Reducing Personal Vehicle Kilometers Travelled to Decrease Air Pollution in Durham, NC

by

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Abstract

Durham, North Carolina is at the center of the metropolitan region known as the Research Triangle. This area is experiencing rapid and sprawling growth. In addition, there is a lack of substantial public transportation, which results in a high level of reliance on personal automobiles. This research aims to examine how reliance on personal automobiles in one aspect of the lives of residents, the daily work commute, can be reduced in order to reduce aggregate vehicle kilometers travelled (VKTs). The transportation mode choices of walking, bicycling, busing, carpooling and vanpooling were examined as potential mode choices that commuters could switch to if given an economic incentive to do so.

A set of equations were developed based on EPA mobile source emissions models and regional data to determine how reductions in VKTs could affect air pollution emissions. A contingent choice survey was developed and sent, via email, to a sample of employees of Duke University and Hospital, in order to determine the marginal willingness to accept payment for an alternative commute. A mode choice model was developed using logit regression techniques based on the survey results to extrapolate the behaviors to employees of Duke at large and commuters to the City of Durham. A log-transformed bid variable was determined to be the most appropriate functional form to predict the likelihood of switching modes. Finally, marginal economic damages of air pollutants were obtained from peer-reviewed research and the economically efficient level of potential benefits were estimated.

The air quality models showed that the criteria air pollutants examined were dealt with well under existing policy. Concerning Carbon Dioxide, the resulting calculations showed that only when the marginal damages of pollution are quite high do the equated marginal benefits provided to a person to reduce their commuting footprint begin to have substantial impacts on VKTs.

Keywords:

Transportation, Air Quality, LUTRAQ, Greenhouse Gasses, Carbon Dioxide, Criteria Air Pollution, Alternative Transportation, Mode Choice, Commuting, VKT Reduction, Dichotomous Choice, Contingent Valuation, Durham, Duke, Research Triangle

IRB:

This was an IRB exempt study. If you require details concerning this please contact the author.

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Introduction

The Research Triangle is a region in central North Carolina that encompasses Raleigh, Durham, Chapel Hill and the surrounding developed areas (including Cary, Apex, Carrboro, and Hillsborough). Durham, Wake and Orange counties are considered the core counties of the triangle, but Alamance, Chatham, Franklin, Granville, Harnett, Johnston, Lee, Moore, Nash, and Person get included in the greater region due to their proximity to the major urban areas in the region. A map of this region can be seen in Figure 1. Over the past few decades this region has been experiencing large growth in population and development, similar to what is occurring in other southern cities. Due to factors to be discussed later, this area is particularly prone to sprawling development and has a transportation network that promotes automobile dependence. The latter is a particular issue in the context of increases in air pollution, both in relation to the so called "criteria air pollutants" and green house gasses (GHGs). Planners and policies makers have no short term plans to bring forth a system that is less automobile dependent, meaning we would expect to see rising annual air pollution rates in the near term future.

