Proposal Title: A Model-Based Approach to Optimizing Rutgers Transportation Efficiency
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Project Summary:

A model of the current bus transportation system was created and analyzed to propose a more efficient model system. This proposed model can decrease travel times between campus centers by 23.5-66.6% and increase the maximum number of students transported between campuses by 16.1% while using six fewer buses. Reallocating these projected savings to a bike-share program can encourage eco-friendly practices and offer alternative and convenient means of travel for Rutgers students. Over a ten-year period, we expect to save over $740,000 and prevent over 190,000 kilograms of greenhouse-gas emissions.

A Model-Based Approach to Optimizing Rutgers Transportation Efficiency

I. Research Problem and Potential Impact

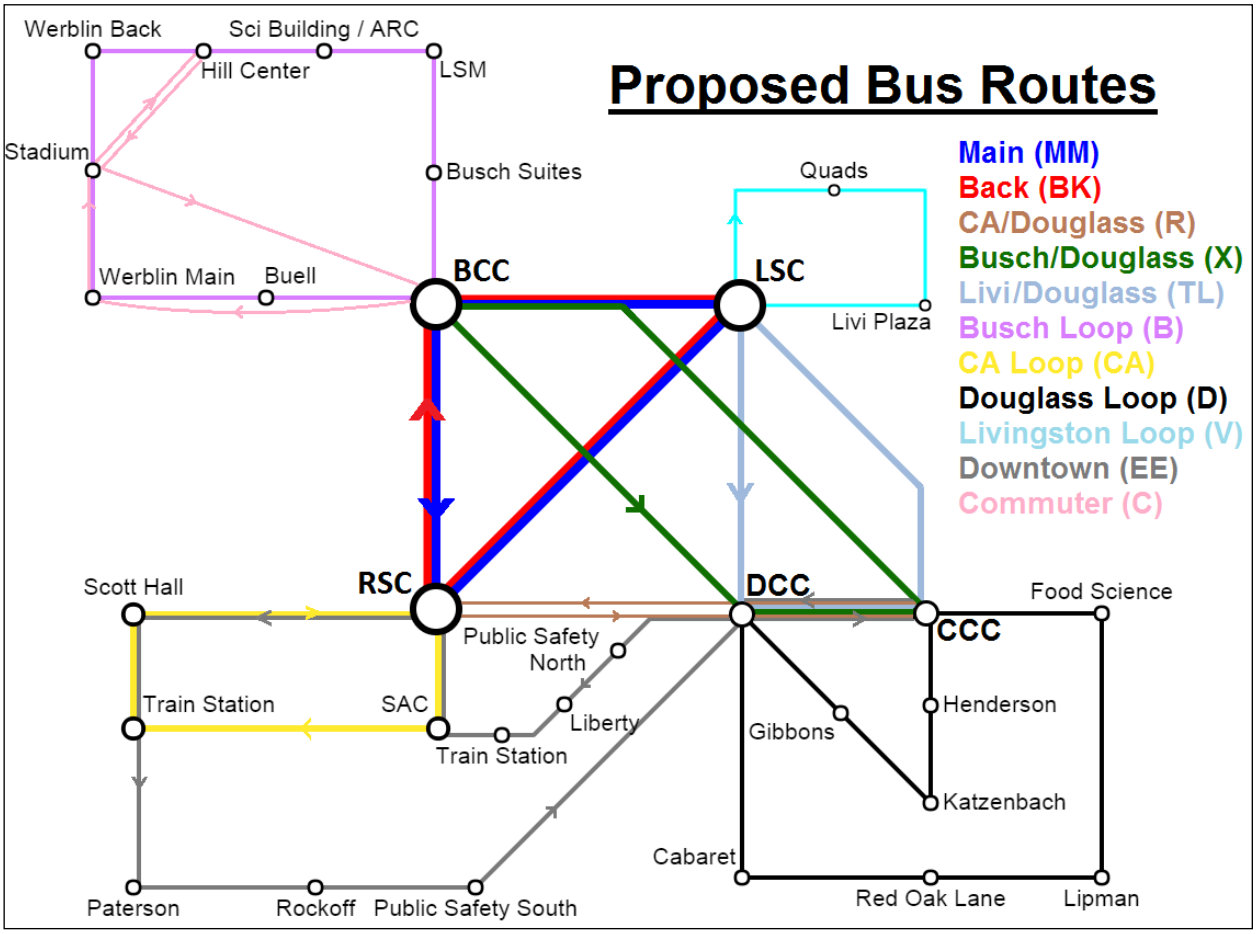
With the creation of *Rutgers 2030*, much of our focus has been on the future development and restructuring of the existing campuses. We have seen tremendous progress already with completed housing projects on College Avenue, which will accommodate over a thousand students living in the Honors College, the Bishop Quads, and the nearly completed "The Yard" Apartments. While Rutgers continues to grow, our transportation services have remained stagnant in comparison and may become overwhelmed with the larger influx of students. Our goal is to improve the bus transportation system to match the stepwise growth of Rutgers University without significant cost increases, changing major bus stop locations, or adding more buses. We aim to lower the overall carbon footprint of our transportation system through maximizing the efficiency of the bus transportation system and through encouraging and developing alternative methods of travel via a bike-share program.

