Campus Shuttle: Design of a College Campus Parking and Transportation System

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Abstract — **George Mason University is a commuter campus in Fairfax, VA. To meet forecast growth, parking lots are being removed to make space for classroom buildings. The loss of parking slots requires either additional parking garages or mass-transit shuttles to make up for the loss in parking spaces. There are also concerns about traffic congestion and emissions caused by the college's commuters.**

The Fairfax campus population is predominantly made up of commuters, with 77% of the population living off campus, a vast majority of which drive single occupant vehicles (SOV) to campus due to poor access to mass transit. At present, the GMU Fairfax campus has a parking utilization of 86%, leaving a surplus of approximately 900 parking spaces. Fairfax campus is predicted to start having a parking deficit sometime between 2014 and 2015. Projections out to 2020 show a deficit of 3,800 spaces. To counter that deficit, more than 10,600 current commuters would need to switch from SOV transportation to alternate forms of transit. A reduction of SOV commuters would also lead to lower CO_2 emissions from the Fairfax campus.

This paper describes the design of a system for addressing transportation and parking demand. This has 3 major parts: (1) identifying surrounding areas of significant Fairfax commuter populations; (2) the ability to predict ridership if a shuttle stop were to be placed in any of those areas by using a decision support tool (DST); and (3) a utility analysis (CO_2, parking, and cost) of creating shuttle routes or garages to meet parking needs.

In order for GMU to continue growing, both commuter shuttles and parking garages will be needed. If four additional routes are added, GMU can continue to grow through 2016 with a parking utilization of 96%. To continue growth beyond that point will require additional parking garages or bus routes.

I. INTRODUCTION

GEORGE Mason University was established as a branch of the University of Virginia in 1957. It became an independent university in 1972 with an initial enrollment of 4,166 students and a single campus in Fairfax, Virginia [1].

GMU has since added four more regional campuses in Northern Virginia, in Loudon, Prince William, Arlington, and Warren counties. GMU has grown to a total enrollment of 32,961 students (fall 2012 census) between all of the campuses. Of those, the Fairfax campus accounts for the majority of the students with 27,041, 22% of which reside on campus. GMU is committed to continued annual growth through 2020 [2].

A. Population Density

GMU population densities were derived from historical parking permit data from the GMU Parking and Transportation Department which included approximately 319,000 permits. Each permit was associated with a zip code and whether it was for a faculty or student. This data enabled identified the percentage of Fairfax GMU population for each zip code. The areas with at least 1% of the Fairfax GMU population are all considered to be potential shuttle route alternatives.

City / County	%	City / County	%
Alexandria	3.41%	Prince William	9.96%
Arlington	6.56%	Stafford	1.26%
Fairfax	45.95%	Washington DC	1.90%
Loudon	5.30%	Montgomery	1.65%
Fauquier	0.89%	Prince George's	0.97%
Total			**77.87%**

Table 1. Areas of significant Fairfax GMU populations.

B. Population Growth

The University Master Plan [3] and Fairfax Campus Transportation Master Plan [4] forecast a sustained annual enrollment growth of 2% through 2020 with a projected enrollment of 29,925 students. To supplement this 2% growth prediction, Fairfax campus population data from 2004 to 2012 was analyzed [2]. Trendlines for students and faculty population.

Faculty: ,
Students: ,

Using these trendlines predictions for 2020 yielded a Farifax campus population of 31,339 students and 6,814 faculty, higher than the 29,925 projected students in the master plan.

C. Parking Demand

The GMU Fairfax campus currently has approximately 12,500 parking spaces. The 5 - 10 year facility growth plan will lead to a net reduction of 2,443 spaces to make way for classrooms and housing [4]. Projected Parking demand is generated using utilization ratios from the Transportation Master Plan. For faculty and off campus students a 0.34 ratio is used, and for on campus students a 0.44 ratio.

From the utilization ratios we can determine a per space utilization of 0.363 using the formula

, where 0.77 and 0.23 are the proportions of commuters and on campus residents respectively. This means that one parking space services 2.75 faculty and students.