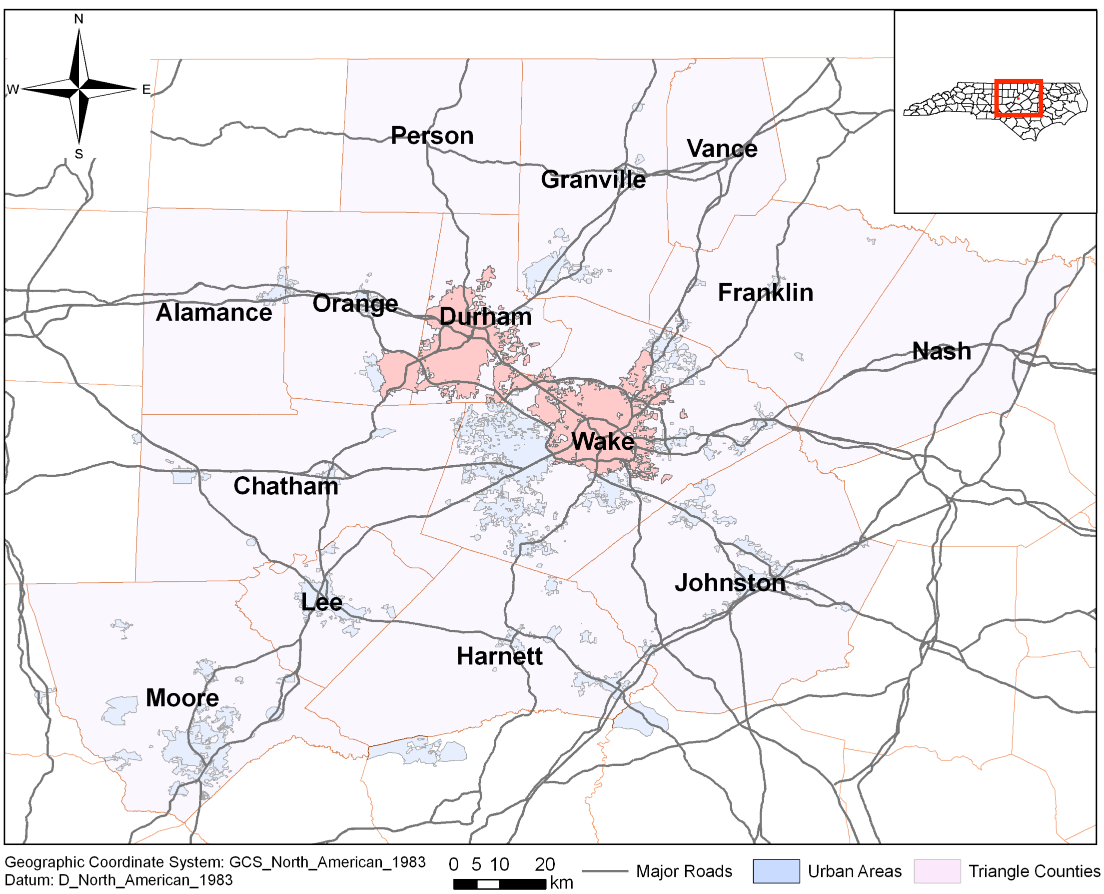

Figure 1: The Greater Research Triangle Region

This paper will first discuss background and trends related to the current transportation policies in the Research Triangle. Then air pollution models were examined under the assumptions that travel trends will continue as is to develop a picture as to the amount of air pollution arising from mobile source in the region, and from personal light duty vehicles in particular. After that the effects of Vehicle Kilometers travelled (VKT) reductions on air pollution levels were examined. Next several proposed short-term VKT reduction mechanisms were discussed. Following that a transportation mode choice model was employed based on the results of a survey taken by employees at Duke University and Hospital that hold parking permits to determine how many users will reduce their driving as the result of receiving compensation for commuting via said reduction mechanisms. Finally, the costs to the region as a whole for each reduction mechanism were calculated to determine how much compensation was economically efficient to provide to commuters.

Research Triangle Background

Governing Bodies

Political Structure

The dynamic that exists between the various political entities greatly affects the way transportation and land use have developed over the years. The Research Triangle consists of several mid-sized municipalities; each of these has their distinct civic government. There are then counties, which are run by commissioners. Depending on the organization that is working in the region, the Triangle could be considered to consist of anywhere from 3 to 13 counties. In addition, Durham and Raleigh each cross county lines, albeit only slightly. To assist in the management of the counties, councils of government were created in 1972 to create consensus among several counties in regional issues, of which Triangle J covers the region. Finally, above the 17 councils of government, you have the state, the capital of which is located in the region. The counties and municipalities in the state operate under a modified Dillon Rule, creating the potential for weak local organizations (Krane, Hill et al. 2001).

Transportation Agencies

There are several tiers and divisions of transportation planning agencies in the region that further exacerbate the lack of the comprehensive transportation and land use planning. At the state level exists the North Carolina Department of Transportation (NCDOT), which is charged with providing "a safe modern and integrated transportation system that expands opportunities for citizens across the state (State of North Carolina 2007)." Two Metropolitan Planning Organizations (MPOs), the Capital Area MPO (CAMPO) in Raleigh and the Durham-Chapel Hill-Carrboro MPO (DCHC MPO) exist at the regional level. Though MPOs have taken on more authority in local land use decisions around the country CAMPO and DCHC MPO have not been very successful at exerting much influence in this arena and have historically have had more problems working together (Atash 1996; Wells 2006). There also may be changes in the way in which MPOs interact with land use planning and the environment as the result of legislation that will be discussed later.

