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Using a GIS-based, Hitchcock algorithm to optimize parking allocations for special events

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Abstract - Clemson, a small college town in South Carolina, deals with a massive over-saturation of its transportation system during special events, especially during home football games, resulting in total system failure. This research has developed a methodology to optimize parking, using a Geographic Information System (GIS)-based transshipment algorithm, and it has produced great time savings compared with the individual, "manual" efforts of thousands of drivers attempting to find spaces where available. As such, this research constitutes an effective implementation of the Hitchcock Transportation Algorithm for solving a transshipment problem applied to parking lot distribution. Because the Hitchcock Algorithm considers the network cost for distributions, it gives very realistic solutions, and so a system equilibrium that minimizes overall system delay has been achieved through optimal parking assignment combined with pre- and post-game traffic control strategies. This has been validated using a simulation model that was developed for evaluating the strategies.

Keywords – special event planning; optimal parking assignment; Hitchcock transportation problem;

1 Introduction

Planned special events are public activities, with scheduled times and locations which impact upon normal transportation system operations due to increased travel demands and/or reduced roadway capacity because of event staging. Planned special events significantly impact upon travel safety and they reduce roadway capacity and travel time. The impact of these events depends on the event operation's characteristics, including attendance, rate of event patron arrival and departure, venue location, and roadway capacity (Latoski et al, 2003).

Planned special events have a greater impact in small towns than in medium or large cities because in the latter transportation infrastructure is usually capable of dealing, at specific times, very high traffic that over saturates roadways. Hence over saturation is a particular problem in Clemson, South Carolina, because it is a small, college town with 12,000 residents, 19,000 enrolled students and 4,000 faculty and staff working for the University. It experiences very heavy traffic volumes during the football season (www.cityofclemson.org, 2011; www.clemson.edu, 2011).

Of the numerous planned special events that Clemson University hosts annually, the largest are home football games at the Memorial Stadium. Some of these football games attract crowds in excess of 80,000 fans, and trying to maneuver traffic for 80,000 people into one venue is a daunting task in itself. Moreover, trying to maneuver it through a local transportation system designed for the university and local traffic for 12,000 residents can be a nightmare for state and local traffic enforcement officials.

The National Cooperative Highway Research Program (NCHRP) Synthesis 309 report, *Transportation Planning and Management for Special Event*s, reported that most jurisdictions use motorist information, traffic management and travel demand management as tools for managing traffic flow at special events. Its survey found that one out of every 36 respondents has predefined performance measures for evaluating efforts in special event management (NCHRP, 2003). But because most jurisdictions have no performance measures in place, the Federal Highway Administration developed a guidebook for the planning and operation of special events in terms of personnel, resource and information requirements (Latoski et al, 2003).

While there is a great deal of literature available that focuses on major event traffic, very little focuses on major college sporting events. However, Sattayhatewa et al (2003) presented an approach for parking lot distribution and network assignment based on parking demand and available supply of parking spaces, and in their study users could choose any parking lots. But in Clemson, each patron has a designated parking lot. Also, Chester et al reported the benefits of transportation planning, in terms of traffic and parking management, in Nashville's Titan Stadium, and this generated safe and efficient traffic flow before and after the game (Chester et al, 2000).

Many studies reported the benefits of using variable message signs which monitor lots and provide real-time parking information (Crowder et al, 2003, Sundaram, 2000, Edwards & Kelcey, 1997, David Evans and Associates & IBI Group, 1999). However, the infrastructure requirements for monitoring parking lots and disseminating real-time parking information are too great for a small town like Clemson.

In 1952, John G. Wardrop stated two equilibrium principles for the prediction of how traffic runs through a transportation network. His first principle states:

> *The journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route.*

The underlying premise of this "user equilibrium" is that a driver chooses routes in a selfish manner by minimizing his or her travel cost regardless of how this route choice affects the network as a whole. Thus, a user-optimized equilibrium is reached when no user may lower their transportation cost through unilateral action. User equilibrium usually results in discrepancies in individual travel costs. A more efficient use of the network would balance travel costs over the network.

Wardrop's second principle states: "

> *At equilibrium the average journey time is minimum.*

This implies that each user behaves cooperatively in choosing routes so that total system cost is minimized. While this would be the most sustainable form of network traffic assignment, it is unrealistic for travelers to behave in this manner unless there are network constraints that influence this.