To predict future parking demand for the Fairfax campus,

these ratios were combined with the trendline formulas for population,

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If no additional parking garages are built or bus routes added, by 2020 the deficit will be approximately 3800 spaces. Available parking spaces through 2020 are based on future construction projects outlined in Transportation Master Plan [4]. Table 2 shows the surplus/demand of parking spaces through 2020.

Year	Faculty	Off-campus	On-campus	Demand	Available	Net
2012	5244	20966	6075	11584	12500	916
2013	5440	22078	6075	12029	12450	421
2014	5636	22023	6585	12302	12350	48
2015	5833	22479	6585	12523	11984	(539)
2016	6029	22934	6585	12745	11502	(1,243)
2017	6225	22589	7385	13046	11020	(2,026)
2018	6421	22244	8185	13348	10539	(2,809)
2019	6618	21899	8985	13649	10058	(3,591)
2020	6814	22354	8985	13870	10057	(3,813)

Table 2. Future parking demand projections for Fairfax GMU campus.

Using the per space utilization figure, we can equate the parking deficit in terms of campus population. 2020 has a deficit of 3,813 spaces, this means parking demand for 10,504 faculty and students would not be met.

D. Parking Construction

Any additional parking added to the Fairfax GMU campus will be in the form of parking garages due to land constraints. Outlined in GMU's master plans are several parking garages along with the construction of new buildings and housing. One such garage is Parking Deck V, adding 1200 spaces, having a projected cost of $35.3M, and an earliest completion date in 2015 [5]. The transportation department budgets a yearly maintenance fee of $200 per space.

E. Shuttle System

Figure 1. Current routes (blue) and design alternatives (red) of the Mason shuttle system.

The Mason shuttle system is free to all GMU faculty and students. Students account for 85% of the ridership [4]. The shuttle system consists of two commuter shuttle routes, Prince William and Mason to Metro. The Prince William shuttle runs between the GMU Prince William and Fairfax campuses with an additional stop at Manassas Mall. The Mason to Metro shuttle is the most used, operating several shuttles simultaneously and offering express buses at peak times. The GMU populations of Washington, D.C. and parts of Arlington, Alexandria, and Maryland are serviced by the Metro transit system, which is then connected to GMU by the Mason to Metro shuttle.

Figure 1 represents over 90% of the Fairfax GMU commuting population. Based on the current routes highlighted in blue, it can be noted that significant portions of GMU's commuting population in Fairfax, Loudoun, and Prince William counties remain underserviced. These areas require numerous transfers between multiple transit systems via roundabout routes to access the Fairfax campus, even with the new Metro Silver Line creating more connections in Herndon and Reston.

F. Fuel Trends

As of February 2013, the price of crude oil made up approximately 67% of the cost of regular gasoline [6]. Based on trends in the current economic conditions, the future price of transportation fuels can be forecasted. High economic growth would lead to more demand and consumption of fuels therefore resulting in a steeper price increase and vice versa for lower economic growth.

G. Emissions

A nonattainment area is an area considered to have air quality worse than the National Ambient Air Quality Standards (NAAQS) as defined in the Clean Air Act Amendments of 1970 (P.L. 91-604, Sec. 109) [7].

Currently, Fairfax County is a non-attainment area and recent initiatives to improve the air quality have been initiated by the community as a whole. For example, George Mason University Transportation Master Plan identifies a long term objective of reducing single-occupant vehicle trips by use of transit or ride sharing, which would significantly reduce greenhouse gas emissions and support the University's goal of carbon neutrality.

II. STAKEHOLDERS

A. Primary

Two main groups have been identified as primary stakeholders in the GMU transportation system. The GMU population composed of the faculty, staff, and students, who help finance and are also potential users of the system. The GMU Parking and Transportation Department manages the system. Currently the shuttle system is contracted out to a service provider creating a sub-primary stakeholder.

B. Secondary

The secondary stakeholders can be grouped into three

main categories. The first group comprises of other GMU departments affected by changes in the system. Administration and Finance sets the budget, Public Safety is responsible for policing the system, and Facilities Administration builds and maintains the system infrastructure.

The second group has the public entities that play a role in the system. These include the state, county, and local governments, as well as the public transit authorities.

The last group covers private entities tied to the system. This includes the local neighborhoods surrounding GMU and the shopping centers connected to the Mason shuttle system.