Concerning public transit systems, five municipalities (Raleigh, Durham, Chapel Hill/Carrboro, and Cary) have their own transit authority. There are also two university-run transit systems (Duke University and NC State). Given that there is transit need between each of the municipalities, an intermediate transit agency, Triangle Transit runs buses and vanpools that link the various city's services.

Table 1: Transit agencies in the Greater Triangle Region

System	NTD ID	Town	Service Area (km2)	Service Area Pop.
Capital Area Transit	4007	Raleigh	324	347,729
Chapel Hill Transit	4051	Chapel Hill	65	71,069
Durham Area Transit Authority	4087	Durham	241	187,000
Duke University	-	Durham	-	-
NC State University	4147	Raleigh	23	40,000
Triangle Transit	4108	RTP	3948	1,002,876
C-Tran	4143	Cary	129	107,973

Interactions between Organizations
"In the Triangle region of the State, the relationship between Triangle Transit and the two MPOs can be can be characterized as independent whereby each entity conducts planning from its own perspective (Wells 2006)." This interaction has created problems, especially since the two MPOs have differing philosophies on planning responsibilities and, in addition, perform their air quality management differently, despite being in the same airshed (Wells 2006). There is also anecdotal evidence of problems in the relationships between NCDOT and Triangle Transit in regards to their approaches towards public transit (McDonough 2009).

Trends
Population Trends
North Carolina had an estimated population of 9,222,414 in 2008 according to the U.S. Census Bureau. Population models predict that this number will increase by almost 38.3%, to 12,753,597, residents by 2029 (North Carolina Office of State Budget and Management 2009). The Research Triangle is expected to see even more substantial increases in population with the populations of Wake and Durham counties expected to increase by 85.7% and 54.9% to 1,609,306 and 406,895, both respectively (North Carolina Office of State Budget and Management 2009). Orange County is still expected to see growth in population, though at a rate slightly less than that of North Carolina as a whole.

Additionally there are similar, but less stark trends in the population of working aged persons (defined as 18-65) and driving aged persons (defined as 16+). Based on 2009 rather than 2008 numbers there is expected to be a 29.7% and 17. 8% increase in the working aged population for Wake and Durham counties by 2029 respectively. Adjacent counties range in working aged population increases from 28.8% in Johnston County to 7.3% in Orange County. Also 39.4% and 24.6% increases are expected in driving aged populations from 2009 to 2029 in Wake and Durham counties respectively. Adjacent counties range in driving aged population increases from 35.2% in Johnston County to 15.5% in Lee County. These trends imply that there will be substantial increases in the vehicles on the road, and commuters in particular, as well as an increase in demand for single family homes.

Table 2: Changes in populations of the Greater Research Triangle Region from 2008-2029 (estimate) (North Carolina Office of State Budget and Management 2009)

	Total Population			Working Aged Population			Driving Aged Population		
	2009	**2029**	**Growth**	**2009**	**2029**	**Growth**	**2009**	**2029**	**Growth**
Alamance	148,053	215,515	45.57%	94,228	111,746	18.59%	118,667	145,042	22.23%
Chatham	63,077	93,799	48.71%	39,609	46,852	18.29%	50,262	62,236	23.82%
Durham	262,715	406,895	54.88%	173,422	204,265	17.78%	206,323	257,115	24.62%
Franklin	58,927	80,533	36.67%	38,491	42,681	10.89%	46,990	55,114	17.29%
Granville	57,044	69,392	21.65%	37,416	38,008	1.58%	46,064	49,222	6.86%
Harnett	112,030	179,280	60.03%	72,174	91,077	26.19%	87,610	114,272	30.43%
Johnston	163,428	44,572	- 72.73%	107,778	138,862	28.84%	130,364	176,247	35.20%
Lee	59,091	82,489	39.60%	36,143	40,749	12.74%	45,270	53,039	17.16%
Moore	85,608	116,509	36.10%	50,991	58,907	15.52%	70,742	81,734	15.54%
Nash	93,674	120,259	28.38%	60,324	64,844	7.49%	75,224	84,555	12.40%
Orange	126,532	167,679	32.52%	93,583	100,394	7.28%	109,743	126,846	15.58%
Person	37,438	39,098	4.43%	23,829	22,747	-4.54%	30,216	30,593	1.25%
Vance	42,891	44,232	3.13%	26,330	25,329	-3.80%	33,249	33,299	0.15%
Wake	866,410	1,609,306	85.74%	597,163	774,722	29.73%	702,104	980,724	39.68%

Economic Trends

There has been a trend towards job growth in the core of the region despite the sagging national economy. Most other counties in the region saw substantial increases in employment from 2001-2009 as well, as can be seen in Table 3. Unfortunately the Employment Security Commission of North Carolina does not have employment projections, but even if the trends do not continue to such a degree, the region will still see substantial job growth in the future.