II. Proposed Investigation Part A: Modeling the Rutgers Bus Transportation Systems

In order to first understand the pitfalls of the current transportation system, a working model during peak hours was developed using NextBus tracking systems. The breakdown of individual travel time between bus stops is shown in Table A (See Appendix). The summary table was created from the sum of the each route's individual travel time components. Dividing that sum by the number of buses produced the minutes/bus values. Data for the number of buses, distribution of buses, full bus data, and the reported buses per minute were provided by Rutgers DOTS from Spring 2015. The created peak-hours current model and the reported bus times match closely with slight discrepancies due to constants such as traffic.

Because NextBus tracking relies on Google Maps for travel time data, we can reduce the error in designing a new bus transportation system by also using Google Maps. We plan to

maximize travel efficiency by separating "intercampus" and "intracampus" traveling. Our proposal abolished the large looping idea from the current system and instead used more direct bus routes for intercampus travel. Meanwhile, each campus will also get a circular loop to aid in intracampus travel. We created models that connected two campus centers or four campus centers, but our methods of evaluation showed that connecting three campus centers resulted in the best overall system, shown in Table B (See Appendix) and in the figure below.



The motivation for using a direct bus transportation system like this is to prioritize the bus system's main purpose of intercampus travel. The current bus system has a heavily taxing role of accommodating for both intercampus and intracampus travel due to the large looping design, and this dual purpose creates inefficiencies. For example, in the first three weeks of the Spring 2015 semester, the B-bus route reached maximum capacity 20 out of 226 times (9%) at

the Hill Center, which is its first stop on Busch Campus. The bus usually does not fully unload until reaching the Livingston Campus, meaning there is wasted efficiency by having the B-bus travel through the rest of Busch Campus. Similarly, the LX-bus route reached maximum capacity 70 out of 390 times (18%) at its first stop on College Avenue at the RSC with minimal unloading until it reached the Livingston Campus. By having direct routing between campus centers, we can focus on improving intercampus travel.

We evaluate the proposed bus transportation system based on two main parameters: transportation time between campus centers and maximum number of students transported. Optimization of these parameters determined the proposed distribution of buses as shown in Table B, and this distribution was analyzed in Tables C and D (See Appendix). The proposed model predicts that using six fewer buses, we can decrease travel time between campus centers by 23.5-66.6% and increase the maximum number of students transported between campuses by 16.1%. Manipulation of the distribution of buses in the current and proposed bus routes from Tables A and B influenced the results in these tables. These manipulations showed several interesting results: (1) using six fewer buses in the proposed model, we were able to show positive improvement in every category; (2) increasing the buses in the current model can only outperform the proposed model in number of students transported by distributing ten buses throughout the current routes; (3) increasing the buses in the current model will not outperform campus travel times unless adding over ten buses to each bus route (virtually removing wait-times from the current model). Thus, the most optimistic interpretation of the data suggests that the proposed model has a net advantage of sixteen buses.

RUDOTS places a value of $200,000 to $300,000 per additional bus added to a route (assumed over a ten-year period). Although the potential of this proposal is worth a net gain of $4 million, the immediate gain from using six fewer buses is about $1.5 million. Since Rutgers

uses New Flyer diesel buses, we can use an emission energy report released by MJB&A for New Flyer buses to estimate the environmental impact. Using the UDDS model (18.9 MPH average speed with 1.3 stops/mi), a New Flyer diesel bus emits about 875g/mi of greenhouse gas emissions for a ten-year period. Using an average annual bus mileage of 36,424 miles per year, it is estimated that the removal of six buses will prevent a total of 191,226 kilograms of GHG emissions over a ten-year period.