The primary objective of this paper is to develop an optimal parking allocation that will improve system-wide traffic circulation before and after football games. By optimally assigning parking and combining the result with carefully planned, traffic-control strategies, attainment of Wardrop's system equilibrium is possible. To demonstrate this the authors will describe an effective application of the Geographical Information System (GIS) for solving the parking lot-distribution problem via the Hitchcock Transportation Problem (Gass, 1990). The latter is a linear algorithm which can be used to distribute vehicles coming from roads entering Clemson to numerous parking lots around the stadium. This study will also develop a simulation model to evaluate the recommended, parking allocations and corresponding route assignments.

2 Existing conditions

Several highways provide primary access to the university. US 76 and US 123 merge with one another to provide east/west access to Clemson. Much of the central campus is bordered by SR 93 - a four-lane arterial, and circling much of the remaining campus is Perimeter Road - a two-lane and four-lane collector. All other local connecting roads within the university limits are two-lane roads. The local road network is quite capable of handling traffic throughout a typical school day, with only moderate delays experienced at the busiest intersections during daily peak periods. A general road network, showing major streets in and around the university area, is shown in Figure 1.

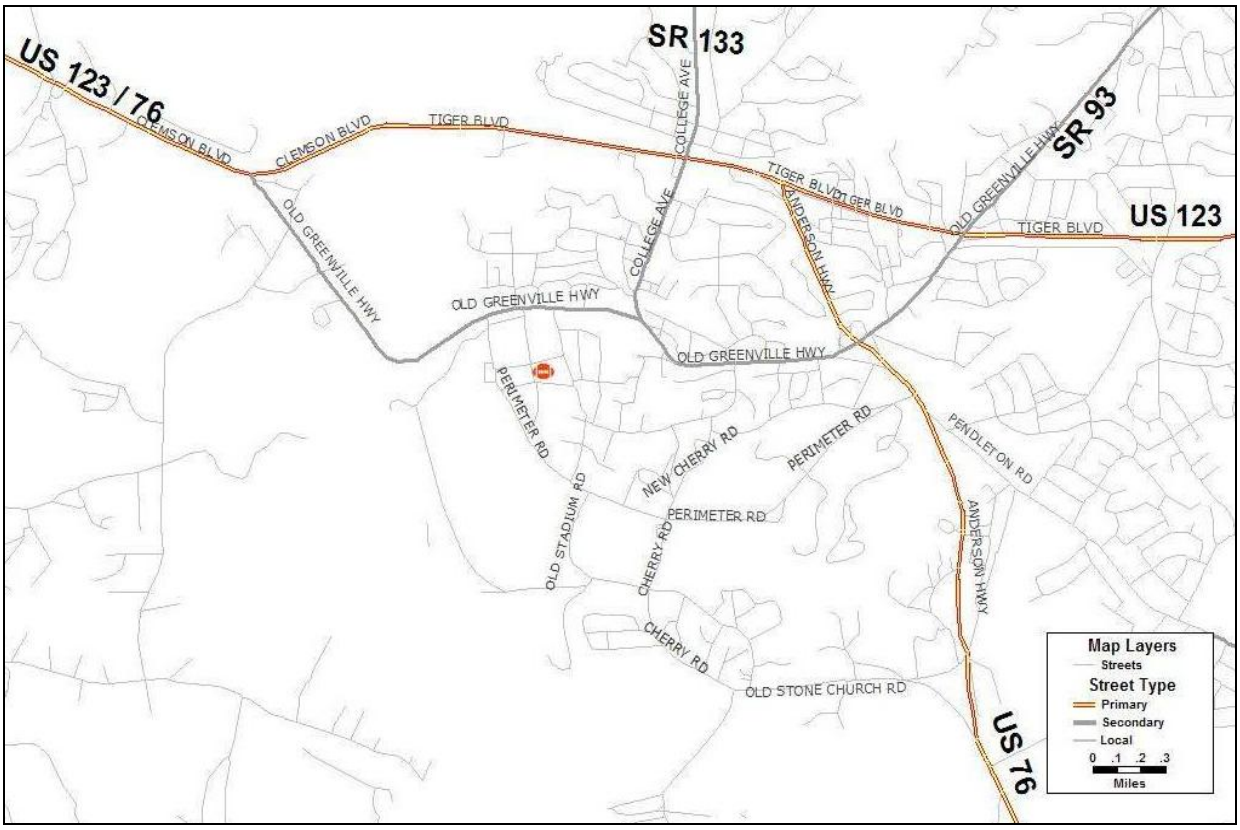

Figure 1 – The road network in the university area

There are three major primary-access roads used to reach Clemson:

1. US 123 from the north east (from Greenville),
2. US 76 from the south (from Anderson) and
3. US 76/123 from the west (from Seneca).