Table 3: Employment in the Greater Research Triangle Region from 2001-2009 (Employment Security Commission 2010)

	2009	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**Growth**
Alamance	59,880	59,840	58,010	52,550	53,290	60,500	59,780	64,710	67,900	-11.81%
Chatham	17,800	18,440	18,350	20,020	15,240	14,270	16,090	14,810	19,210	-7.34%
Durham	190,200	183,230	176,460	160,540	165,250	145,610	148,300	152,390	157,040	21.12%
Franklin	20,550	16,430	14,940	11,800	10,700	10,200	11,470	12,210	8,440	143.48%
Granville	16,860	17,620	16,990	14,540	14,610	14,220	15,070	14,810	8,860	90.29%
Harnett	21,330	22,920	23,540	22,610	22,820	23,380	23,530	21,540	24,380	-12.51%
Johnston	43,250	40,920	38,090	36,910	32,700	29,990	29,280	32,140	22,730	90.28%
Lee	28,420	27,540	26,530	27,130	25,890	27,100	25,190	26,090	22,150	28.31%
Moore	32,880	32,370	31,740	30,500	30,260	31,220	31,920	30,220	21,760	51.10%
Nash	40,340	37,420	39,180	40,850	38,040	40,780	39,930	34,210	34,630	16.49%
Orange	59,870	54,710	53,150	52,710	53,620	57,440	60,880	84,690	38,500	55.51%
Person	11,160	12,070	12,490	11,490	13,970	14,810	13,630	11,200	10,940	2.01%
Vance	15,770	16,980	18,480	16,460	16,800	17,670	18,680	22,490	17,810	-11.45%
Wake	451,770	448,260	424,450	407,290	390,140	403,770	395,320	378,760	393,650	14.76%

Development Trends

Sprawl, which can be defined on having four criteria:

> *a population that is widely dispersed in low-density development;*
> *rigidly separated homes, shops, and workplaces;*
> *a network of roads marked by huge blocks and poor access; and*
> *a lack of well-defined, thriving activity centers, such as downtowns and town centers*

has been increasing in the region, in fact a 2002 report ranked the region as the third most sprawling in the nation (Ewing, Pendall et al. 2002). To demonstrate what would happen if existing trends continue a logit regression was run on several key variables (slope, elevation, proximity to roads, proximity to major roads, presence of agriculture, and proximity to developed areas) to predict which areas would be developed in the future. These predictions were based on the 1992 and 2001 USGS land use land cover maps and a technique that was developed from a paper by David Wear and Paul Bolstad (Wear and Bolstad 1998). If these predictions hold true the region will become even more urbanized and sprawling as time progresses as can be seen in Figure 2, though it will be centralized around the major highways. One source of error is that land values were not taken into account, which could have an effect on the level of centralization around the highway system. The values obtained from the logit model can be viewed in Appendix D.