III. Proposed Investigation Part B: Creating a Bike-Share Program

Rutgers University is known for having the largest campus transportation system in the nation; now we can be known for having the largest campus bike-share program. Using the savings generated by removing buses, we propose to reallocate half of these funds towards expanding the current BikeRU bicycle rental program into a bike-share program. The bicycle rental program currently holds approximately 120 bikes, which would be expanded initially to a fleet of 400 bikes under our proposal. These bikes will be distributed according to demand at each campus center (RSC, LSC, BCC, and DCC), where a bike station will be established to hold the bikes. (See the Appendix for more details on the bike-share program.) We expect total costs to reach around $750,800, and with the $1.5 million in savings from using six fewer buses, we expect a total profit of $749,200 over a ten-year period.

Bike-share Program Expected Costs

Overhead Costs	**Unit Price**	**Cost**	**10-Year Maintenance**	**Cost**
280 Jamis Earth Cruiser bicycles	$410	$114,800	500 Bicycle Replacements	$205,000
23 Bicycle Racks (Holds 18 ea)	$455	$10,500	Attendant Pay	$540,000
4 Bike Stations (Gazebos/Fencing)	$10,000	$40,000	Semester Dues	-$160,000
Total		**$165,300**	**Total**	**$585,000**

The benefits of a bike share system are self-evident: it is an efficient, eco-friendly, and healthy mode of transportation. We also hope to increase bicycle usage through the convenience

of having a bike ready for each participant at any time or campus with the installment of bike-centers. For example, this allows for a student living on College Avenue to take a bus to Busch and then grab a bike to get to class. This bike share program can also negate the disadvantages of the proposed bus system. With a bus system that optimizes intercampus travel, it is important to provide options that relieve the burden of intracampus travel. Cycling reduces pedestrian travel time by two thirds, and it makes students less vulnerable to the variability of the buses. This program also gives students another way to enjoy the outdoors more on beautiful, sunny days. By expanding the preexisting bike rental program and optimizing the bus routes, Rutgers can make significant progress to achieving its goal of being carbon neutral.

IV. Implementation

Phase 1: The first step is to test our hypothesis by implementing the proposed model during the Summer 2016 session. Since the demand of transportation is comparably lower in the summer months, implementation of the proposed model is best during this time to track its functionality, look for any unforeseen circumstances, and to receive feedback from students.

Phase 2: Contingent on the success of Phase 1, we will use the Fall and Winter 2016 session to plan for a formal change. This includes purchasing the bikes and creating the bike stations. Rework of any bus stop or road as necessary from information received in Phase 1 is also important to accomplish during this time.

Phase 3: In the Spring 2017 session, implementation of the proposed bus system will begin for a trial semester. It is beneficial to introduce the new system in the spring semester to avoid confusing freshmen who may enter in the fall. Careful monitoring of the bus system and gathering feedback are important for the bus transportation system moving forward

Phase 4: Much further in the future and in light of the Rutgers 2030 Master Plan, eventual "Transit Hubs" can be installed at the main campus centers. We believe our proposed bus system

serves as a better stepping-stone compared to the current bus system, and implementation of this proposal will allow for a smoother transition for future development of Rutgers University and any transportation model later to come.

V. Appendix

Additional Notes on the Bus Model:

- The proposed bus model will not change the NB1 or NB2 routes due to their special use.
- The Commuter route (C) was changed to match the functionality of this proposal.
- An additional purpose of the three-campus-center design of the routes was to separate the Cook/Douglass campus from the other main campuses because of the heavy amounts of traffic that build up around the Cook/Douglass campus. This allows for additional efficiency that may not necessarily appear in the model because traffic considerations are not included in the tables.
- The proposed model places two buses each in the Busch loop and the Douglass loop with the intent that one bus travels clockwise, while the other travels counterclockwise.
- The proposed College Ave loop was redesigned to go counter-clockwise because doing so will mean using right-turns only, which is faster compared to the current model which uses only left-turns around the College Avenue Campus.
- The models show that the proposed model still outperforms the current model during non-peak hours. Therefore, late night or weekend route scalability can easily be accomplished by stopping the intracampus loops and reducing the amount of intercampus travel buses.
- All proposed individual routes without a comparable Nextbus travel time component were given an additional minute in to avoid underestimation.
- The DCC stop refers to the College Hall bus stop, and the CCC stop refers to the Biel Road bus stop. The College Hall bus stop may need to be reworked for the proposed plan.