C. Tensions

Several tensions exist between the stakeholders and the system. There is a large unmet ridership demand as it is only available to a small portion of the GMU population, as many only have the option of driving to campus. Increases in parking rates, fuel prices, and a worsening traffic situation will only add to the unmet shuttle demand. As parking spaces become sparser, the overflow will further spill into the surrounding neighborhoods, which is already taking place, forcing them to institute parking restrictions at additional cost and inconvenience to themselves.

III. PROBLEM AND NEED

A. Problem

There are four major problems that need to be addressed with the current system [1]. GMU is not prepared to meet the increased parking demand if it continues its current growth rate [2]. The current shuttle system only services a few areas, missing many high Fairfax GMU population areas [3]. The GMU Department of Parking and Transportation does not have a way to predict demand for alternative shuttle routes [4]. Finally, GMU has no documented vehicle emission calculations.

B. Need

For GMU to keep expanding, it needs to increase shuttle ridership. Approximately every 3 commuters that take a bus to campus is one less parking space that GMU has to pay for. This is mutually beneficial to both parties, since students will save on rising transportation costs. To effectively bring in as many students as possible, both parking and public transportation options need to be pursued simultaneously.

To increase shuttle ridership effectively, the shuttle system needs to expand to new areas. There is little growth in the Prince William shuttle route, and none in the Metro route. These two locations have little to gain by adding additional capacity to the route. The shuttle system needs to provide service to other areas with similar or higher commuter population densities.

To expand the shuttle system effectively, GMU needs to be able to predict demand in any area. When presented with alternatives, GMU needs a way to choose the best area to

place a bus route to capture the most commuters with the new shuttle. This leads to our need for a simulation in order to predict commuter reaction to a bus stop in any area.

There needs to be a way for GMU to show how Single Occupancy Vehicle (SOV) and Emission values have changed due to their efforts as a way of meeting their goals. This will give them a measure they can use to make quantitative emissions goals. Any potential bus route should also be evaluated by its impact on emissions.

C. Scope

For this project the Prince William route is used as the data source. This route is entirely SOV commuters and will be similar to any new shuttle route alternatives. The cost and bus alternatives are determined by the GMU contract with the shuttle service provider. Emissions are also to be based on shuttle alternative limitations.

IV. DESIGN ALTERNATIVES

A. Locations

From the parking permit analysis, four areas of interest were identified for analysis as a shuttle route alternative. These are in Burke (9.06%), Herndon/Reston (3.82%), Loudoun (2.75%), and Woodbridge (4.73%).

B. Bus

The models of buses used for all the shuttles are the IC Bus AC Series and the IC Bus HC Series. The IC Bus AC Series is the smaller bus which has a seating capacity of about 22 - 24 passengers and fuel consumption of the bus is 7.5 miles per gallon (MPG). The HC Series, the larger bus, has a seating capacity of 32 passengers and the fuel consumption is 9 MPG. All the current buses available run on diesel [8].

The IC Bus AC Series has an hourly charge $68.83 and the HC Series has an hourly charge of $75.40 for the operation of the buses. The maintenance of the bus is included in the hourly fee.

An alternative bus, that is under consideration as a possible recommendation for this system, is the HC Series Hybrid bus. The bus has a passenger capacity up to 45 and due to its diesel engine and the parallel drives hybrid system, it can give up to 32% improvement in fuel economy. The fuel consumption of this bus is 10 miles per gallon. Using the previous AC Series and HC series hourly charge, as estimated hourly charge of $96.94 can be applied for the hybrid bus.

V. METHOD OF ANALYSIS

A. Decision Support Tool

This decision support tool's main purpose is to estimate ridership at new locations. Several main assumptions are made for this decision-support system. Buses leave hourly and on time, each rider takes each shuttle both ways exactly once and the buses do not break down. Buses will be scheduled to stay on a route all day. People in each zip code

depart for campus based on a 'Demand Profile'. It is assumed that full time students travel to school 4 days a week and the others students attend 2 times a week. This gives 85.5%, which is the percent of people that will be assumed to commute each day.