These access roads provide connection to major freeways such as I-85 and I-26 that are used to bring traffic to Clemson from throughout the southeast and beyond. On game days, the traffic flow on these interstates and access roads is usually below capacity, but saturation conditions occur as traffic approaches the university. Stop-and-go traffic usually occurs throughout the campus before and after games.

There are presently 34 reserved parking lots and four general parking lots on campus that are used for football game traffic. Reserved parking lot assignments are distributed according to season ticket holder priorities. According to the ticket office, this distribution does not consider traffic efficiency.

It takes a small army of over 100 traffic enforcement officers to manage traffic circulation during football games. The traffic enforcement officers have to control traffic, allow for safe pedestrian crossing at major intersections, and direct vehicles to their respective parking lots. To manage this process efficiently, officers make many temporary modifications to the traffic network during football games. These include dedicated turn lanes, contra-flowing certain roads, and prohibiting movements at some locations. But there are limitations to the effectiveness of these modifications because the existing traffic network is not designed to handle the traffic generated during football games.

3 Methodology

The methodology of this research focuses on the reallocation of season ticket holders' parking lot assignments, based on the origin of their trip. The data for this study was provided by field surveys of the Clemson road network, including the critical intersections, the Clemson University Athletic Department and law enforcement officers charged with traffic management on game days.

The first major task, optimal reallocation of parking, was done by GIS and Transshipment analysis. The GIS was used to spatially allocate and manipulate the season ticket holder database. Initially, the GIS was used to geo code the location of all season ticket holders, as well as their assigned parking lot and their likely driving route to the game. A parking reallocation was implemented using a GIS-based transshipment procedure based on the Hitchcock algorithm (Gass, 1990). In solving the Hitchcock Transportation Problem (HTP), ticket holders coming from six different road zones were re-assigned to three parking lots to minimize system-wide travel times.

HTP is typically applied to optimize the distribution of commodities so that total shipping cost is minimized. The authors hypothesized that this would be an ideal parking assignment algorithm because its objective is essentially the same as Wardrop's system equilibrium. More conventional models such as gravity models were not considered because they consider human behavior, through the use of such methods as friction factors, in a way that generates a user equilibrium rather than a system-wide, optimal pattern.

In order to evaluate the parking re-allocation strategies, a simulation model was developed using *Synchro*. It was applied to evaluate three selected route-assignment strategies based on the parking reallocation under existing conditions.

4 Data collection

Two data collection tasks were performed. The first was to collect information regarding season ticket holders; the second was to collect traffic data at selected games. The Clemson University Athletic Department maintains a database of the addresses of season ticket holders. Most season ticket holders have parking spaces in reserved parking lots. The data obtained was in digital format and was further classified.

Data classification types for season ticket holders include customer ID, name, address, zip code and the number of tickets purchased. The data file of the parking lot information has the customer ID, name, address, number of parking spaces assigned and the parking lots assigned. Both the ticket information and the parking lot information data were classified into separate columns of the aforementioned categories.

Video surveillance was selected as the primary traffic data collection tool, supplemented by manual, field survey methods to measure queues. The initial field survey showed that most vehicles flow into Clemson roughly three hours before game and disperse within three hours after the game. These times vary greatly depending on game start and end times as well as the crowd size. The vehicle data was collected for two games where a huge traffic influx was expected. One the games selected was the Clemson homecoming game against

University of Virginia on October 11, 2003. The other game selected was against Florida State University, on November 8, 2003.

5 Processing and analysis

Extensive GIS usage was required to conduct the research. Mapping of ticket holders, GIS layer development, spatial aggregation, and extensive network analysis was done. *TransCAD* was chosen as the GIS because it is the only known GIS that incorporates an implementation of HTP. The following sections discuss the GIS tasks.

5.1 Inputting ticket-holder data to the GIS

After obtaining the ticket holder data, the next research task was to map the location of each customer based on their address. That is, GIS address matching was used to identify the location of the residence for each customer and assign geographical coordinates for each record. The geo coding process resulted in a GIS point database of season ticket holders.

Using *TransCAD*, a geographic layer was then created for both the ticket data and parking data, by locating their addresses. For ticket holder data, out of 12,233 records the “locate by address” tool was able to identify 9,643 records. The, “locate by zip code” tool was used to identify 2,555 records from the remaining, unidentified records. The remaining seven records were identified manually.

Of the 12,205 identified ticket data records, 49,567 tickets had been purchased. This indicates a 98.6% success rate in address location for fans attending the games. Out of 13,207 parking spaces assigned, 13,089 records were identified, and this indicates a 98.7% success rate in address location of the vehicles arriving for the games.