Additional Notes on the Bike-Share Program:

- The bike stations will be an outdoor enclosed area within close proximity to the main campus bus stops. The bike stations will be manned to facilitate check-out and check-in of bikes from 8 a.m. to 5 p.m. on weekdays.
- Students will be charged $20 per semester if they wish to join the program, which will allow them to check out a bicycle for 24 hours. This time limit will be extended for weekend bike usage, and a late-fee will apply for those who fail to return a bike in time. The time limit ensures that people are returning the bikes so that a supply is always available and to keep the bikes safe at a bike station from the weather or from thieves.
- Rutgers already has a bike-friendly infrastructure, so this plan would not require the enormous initial investments that come with most bike-share proposals.
- Customized Rutgers bicycle locks and bicycle helmets will be sold at competitive retail prices to encourage the use of bicycling. Any profits from these sales are not listed.
- As with the current bike-rental program, students will be billed for damaged, lost, or stolen bicycles and/or parts. This will help reduce costs over a ten-year maintenance period.

Table A: Current Bus System Travel Times and Route Breakdowns

Current Bus System - Summary of travel time for all routes							
A		**B**		**EE**		**F**	
Total Time	28.5	Total Time	24.5	Total Time	34.5	Total Time	27.5
# of Buses	4	# of Buses	6	# of Buses	5	# of Buses	6
Minutes/Bus	7.13	Minutes/Bus	4.08	Minutes/Bus	6.90	Minutes/Bus	4.58
Reported Min/Bus	7	Reported Min/Bus	5	Reported Min/Bus	9	Reported Min/Bus	5
H		**LX**		**REXB**		**REXL**	
Total Time	29.5	Total Time	26	Total Time	31.5	Total Time	32.5
# of Buses	5	# of Buses	9	# of Buses	4	# of Buses	5
Minutes/Bus	5.90	Minutes/Bus	2.89	Minutes/Bus	7.88	BUS/MIN	6.50
Reported Min/Bus	9	Reported Min/Bus	3	Reported Min/Bus	9	Reported Min/Bus	7

Current Bus System - Breakdown of individual travel time between bus stops							
A	**t**	**B**	**t**	**EE**	**t**	**F**	**t**
RSC	1.5	Quads	7	RSC	1.5	Scott Hall	5
Scott Hall	3	Werblin Back	1	Scott Hall	2	Public Safe South	2
SAC	5	Hill Center	2	Train Station	2	Cabaret	2
Visitor Center	1	Science Building	2	Paterson	2	Red Oak Lane	1.5
Stadium	2	Library SM	2	RockOff	2	Lipman	1
Werblin Back	1	Busch Suites	2	Public Safe South	2	Food Sciences	1
Hill Center	2	BCC	4.5	Cabaret	2	Biel Road	1
Science Buildings	2	Livi Plaza	2	Red Oak Lane	1.5	Henderson	1.5
Library SM	2	LSC	2	Lipman	1	Katzenbach	1
Busch Suites	2			Food Sciences	1	Gibbons	2
BCC	1			Biel Road	1	College Hall	5
Buell	1			Henderson	1.5	SAC	3
Werblin Main	5			Katzenbach	1	RSC	1.5
				Gibbons	2		
				College Hall	2		
				Public Safe North	2		
				Liberty Street	1		
				Paterson	2		
				Train Station	1		
				Zimmerli	1		
				SAC	3		
H	**t**	**LX**	**t**	**REXB**	**t**	**REXL**	**t**
Scott Hall	3	Quads	9	Lipman	3	Lipman	3
SAC	5	RSC	4	College Hall	10	College Hall	10
Werblin Main	2	Scott	3	Hill Center	2	Livi Plaza	2
Buell	1	SAC	6	ARC	2	LSC	12
BCC	2	Livi Plaza	2	Hill Center	9	Public Safe South	2
Davidson	2	LSC	2	Public Safe South	2	Cabaret	2
Library SM	2			Cabaret	2	Red Oak Lane	1.5
ARC	2			Red Oak Lane	1.5		
Hill Center	3						
Stadium	6						
RSC	1.5	"t" - time in minutes until arriving at next bus stop on list					