The simulation will have some requirements to fulfill to have a functional program. The program will need a user interface for user input. The simulation will need access to the internet. Data required by the simulation needs to be stored. Ridership for each design alternative will need to be simulated. Reduced parking space shall be calculated using the utilization ratios for the faculty and students [1].

To facilitate all requirements, the simulation will run with an HTML/JavaScript interface. The user interface will be used to input design alternatives and display results. PHP will be used to run the simulation. A MySQL database will be used to store data needed for simulation.

For the simulation there are two types of user inputs, 'Location', and 'Year/Semester'. Simulation variables are held in the database 'Population Density', 'Campus Demographics', 'Growth Rate', 'Demand Profile', and 'Bus Alternatives'. These inputs are used to create the 'Ridership profile by Zip code'. With the zip code profiles, the simulation is run and 'Total Ridership' is outputted. From there, the simulation can calculate the number of buses needed, the cost and emissions produced by the system.

Calculating 'Ridership Profile by Zip code' is the most important part of the simulation. Each zip code is assigned a demand profile individually which is then calculated using a generic demand profile and scaling it to the population of that zip code. This is done in two steps. First, the current population of that zip code is calculated using the commuter population for the year and semester that is inputted and then multiplied by the percentage of GMU's commuter population in that zip code. Then the demand profile is scaled to the population of that zip code. This is done for every zip code within 10 miles a bus stop.

From there the stochastic 'Simulate Demand' can begin. The demand profile for each zip code has both a mean and standard deviation. The simulation generates a number of commuters using that information at each hour. Each zip code now has randomly generated commuters who are then given a choice to take the bus or take a SOV. The choise is made using our decision model where it is assumed that a longer commuting delay is less desirable. This decision model was built using historical data, fitting the probability function until the mean square error for fall and spring data that was collected could be minimized. The mean square error for any route is between 1.0 and 1.2 passengers when compared to historical data.

When the 'Total Ridership' has been calculated, the 'Calculate Costs' function can now determine a bus schedule for 'cost', 'emissions', and 'SOV Ridership', which is the the difference between the total ridership and the total commuters. Calculating cost is based on the minimum number of buses needed to meet demand and the hourly rate of each bus. Emissions can be calculated using the emission model explained in section VI and the bus schedule.

B. Data Sources

Data was collected from Reston Limousine, GMU Department of Parking and Transportation and GMU Institute of Research and Reporting (IRR). Reston Limousine provided historical data that was used to built the 'Demand Profile' and decision model. The data used for this project is from the 2010 and 2011 semesters for the Prince William route. GMU Parking and Transportation provided access to some financial information used in calculating shuttle costs. IRR provided historical data on parking permit purchases, which was analyzed to give us population densities for each zip code. Publicly available documentation from GMU has the population projection estimates and planned construction projects. 'Travel Time' and distances were collected using Google Maps. Travel times were all collected on a Saturday afternoon.

C. Design of Experiment

The simulation will be run using alternative locations that were selected by finding the highest commuter population density areas. The four areas selected are: Burke, Herndon, Loudoun, and Woodbridge. The year selected is 2014 and 2015 because that is when the parking deficit should begin. All but one data input was gathered from GMU departments.

VI. MODELS

A. Emissions

To calculate the carbon dioxide (CO_2) emissions from a fuel, the ratio of the fuel carbon content to its energy content is multiplied by the ratio of the molecular weight of CO_2 to the molecular weight of carbon [9]. Table 3 shows the CO_2 emissions for the fuels used in our emissions model.

Fuel	Specific Carbon Content (kgC/kg-fuel)	Specific Energy Content (kWh/kg-fuel)	Specific CO2 Emission (kgCO2/kg-fuel)	Specific CO2Emission (kgCO2/kWh)
Gasoline	0.9	12.5	3.3	0.27
Diesel	0.86	11.8	3.2	0.24
(CNG) Methane	0.75	12	2.8	0.23

Table 3. Emission values for gas, diesel, and CNG.

For our model three emissions equations were used, one for diesel, CNG and gasoline. The 3.402 kg/gal in the diesel formula is for converting the mass of diesel. Gasoline gives off 0.423 kg CO2 per gallon and average SOV mpg is

21[10].