5.2 Creating a network

The *TransCAD* GIS requires a specialized network file that facilitates network analysis. Networks are used to analyze the flow of people or vehicles from one location to another (*TransCAD* Users Guide, 2000). The network file used in this research was created using a modified U.S. street file, which has several attributes available for each street link.

The link name, length, and functional class were of interest for this research, and depending on the functional class, each link was assigned speeds. A travel time field was then added to the database using the following data:

- Length (miles)
- Speed (miles per hour), and
- Travel time (minutes = (length / speed) * 60.

The modified street layer was then processed, and a network was created in *TransCAD*.

5.3 Partitioning the network

The street network was divided into zones based on optimal routes into Clemson. Primarily, traffic traveling from interstates I-85 or I-26 uses the three major access roads into the Clemson area. Initially, the network was divided into three zones based on the usage of these access roads by performing a network partitioning, spatial allocation analysis using *TransCAD*.

TransCAD partitions a network by computing the network cost between service locations and all the links and nodes of the network. After the algorithm is processed, each link and node is labeled with the ID of the closest service location and the cost of the trip. Accordingly, since the three primary access roads - US 76 N, US 123 W, and US 76/123 E, intersect adjacent to Clemson University, the nearest nodes from the point of intersection on the three access roads were selected as service locations. Here the cost of the trip was the travel time.

A polygon layer was then created based on the network-partitioning solution. This generated a zone system that showed how ticket holders would drive to Clemson, based on their shortest path. Initially three zones were created, with the area of motorists taking the US 76 N, US 123 W, and US 76/123 E to reach Clemson.

Traffic accessing US 76 N was observed to have come from interstate I-85 along with traffic using US 76 N, and so this zone was sub-divided according to the approach used, US 76, I-85 N and I-85 S, and a boundary was drawn around the new partitions. Since motorists accessing through I-26 N must merge with I-85 S to access Clemson, those using I-85 S and I-26 N were initially combined and analyzed as one zone. But this zone was later divided into two sub-zones based on the route chosen.

A similar procedure discussed earlier for network partitioning was then followed to divide the zone of the I-85 S approach into two zones, from where motorists were expected to access I-26 N and I-85 S separately. A separate zone for patrons choosing SR 133 to access Clemson was also created.

Hence the final polygon layer had six zones as shown in Figure 2. Using a polygon overlay, ticket holders and parking lot assignments were assigned to the zones and grouped as follows:

Group A: driving in on **I-85 S** & **I-26 N**

Group B: driving in on **I-26 South** & **US 123 East**

Group C: driving in on **I-85 North**

Group D: driving in on **US-76 North**

Group E: driving in on **US-76 / 123 East**

Group F: driving in on **SR 133 South**

5.4 Allocating parking

The current parking lot assignment is based on customer priority. The point-in-polygon overlay of patrons' origins, along with their assigned parking lots, over the zone layer gave the current distribution of parking lots to each zone, and this is shown in Table 1. The distribution was not optimized and it clearly shows that the origin of the vehicle trip has not been considered.

Zone	Lot 4	Lot 9	Lot 10
Group A	50.56%	53.12%	53.58%
Group B	18.51%	17.58%	17.91%
Group C	6.72%	8.56%	7.99%
Group D	10.27%	4.32%	7.85%
Group E	12.61%	15.42%	11.02%
Group F	1.33%	1.00%	1.65%

Table 1 - Percentage distribution of parking lots in each zone

Optimal parking allocation can be accomplished by solving the parking distribution problem in a similar manner to solving a transshipment problem using network analysis algorithms. Knowing the origin, destination parking lot, and the route chosen for each trip helped to estimate the volume accessing each link. Hence a new Clemson-area network was created manually for access to Lot 4, Lot 9, and Lot 10, along with the gateways for each zone. Lots 4, 9 and 10 are shown in Figure 3. Speeds and travel times for each link were manually entered, based on observations made from field surveys during football games. The network was created with travel time acting as link cost.