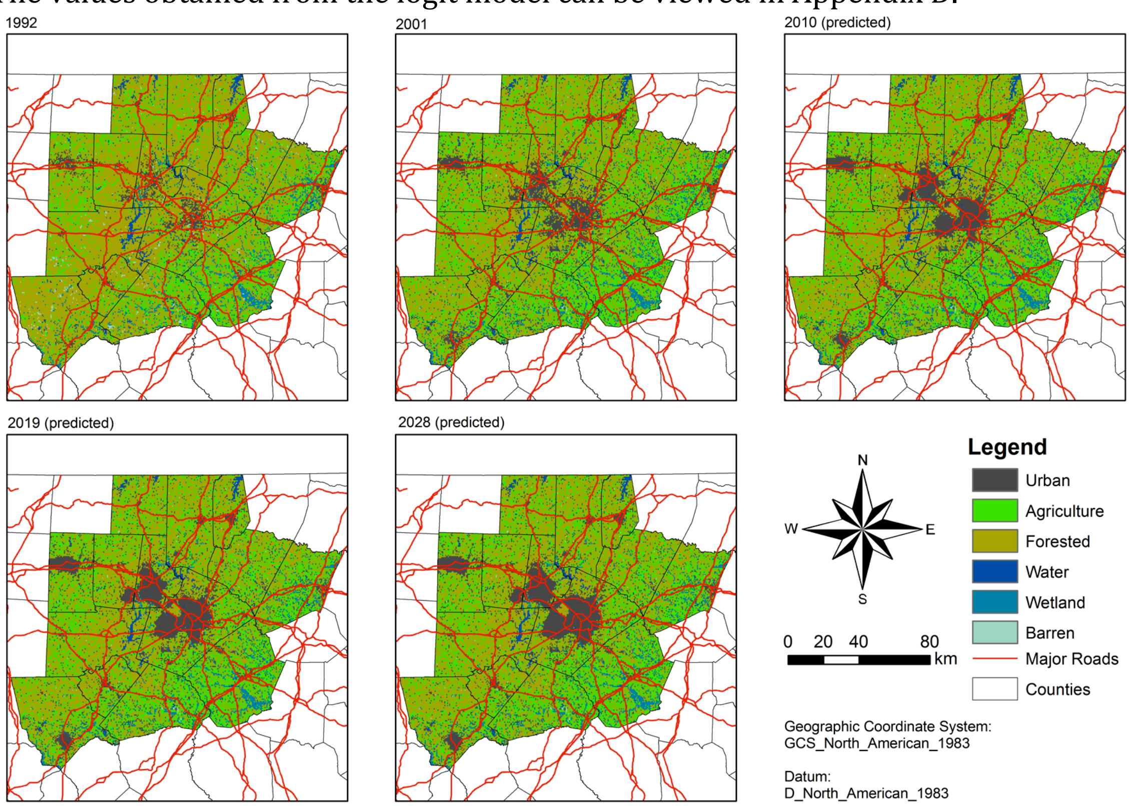

Figure 2: Changes in land use in the Greater Research Triangle from 1992-2028

Transit Trends

The state transportation system is dominated by the highway system. The highway system is about 79,000 miles, the second largest state-maintained system in the nation and is augmented by the 14th largest share of the federal highway system (Federal Highway Administration 2001; State of North Carolina 2007). This is particularly striking since North Carolina is the 28th largest state by area. Figure 3 presents a more graphical view of the extent of the areas road systems.