Diesel: — — —

CNG: —— —

B. Cost

Cost is calculated using hourly rates based on efficient shuttle scheduling. Shuttle schedule is computed by minimizing hourly cost while meeting a 95% level of service (LOS). The number of hours operated needs to be doubled since another bus will be operating in the opposite direction. Each bus will then operate 16 hours a day, 5 days a week, 16 weeks per semester for 2 semesters per year. This gives the yearly cost of operation.

LOS is calculated by averaging the probability the capacity of the shuttle(s) will meet demand for each route time. Since the simulation is based on a normal distribution, the results are also normal and   can be used. The P for all times are averaged together and compared to the desired 95% value. Each route has its LOS computed individually.

VII. RESULTS

A. Ridership

The simulation was first run to provide verification and validation. It was able to do both. These results provided estimates that had less than a mean square error of 1.5.

The simulation was run for all four locations to see how much ridership could be expected from these areas. A total of 1836 students would be expected to ride the bus on average per day if all four locations had bus stops.

Ridership	
Burke	839
Herndon	336
Loudoun	245
Woodbridge	417
Total	1836

Table 4. Fall Simulation results of all four design alternatives and expected parking space gain due to increased ridership.

Burke Simulation							
Time	Mean	Stdev	Variance	Time	Mean	Stdev	Variance
700	54.8	6.5	42.8	1500	77.2	7.8	60.2
800	62.4	7.7	58.6	1600	35.0	5.6	30.9
900	111.9	9.1	82.9	1700	45.6	6.4	41.0
1000	46.1	6.2	38.9	1800	39.5	5.7	32.0
1100	75.6	7.8	61.6	1900	51.1	6.6	43.2
1200	49.3	6.4	40.7	2000	16.3	4.1	16.8
1300	79.4	7.9	62.9	2100	19.7	4.3	18.4
1400	55.1	6.8	45.9	2200	19.9	4.5	20.1

Table 5. Fall simulation results for Burke using current Fairfax GMU commuter population. Time indicates when the bus leaves the first stop.

B. Emissions

Emissions was calculated based on the shuttle schedule and the mileage for each route in both directions and then compared to the average car travel distance. For every rider

that chose to take the shuttle, the emissions of an average car was subtracted from the total emissions.

Emissions (Daily Kg of CO_2)				
	Car Miles	Em. of 1 Car	Area Pop	Car Em.
Burke	7.2	6.0912	2304	10259.296
Herndon	11.7	9.8982	967	6997.0492
Loudoun	23	19.458	696	9900.102
Woodbridge	20.3	17.1738	1196	15015.155
			Total	42171.602

Table 6. Daily emissions. Car emissions are using average travel distance for the area. A car averages 21mpg.[10] 85.5% of an area's population is used to calculate SOV emissions.

C. Cost

Two schedules were calculated for cost. 'Schedule 1' is shown. 'Schedule 2' has the added advantage of the HC series hybrid bus which is currently unavailable, but shows a total hourly decrease in cost by $200 between all four routes.

Schedule1			
Location	Cost	LOS	Yearly Cost
Burke	590.06	0.9883625	1510553.6
Herndon	275.32	0.9797768	704819.2
Loudoun	150.8	0.9607745	386048
Woodbridge	288.46	0.9681814	738457.6
Total	1304.64	0.9742738	3339878.4

Table 7. Hourly cost, LOS and yearly cost for all four simulated routes.

D. Parking

Three primary cases were considered. The status quo (case1) is that GMU negotiates a Burke shuttle route and builds Parking Deck V. Case 2 is the use of a smaller garage in conjunction with all four additional shuttle routes. Case 3 is where both Parking Deck V and all shuttle routes are implemented. Results are in the form of percent of on-campus parking ultilization.

Year	Demand	Case 1	Case 2	Case 3
2012	11584	0.92672	0.92672	0.92672
2013	12029	0.945156	0.921339	0.921339
2014	12302	0.974262	0.949521	0.949521
2015	12523	0.930317	0.949863	0.908122
2016	12745	0.981971	1.003385	0.957695
2017	13046	1.043931	1.067594	1.017153
2018	13348	1.110852	1.137064	1.081247
2019	13649	1.183268	1.212382	1.150455
2020	13870	1.202532	1.232122	1.169181

Table 8. Parking utilization values out to 2020 for each case described.