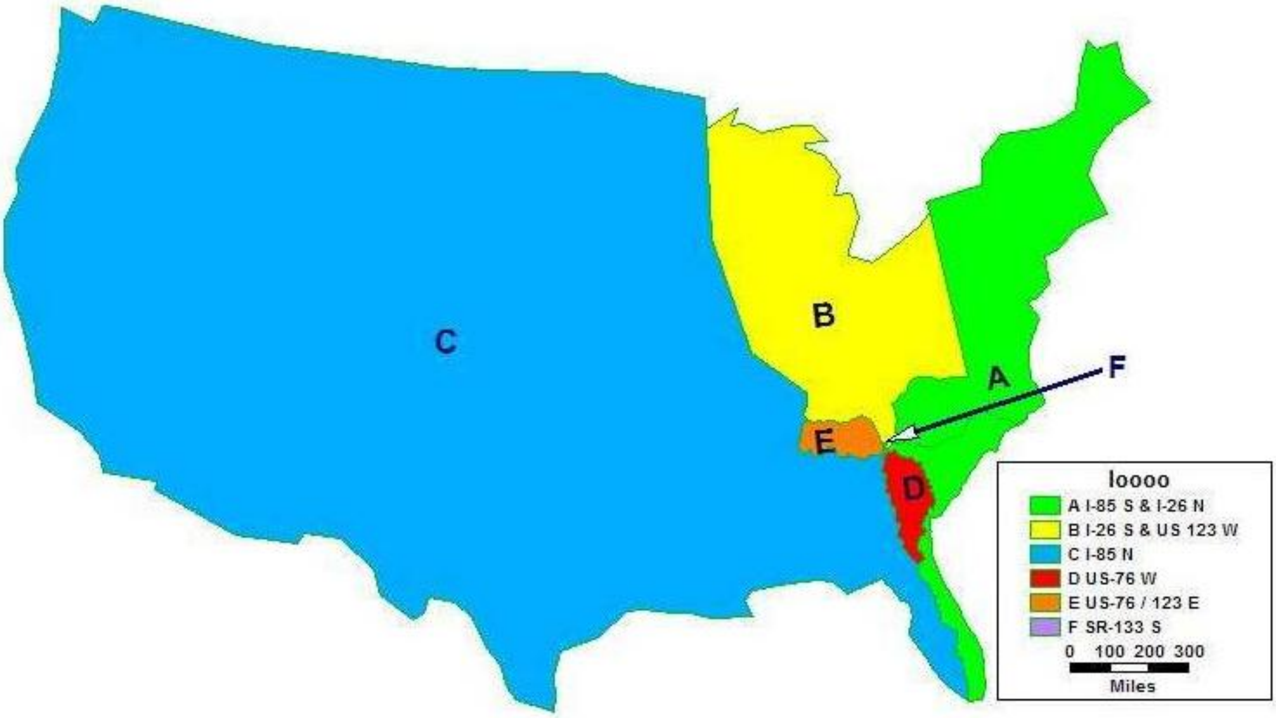

Figure 2 - Six Ticket Holder Distribution Zones created using GIS Network Partitioning