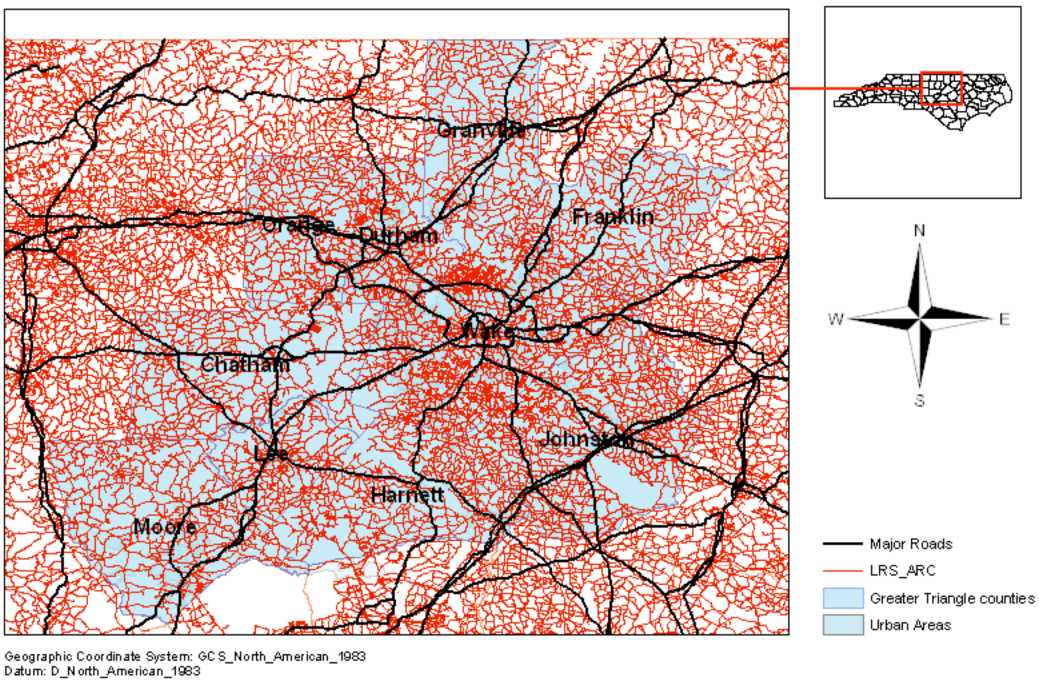

Figure 3: Road system in the Greater Research Triangle Region

The public transit systems seem rather lacking but there are at least 7 university, city, or regionally oriented public transit entities. They might appear insignificant, but when you consider that the largest counties by population in the state in 1950 were 6-8 times smaller than a mid-sized city such as Baltimore, it is no wonder that an institution of buses and public transit was not developing to the same extent as in other major east coast cities. Furthermore, there very likely remain perceptions of buses in a negative context for a variety of historical and cultural reasons.

There has been an even more recent trend of the development of rail systems; however this trend is far from significant. The only rail transit to go into service in the state is a 15-station, 1-line system in Charlotte, the most populous and second densest metropolitan area in the state. Other rail systems have been discussed, but as we shall see later their future remains tenuous.

Pollution Trends

8 counties in the triangle region are currently in Clean Air Act (CAA) maintenance status for the 8-hour tropospheric Ozone (O_3) standard. Durham, Wake, and Granville counties are also in maintenance status for the 1-hour tropospheric O_3

standard (Environmental Protection Agency 2009). They were placed into maintenance status on December 26, 2007 (Capital Area MPO and Durham/Chapel Hill/Carrboro MPO 2009). Furthermore, Wake and Durham counties are both in maintenance status for Carbon Monoxide (CO). In addition, VOCs and NOx are the two prominent precursors to tropospheric O_3, with the limiting pollutant varying in relation to the ratio of both of these substances found in the airshed (Finlayson-Pitts and Pitts 1993). There are large amounts of loblolly pines that produce VOCs in the region and it has been found that high levels of O_3 can be attributed to the biogenic

Table 4: Clean Air Act attainment status in the Greater Research Triangle Region in 2009 (Environmental Protection Agency 2009)

County	Alamance	Chatham	Durham	Franklin	Granville	Harnett	Johnston
1-hour O_3	NA		M		M		
8-hour O_3		M	M	M	M		M
CO			M				

County	Lee	Moore	Nash	Orange	Person	Vance	Wake
1-hour O_3							M
8-hour O_3				M	M		M
CO							M

NA - Non Attainment/M - Maintenance

VOCs emitted in a pine dominated region like the southeastern United States (Kang, Aneja et al. 2004). In fact, it was expected in a 2004 report that 73% of VOCs emissions will come from biogenic sources in the region in 2007 (Division of Air Quality 2004). This is in contrast to the limiting agent, NOx, which largely comes from anthropogenic sources. In the same report it was expected that in 2007 mobile sources will produce 55% of the NOx in the region and personal vehicles (light duty gasoline vehicles and class 1 trucks) will produce 15% of the NOx in the region (Division of Air Quality 2004).

The Triangle region currently teeters on the edge of nonattainment in relation to tropospheric O_3 pollution. Though, in 2009, all of the area's counties were in Clean Air Act attainment, excepting Alamance County. That being said, it is expected that standards for most of the criteria pollutants will increase in stringency by the Obama administration because of an increased reliance on science based evidence, which would make it tough for an area that is in maintenance to continue to be so (Gardner 2009). Because of this additional policies could need to be instituted to reduce total air pollution from automobiles in the region. More details concerning regional air quality will be discussed in subsequent portions of this paper.

Current Transit Plans

MPOs are required under the Intermodal Surface Transportation Efficiency Act (ISTEA) to create two financially constrained documents in regards to transportation planning, The Transportation Improvement Plan (TIP) and the Constrained Long Range Plan (CLRP), both of which should take land use into consideration to an extent (Goetz, Dempsey et al. 2002). States are also required to produce similar documents at similar intervals. In addition Triangle Transit also produced both short (5-year) and long term (30-year) plans for its organization.