VIII. ANALYSIS

The GMU Department of Parking and Transportation provided weights for meeting 'Parking' demand, reducing 'Emissions', and 'Cost'. On a scale of 1 to 10, each was rated as a 8, 6, and 7, respectively. Utility values were normalized resulting an a utility of 0.33, 0.29, and 0.38. Each is assumed to use a linear scale, where lower cost is better, lower emissions is better, and lower parking utilization is better.

Several design alternatives were considered for the analysis. Parking Deck V with the addition of a Burke shuttle route is the baseline. Optimistic estimates of implementation were used, Burke route effective 2013 and Parking Deck V is usable in 2015. For the other design alternatives, combinations of the four shuttle routes simulated were used as well as a smaller parking garage. The smaller garage was chosen to see if 606 simulated riders and a 594 parking space garage would be better than one 1200 space garage.

Design Alternatives					
Number	Bus Stops	Garage Size	NPV Cost	Emissions	Parking Util.
1	1	594	65,722,533	38118	1.030074
2	1, 4	594	86,666,897	32376	1.018753
3	1, 4, 3	594	97,616,111	28482	1.012224
4	1,4,3,2	594	117,606,413	26567	1.003385
5	1	1200	84,676,600	38118	0.981979
6	1, 4	1200	105,620,965	32376	0.971685
7	1, 4, 3	1200	116,570,179	28482	0.965744
8	1,4,3,2	1200	136,560,481	26567	0.957695
9	N/A	1200	41,833,808	42172	1.003385

Table 9. Nine design alternatives with four possible additional shuttle stops and two different parking garages. Non-normalized utility values are also shown. Stop 1 is Burke, 2 is Herndon, 3 is Loudon and 4 is Woodbridge.

Parking utility is based on percent utilization. Utilization at 95% or lower is desirable for GMU and even lower for students. Utilization number from 2016 are used because it is the last year that any alternative is at or below 95% utilization. Since all value are close to 100% the range was set from 95% to 105%.

Emissions has a worse case of 42,100 kg daily if no shuttle is implemented and commuters continue to drive SOVs. If all four bus routes are implemented, emissions can be reduced to 26,500 kg.

Cost is best with just Parking Deck V at a NPV of $41.8M. The 594 parking space garage has an NPV of $22.9M. The four shuttle routes have a combined NPV of $94.7M. If alternative 8 is used the total NPV reaches $136.5M, which is the worst case. If HC Hybrid buses can be made available, the NPV for alternative 8 and 4 reduces by $10.6M.

Utility				
Number	NPV	Emissions	Parking	Total
1	0.747814	0.25980	0.199259	0.37
2	0.526711	0.62774	0.312469	0.45
3	0.411124	0.87732	0.377759	0.51
4	0.200092	1.00000	0.466147	0.52
5	0.547722	0.25980	0.680212	0.54
6	0.326619	0.62774	0.783150	0.62
7	0.211031	0.87732	0.842565	0.67
8	0.000000	1.00000	0.923054	0.68
9	1.000000	0.00000	0.466147	0.50

Table 10. Normalized utility values and total utilits for all alternatives.NPV is calculated out to 50 years, the expected lifecycle of a parking garage.

Sensitivity of the results show that alternative 7 and 8 keep their value. When 'Cost' is increased to 0.5, alternative

9 becomes the best option. When increasing 'Emissions' by any amount, alternative 8 becomes better. 'Parking' favors 7 until it reaches 0.5 at which point it begins to favor alternative 8. Alternative 7 and 8 compete closely because the only difference between them is route 2, which is the least significant of the routes simulated.

IX. CONCLUSION

Parking will be a constraint in GMU's forecast growth This will be critical by 2016 when over 2000 parking spaces have been removed. The addition of the four shuttle routes can only capture 600 of those needed parking spaces.

For GMU to maintain growth while having a parking utilization around 95%, it will need to pursue both parking garages and additional shuttles. The routes selected here are the most likely to capture the most commuters and additional routes or parking garages will need to be implemented by 2017 in addition to all of the recommended routes suggested here. If Burke is the only additional route, another parking garage will be needed by 2016.

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