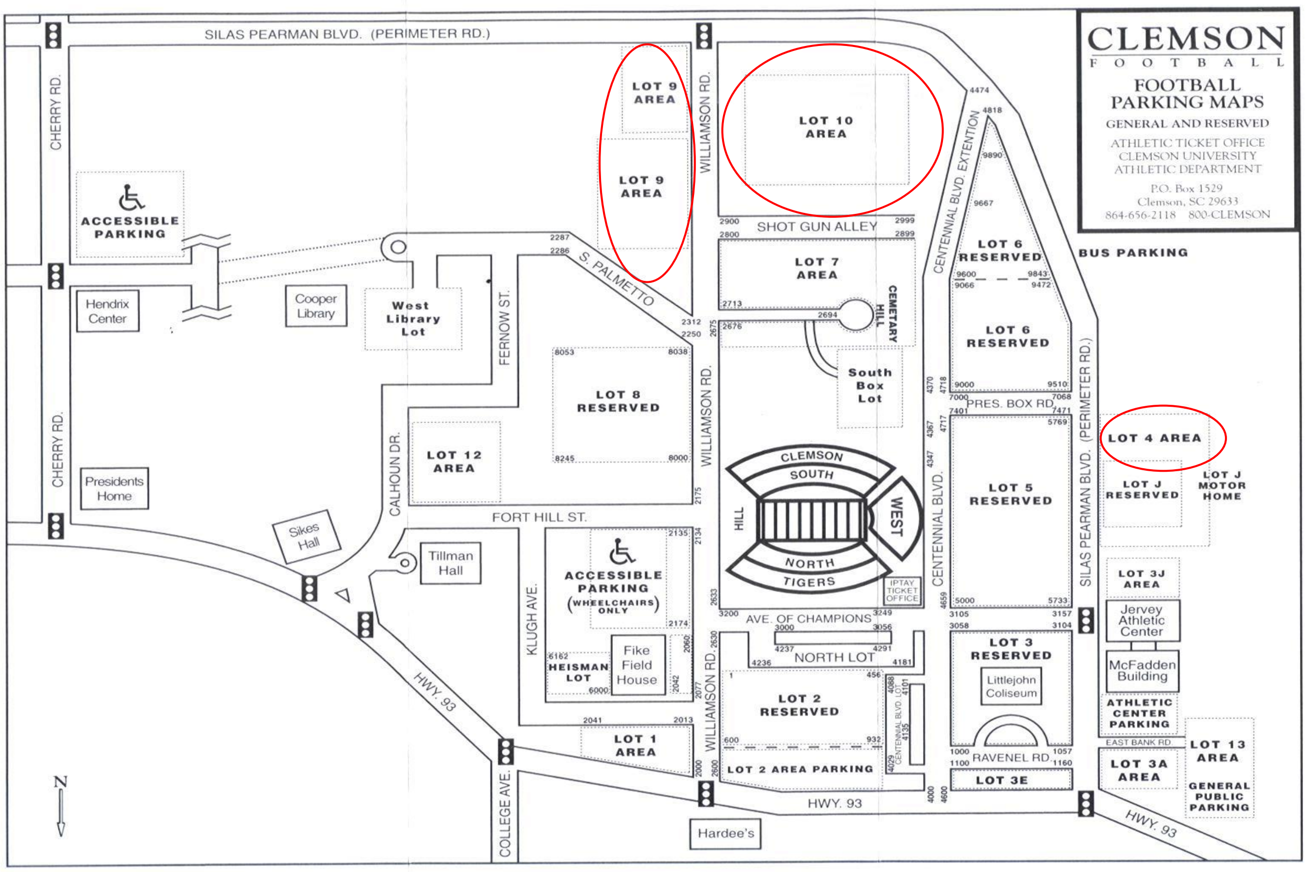

Figure 3 - Reserved parking lots in Clemson including lots 4, 9 and 10

5.5 Trans-shipment analysis and the Hitchcock transportation problem

The parking reallocation problem was resolved by setting up and solving the Hitchcock Transportation Problem (HTP). The HTP is concerned with distributing any commodity from any group of supply centers, called sources, to any group of receiving centers, called destinations, in such a way as to minimize the total distribution cost. In the parking allocation problem, the supply centers are the ticket holders' residing zones and the receiving centers are parking lots 4, 9, and 10. The actual numbers involved are shown in Table 2.

Zone	Lot 4	Lot 9	Lot 10	Total
Group A	1943	691	389	**3023**
Group B	675	228	130	**1033**
Group C	196	111	58	**365**
Group D	263	56	57	**376**
Group E	432	198	80	**710**
Group F	35	13	12	**60**
Total	**3544**	**1297**	**726**	**5567**

Table 2 - Current Volume Distribution between Supply and Demand Centers Before HTP

One requirement of the Hitchcock problem is that total supply equals total demand, which was the case in this project:

$$\sum_{i=1}^{m} S_i = \sum_{j=1}^{n} D_j \qquad (2)$$

where,

S_i = Supply, total number of vehicles at gateway *i* with assigned parking lots 4, 9, & 10, and
D_j = Demand, total number of parking spaces assigned in each lot *j*
[supply centers (gateways), *m* = 6; demand centers (parking lots 4, 9 and 10), *n* = 3]

The cost of the distributing units from any particular source to any particular destination is directly proportional to the number of units distributed (Gass, 1990):

$$\text{Total cost} = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} X_{ij} \qquad (3)$$

where,

C_{ij} = Cost from supply center *i* to demand center *j*
X_{ij} = Number of units distributed from supply center *i* to demand center *j*

The *TransCAD* procedure for minimizing total cost uses an adaptation of the simplex method for linear programming - an algorithm that is based on an important characteristic of the HTP. When the optimal solution is attained, the number of links carrying traffic equals the minimum number of links that can connect supply nodes to demand nodes; all other links are empty.

More specifically, the algorithm starts with an initial, feasible solution that comprises a minimum number of flow-carrying links and it 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 and it adjusts the flow on all other flow-carrying links before updating the network. This process repeats until no further improvements can be found by switching links. Note that the cost matrix was created between the supply nodes (gateways) and demand nodes (lots 4, 9 and 10); it was based on the travel time of links for the Clemson area network and it was created manually.

The transshipment problem based on minimum was solved in *TransCAD* and the results were as shown in Table 3. It can be seen that all of the vehicles from Groups B, C, D and F are assigned to parking lot 4, all vehicles from Group E are assigned to lot 9 and Group A's vehicles are spread across all three lots with the lion's share going to lot 4.

