0%	4.5%
LOT16	7.9%	13.0%	0.0%	26.5%	0.0%	9.7%
NSP	21.3%	39.1%	0.0%	2.0%	100.0%	17.5%
SCM	4.5%	0.0%	100.0%	0.0%	0.0%	29.7%
SNOW	11.2%	0.0%	0.0%	4.1%	0.0%	4.5%
Sum	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 5.3: Recommended Lots Based on Zone

Zone	1	2	3	4	5
A	NSP	CR	LOT 23	SNOW	HX
B	1ST CITIZENS	NSP	LOT 16	-	-
C	SCM	-	-	-	-
D	C1	LOT 16	HX	-	-
E	NSP	-	-	-	-

Table 5.2 displays the optimal distribution of origins to destinations. The clear-cut examples of the optimization are the Seneca Creek Meadow and Newspring lots. The 100% assignment of Zones C and E was an expected outcome. A result that was surprising at first was that Group A (Approaches from US 123 WB / US 76 NB) were mostly assigned to Newspring at 21.1% even though this lot is on the far side from this gateway. However, Newspring has a capacity of 880, making it the largest area lot. Group A also contains the largest percentage of ticket holders. Thus some correlation between Newspring and Group A can be expected due to the dominance of this lot and zone among the parking supply and ticketholder population respectively.

Table 5.3 was the deliverable sent to the athletic department. It gives a desirability ranking to each lot for each zone in order to provide CU Athletics flexibility in assigning zip codes to lots (CU Athletics may be unable to fully implement the Hitchcock solution for every zone). This ranking is based on the percentages of zones assigned to each lot (Table 5.2) More than one lot was included for several zones because the supply and demand had to be taken into consideration. Zone A has the largest distribution of ticket holders at 60.5% (refer to Table 4.2 in Section 4.2); therefore, it was more heavily divided among the lots than the other zones.

Table 5.4: 2016 Area Lot Distributions by Zone

Zone	C1	Lot 11	ELIB	HX	LOT16	LOT23	NEWSPRING	SCM	SNOW
Group A	55.6%	57.4%	62.1%	56.2%	53.2%	54.1%	54.2%	40.6%	41.6%
Group B	5.3%	8.2%	18.2%	13.2%	16.5%	8.9%	11.3%	11.5%	11.2%
Group C	1.8%	5.7%	1.5%	3.8%	5.8%	4.1%	6.9%	16.8%	10.1%
Group D	36.2%	25.4%	15.2%	24.3%	21.6%	24.7%	21.4%	18.1%	29.2%
Group E	1.2%	3.3%	3.0%	2.6%	2.9%	8.2%	6.2%	13.0%	7.9%
Sum	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 5.5: Lot Distribution Based on Hitchcock

Zone	C1	Lot 11	ELIB	HX	LOT16	LOT23	NEWSPRING	SCM	SNOW	CR	FIRST CITIZENS
Group A	13.8%	66.7%	60.0%	57.1%	26.9%	100.0%	40.4%	5.0%	83.3%	100.0%	9.1%
Group B	3.4%	0.0%	0.0%	7.1%	23.1%	0.0%	38.3%	0.0%	0.0%	0.0%	90.9%
Group C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	95.0%	0.0%	0.0%	0.0%
Group D	82.8%	33.3%	40.0%	35.7%	50.0%	0.0%	2.1%	0.0%	16.7%	0.0%	0.0%
Group E	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	19.1%	0.0%	0.0%	0.0%	0.0%
Sum	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

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Table 5.4 shows the breakdown of each lot based on the existing assignment, which indicates that each lot receives trips from zones based on the distribution of the zones amongst the ticketholder population. Assigning ticket holders from each zone proportionately to every lot contributed to intra-campus congestion.

Table 5.5 displays the optimized lot distribution. Zone A has such a large percentage of the overall ticketholder population that the Hitchcock algorithm assigned every lot a portion of this zone. The existing assignment assigned this zone to each lot at approximately the same rate, which was also close to Zone A's percentage of the ticketholder population. In contrast, the optimized assignment placed Zone A into each lot at widely varying rates. It was clearly shown that some lots only catered to one or two zones. Thus assigning only one or two zones to a lot should clear up the overall system. The major additions and subtractions of trips across campus are displayed in Figure 5.1. While there were trips added to some links, trips crossing through campus were reduced. Parking the ticket holders at the lot closest to their origin cut down on their intra-campus trips before and after games.