Table B: Proposed Bus System Travel Times and Individual Breakdown

Proposed Bus System - Summary of travel time for all routes							
Main (MM)		**Back (BK)**		**Downtown (EE)**			
Total Time	19	Total Time	21	Total Time	24.5		
# of Buses	8	# of Buses	8	# of Buses	4		
Minutes/Bus	2.38	Minutes/Bus	2.63	Minutes/Bus	6.13		
CA/Douglass (R)		**Busch/Douglass (X)**		**Livi/Douglass (TL)**			
Total Time	17	Total Time	24	Total Time	24		
# of Buses	4	# of Buses	4	# of Buses	4		
Minutes/Bus	4.25	Minutes/Bus	6.00	Minutes/Bus	6.00		
Busch (B)		**Douglass (D)**		**College Ave (CA)**		**Livingston (V)**	
Total Time	15	Total Time	12	Total Time	8.5	Total Time	7
# of Buses	2	# of Buses	2	# of Buses	1	# of Buses	1
Minutes/Bus	7.50	Minutes/Bus	6.00	Minutes/Bus	8.50	Minutes/Bus	7.00
Proposed Bus System - Breakdown of individual travel time between bus stops							
Main (MM)	**t**	**Back (BK)**	**t**	**Commuter (C)**		**Downtown (EE)**	
LSC	5	RSC	8	BCC		RSC	1.5
BCC	6	BCC	5	Werblin Main		Scott Hall	1
RSC	8	LSC	8	Stadium		Train Station	2
				Hill Center		Paterson	2
CA/Douglass (R)	**t**	**Busch/Douglass (X)**		Stadium		Rockoff	3
RSC	6	BCC	9			Public Safe	2
DCC	3	DCC	3			DCC	3
CCC	3	CCC	12			CCC	1
DCC	5					DCC	2
Busch (B)	**t**	**Douglass (D)**	**t**	**Livi/Douglass(TL)**	**t**	Public Safe	1
BCC	1	College Hall	1	LSC	10	Liberty	1
Buell	1	Cabaret	2	DCC	3	Train Station	3
Werblin Main	2	Red Oak Lane	1.5	CCC	11	SAC	2
Stadium	2	Lipman	1				
Werblin Back	1	Food Sciences	1	**College Ave (CA)**	**t**	**Livingston (V)**	**t**
Hill Center	2	Biel Road	1	RSC	2	LSC	2
Science Buildings	2	Henderson	1.5	SAC	3	Quads	3
Library SM	2	Katzenbach	1	Train Station	2	Livi Plaza	2
Busch Suites	2	Gibbons	2	Scott Hall	1.5		

Table C: Travel Time between Campus Centers (in minutes)

Campus-Center travel times (min)	Current	Proposed	%Decrease
BCC(A) → RSC	14.1	8.4	40.7%
RSC → BCC(H)	18.4	10.6	42.3%
LSC → RSC	13.9	10.6	23.5%
RSC → LSC	17.9	10.4	42.0%
BCC → LSC	10.6	7.6	28.0%
LSC → BCC	22.1	7.4	66.6%
BCC → DCC	20.9	15.0	28.1%
DCC → BCC	12.0	9.0	25.0%
LSC → DCC	27.0	16.0	40.7%
DCC → LSC	18.5	9.0	51.4%
RSC → DCC	24.1	10.3	57.4%
DCC → RSC	12.6	7.3	42.4%

Table D: Maximum Number of Students Transported Between Campuses in 20 Minutes

# Students Transported in 20 min	Current	Proposed	% Increase
Busch ↔ Livi	1102	1203	9.2%
Busch ↔ College Ave	930	1203	29.4%
Livi ↔ College Ave	1038	1203	15.8%
Busch ↔ Cook/Douglass	381	500	31.3%
Livi ↔ Cook/Douglass	462	500	8.3%
College Ave ↔ Cook/Douglass	1089	1196	9.8%
Totals	**5002**	**5805**	**16.1%**

Table C Formula: [Wait for Bus] + [Sum of Individual travel times]
Example calculation for travel time from LSC → RSC using:

- Current Model: Wait for LX bus plus LSC→Quads→RSC; 2.89 + 2 + 9 = 13.89 min
- Proposed Model: Wait for BACK bus plus LSC→RSC; 2.63 + 8 = 10.63 min

Table D Formula: [20 Minutes] / [Minutes/Bus] * [75 Students] for each time crossing campuses
Example calculation for # students transported in 20 min for "Livi↔College ave" using:

- Current Model: [20 minutes / 2.89 Minutes/bus]*[75 students]*[2 since bus goes both ways] = 1038 students
- Proposed Model: [20 minutes / 2.38 from Main]*[75 students] + [20 minutes / 2.63 from Back]*[75 students] = 1203 students

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Proposed Bus Route Model