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Zone	Lot 4	Lot 9	Lot 10	Total
Group A	1710	587	726	**3023**
Group B	1033	0	0	**1033**
Group C	365	0	0	**365**
Group D	376	0	0	**376**
Group E	0	710	0	**710**
Group F	60	0	0	**60**
Total	**3544**	**1297**	**726**	**5567**

Table 3 – Optimal allocation of groups' vehicles to the three parking lots

6. Evaluation of the parking reallocation

Once the parking reallocation was optimized, micro-simulation was used to evaluate its effects in terms of differences in travel time even though calculation of travel time is complex in a congested situation. We begin with a base travel time assuming average speeds through the network in free flow conditions and then adjust it based on the delays experienced when traveling through the intersections. The total delay at a particular intersection is called control delay and it is actually a function of several, component delays including delay from uniform arrivals at intersections, incremental delay to account for effects of random arrivals and oversaturated conditions and initial queue delay.

6.3 Estimating control delay for the alternative strategies

Four alternative strategies were evaluated in the micro-simulation model. The first alternative was the "do-nothing" option and the second strategy incorporated the volume changes along links after solving the Transshipment problem. The third and fourth alternatives were attempts to relieve some of the congestion on the perimeter road by achieving system equilibrium in which traffic dissipates relatively uniformly throughout the network:

- Alternative 1: Current traffic conditions.
- Alternative 2: The transshipment problem solution. The difference in volumes from Group B to lot 9 and lot 10 were subtracted from Perimeter Rd and added on to US 123 plus left-turning movements onto SR 93. Also, the volume of vehicles from Group D making left turns onto Williamson Road were taken from Perimeter Road and added to the right-turn movement into lot 4 from SR 93.
- Alternative 3: Traffic from Group C (from Atlanta) was encouraged to reach Clemson by taking exit # 2 on I-85 and US 123/76 east. Vehicles from Group C that were going to lot 4 were taken from Perimeter Road and added to the traffic coming from US 123/73 east, thereby increasing the right-turn movement from US 123 onto SR 93.
- Alternative 4: Vehicles from Group A vehicles going to lot 4 were taken off Perimeter Road and added to US 123 west, thereby adding to the left-turn movement onto SR 93.

The results of the before-game, microscopic simulation for critical intersections is shown in Table 4, which compares control delay and queues for each of the four alternatives modeled.

Control Delay is measured in seconds per vehicle, and queues are measured in feet. It can be seen that there is a reduction in delay and queue lengths at the intersections on Perimeter Road and on US 76 because of reduced traffic. Also, at the intersection of US 76 and US 123 the westbound approach delay decreases for Alternative 2, because left-turn movements are reduced and added to through movements. However, delay rises for Alternative 4 because of the additional traffic that has been added to the through movement. Finally, Table 4 clearly indicates how the intersection delays for US 123 and SR 93 increase because of an increase in left-turn movements onto SR 93.

Travel time for a single vehicle moving through a network can be calculated by summing its free-flow travel times experienced from when it enters the network until it reaches its assigned parking lot, and the free-flow travel times can be calculated directly from the Hitchcock algorithm. To estimate control delay through the network, one needs a micro simulation that incorporates the following tasks.

	Intersections															
	Perimeter & Williamson				**Perimeter & US 76**				**Old Stone Church & US 76**		**US 76 & US 123**		**US 123 & US 93**			
	EAST-BOUND		**WEST-BOUND**		**NORTH-BOUND**		**SOUTH-BOUND**						**EASTBOUND**		**WESTBOUND**	
Alternative	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**	**DELAY**	**QUEUE**
1	9.9	74	3.9	224	154.6	2594	77.9	636	169.2	3408	13.1	269	143.1	1209	169.3	1473
2	4.8	33	3.2	161	154.1	2594	54.1	370	169.2	3408	7.9	222	143.1	1209	200.3	1697
3	4.8	33	2.8	135	148.7	2542	53.8	366	164.9	3224	7.9	222	157.8	1304	200.3	1697
4	4.8	33	1.2	44	120.1	2259	51.8	341	149	2984	10.7	365	157.8	1304	254.5	2196

Table 4 - Delay (seconds/vehicle) and queue length (feet) for four alternatives at critical intersections

6.1 Vehicular data processing

The vehicular data collected in the field has both vehicles with assigned parking lots and vehicles without any parking permit. The percentage of vehicles with assigned parking lots in the total traffic stream arriving to Clemson was estimated by the following equation:

$$PV_A = F_A / F_T \quad (4)$$

where

PV_A = Percentage of vehicles in the total traffic with an assigned parking lot
F_A = Total fans who attend the game with assigned parking lots
F_T = Total fans who attend the game

The number of fans who attended the Virginia Tech game was 77,000, attendance for the Florida State game was 81,000, the number of people with assigned parking lots was 45,346 and an assumption was made that the number of people attending any game is directly related to number of vehicles arriving in Clemson on the game day.