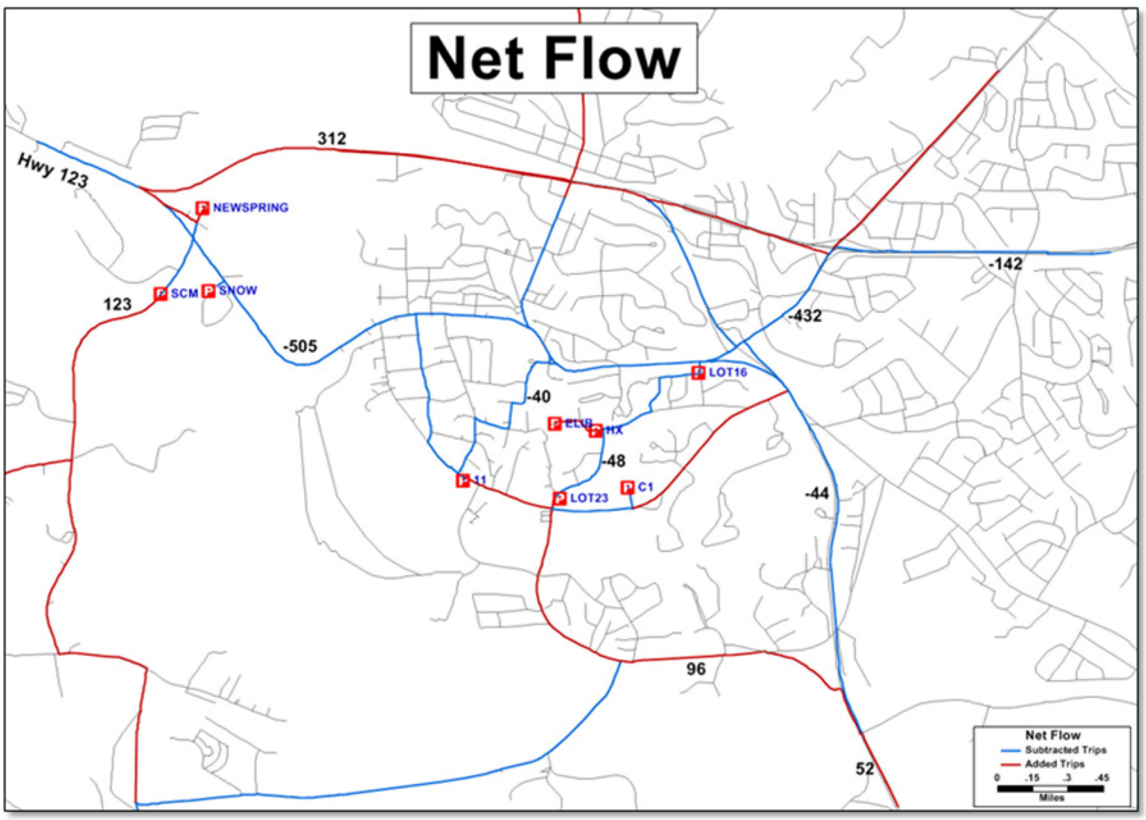

Figure 5.1: Major Additions and Subtractions of Trips across the Clemson Network

CHAPTER 6

CONCLUSIONS

6.1 Summary of the research

The enhanced methodology of parking reallocation, which utilized Bluetooth data to accurately model routes to campus, lead to a more accurate network. The inclusion of the capacity of the links as a constraint also provided a more effective solution over solely considering travel time for the distribution.

The use of the Bluetooth data aided in the determination of route decisions from traffic volumes alone. When the network is oversaturated, turning movements are restricted to the movements' capacities. The Bluetooth data's window covered a wide enough period for the network to clear its queues.

As mentioned in the Background section, the Hitchcock Transshipment Problem is typically used by trucking depots to assign truckers the minimum costing route to the customers. The findings of this research demonstrate the applicability of the Hitchcock Transshipment Problem for optimizing parking assignment for planned special events like football games. The methodology in this thesis could be useful to other planned special event coordinators if they hope to optimize parking at their event.

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