6.2 Model modification

The Virginia game was an early-start game that was not convenient for tailgating and so it had most of its traffic arriving a few hours beforehand. For analyzing traffic conditions before the game a micro-simulation model was developed using *SYNCHRO* for peak hour demand volumes and data collected at the Virginia game. From the peak hour demand volumes generated by the model, the volume of vehicles with a parking permit was determined by following expression

$$MV_A = M * PV_A \tag{5}$$

where

MV_A = Model volume for the vehicles at the intersection with a parking permit
M = Total model volume of vehicles at the intersection
PV_A = Percentage of vehicles in total traffic with a parking permit

The intersections through which vehicles entered the campus were identified. The peak-hour volume of vehicles with parking permits was determined from movements into the campus. Specifically, the volume of vehicles with assigned parking lot 'i' was determined from the model volume at each intersection using the equation:

$$ML_i = MV_A * R \tag{6}$$

where

ML_i = Model volume for vehicles at the intersection with a parking permit for the lot i
R = Fraction

$$R = VL_i / V_A \tag{7}$$

where

VL_i = Volume of vehicles at the intersection with a parking permit to lot i
V_A = Total volume of vehicles at the intersection with parking permit

The volume of vehicles with parking permits on each link of the network was determined by making an assumption that most of the vehicle users select the minimum-cost route to Clemson. Volumes V_A and VL_i were determined by the number of vehicles from each zone and with specific lot passes.

Total system-wide control delay is not very useful for this analysis because the parking allocation only affects a portion of total traffic. Nevertheless, it is critical to evaluate the changes in overall system delay for each alternative because these changes from the baseline are entirely due to the reallocation and rerouting of traffic.

Table 5 shows that the overall system-wide reduction in control delay of the alternative strategies is relatively small for Alternative 2 considering the huge amount of traffic on the network. This is not surprising; while delay is improved at some intersections, the diversion of traffic can actually increase delay at other intersections.

Alternative	Reduction in Delay (hours)
1	0
2	10
3	80
4	70

Table 5 – System-wide change in control delay

6.4 Calculating Changes in Free flow and Total Travel Time

An important consideration is the change in total travel time, of which control delay is only one component. The trans-shipment solution also provides a considerable reduction in free-flow travel time. The reductions in total system-wide travel time considering both control delay and free-flow travel time is shown in Table 6. Clearly, all of the reallocated alternatives show a significant improvement over the baseline strategy. Moreover, the time savings shown are for one hour prior to the game.

Alternative	Reduction in Delay	Reduction in Free-flow Travel time	Reduction in Total Travel Time
1	0	0	0
2	10	36.9	46.9
3	80	35.5	115.5
4	70	30.4	100.4

Table 6 - Total system-wide travel time

The total number of reallocated vehicles in the one hour period is 512 and the time saving per reallocated vehicle for Alternative 2 averages 5.5 minutes per vehicle. Note that reallocation's total time saving will actually be higher, because vehicles arrive at the game over a period of several hours.

7. Conclusions

The results from evaluating all the alternative strategies for changes in the system-wide delay show that an efficient application of the Hitchcock algorithm for parking lot reallocation was achieved, the overall travel time of vehicles being reduced by 46.9 hours, and since this delay has been calculated for the peak hour period, the total time savings of the reallocation will actually be higher because vehicles arrive at the game over a period of several hours. Further, the time savings after the game was not considered, but it would be similar because the greatest savings before the game are in terms of reduced, free-flow, travel time.

For optimal spatial allocation motorists are assumed to have selected a minimum-cost route, but in reality this is not the case because route selection differs for every ticket holder. It follows that conducting a travel survey of sample ticket holders in order to determine the route they selected from origin would improve this research. Selected routes could be determined through statistical analysis of the collected data and the model calibrated accordingly.

For the current Hitchcock algorithm, the network cost (travel time) is the only constraint and minimum cost is the objective function. Yet the capacity of the different links is an important aspect in maintaining smooth traffic circulation and so inclusion of link-capacity data as another constraint would improve our analysis.

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