Short Range Transit Plans

There are expectations that regional bus service will expand, in particular in regards to express services. "New long-distance services will be designed to be express routes provided with over-the-road coaches for comfort and reliability (Commuter Resources Department 2008)." The idea of increasing comforts to provide extra comforts **t**o increase the utility of the ridership on long commutes could potentially win increased ridership. Essentially Triangle Transit is staging their own flavor of Bus Rapid Transit (BRT) that attempts to accommodate the long distance commuting to a variety of centers that are developing as edge cities such as Zebulon and Wake Forest.

There are no short term plans to construct a regional rail system. "In August 2006, the Triangle Transit Board decided to withdraw the regional rail project intended to connect Raleigh, Cary, Research Triangle Park, and Durham from consideration for federal funding (Commuter Resources Department 2008)." The reasoning for this laid in the lack of expectation of New Start funding, which was due to changes in the rules involving New Start funding that required adherence to a stricter benefit-cost standard.

There could be some debate as to what priority is given to regional public transit projects. The 2009-2015 TIP, was approved on August 20, 2008 by CAMPO. In it there are a total of 33 unfunded projects, all but five of which involve public transit. In contrast, only 1 project that involves public transit is considered funded.

Long Range Transit Plans

An important action was undertaken by the North Carolina General Assembly in August of 2009 in regards to the future of transit in the Triangle. The Congestion Relief/Intermodal Transport Fund (NC SL 2009-527) was signed into law on 8/27/2009. This piece of legislation allows the three core triangle counties (as well as the triad counties) to put up for a referendum a ½ cent sales tax that is "to be used only for public transportation systems (NC SL 2009-527)." There are expectations that these referenda will be put up to vote in the 2010 election, but there will be issues if only a subset of the three Triangle counties pass the tax (Freemark 2009).

Several organizations in the Triangle, though a Special Transportation Advisory Committee (STAC), produced a long term Regional Transit Vision Plan in May 2008. This plan outlines a vision for an enhanced intermodal transit network that includes commuter rail and bus network expansions. The three over arching goals of this plan are to create transit that circulates within a municipality, serves long haul commuters, and connects transit-friendly neighborhoods (Special Transit Advisory Commission 2008). Included in this plan are recommendations for mode choice, priority corridors, and even encouragement to include land use in decision making. However this plan is only a vision statement as they say themselves:

> *The Regional Transit Vision Plan is ambitious, and although the entire plan may not be built until 2035, it can be built. The STAC exhorts the region to take a long-range, regional perspective and seize the opportunity to fully implement this "game-changing investment" in our future (Special Transit Advisory Commission 2008).*

In addition to the Triangle Transit LRTP, there exists the federally mandated LRTP that was produced on May 20, 2009. CAMPO and DCHC MPO worked in conjunction to develop this plan and also developed a less fiscally constrained Comprehensive Transportation Plan (CTP) that is required by state law, to complement the 2035 LRTP. This is a demonstration of an integrated vision for the future for the region and was produced by a group with more clout in regional transit issues. When one looks through the lists of projects included in the 2035 LRTP one only finds expansions and improvements to bus system included (including the creation of BRT style system). However, changes to the new start rules that were made in 2010 by the Obama administration and perceptions that BRT does not spur economic development may push local decision makers back towards developing a regional rail system in the long term (Gulley 2010).

Baseline Air Quality Modeling

Methods & Data

To perform the task of modeling mobile emissions in the region DraftMOVES2009 was employed. DraftMOVES2009 is beta software of the model that the Environmental Protection Agency suggests should be used to model mobile emissions once the final version, formally titled MOVES2010, is released at the end of 2009 (Office of Transportation and Air Quality 2009). This software is replacing a piece of air quality modeling software called Mobile 6.

Inputs

Age distribution of the vehicle fleet is the first dataset that is necessary to run DraftMOVES2009. To create this data set, age distributions used in Mobile6 by the North Carolina Department of Air Quality (NCDAQ) were used as a starting point. These input had separate distributions for diesel and gasoline vehicles, but DraftMOVES2009 has a separate data input to manage importing fuel types so the gasoline and diesel vehicle counts by age were summed and were employed to create the distribution percentages. Data were provided for Durham County. The Mobile 6 datasets did not include information on transit or school buses. Baseline data for the transit systems were obtained from the National Transit Database (NTD). Since the size of the fleets are so small compared to those of automobiles future age distributions were modeled individually, with fleet expansion being predicted to occur at the same rate as the personal automobile fleet in the region.

School bus data was obtained from the North Carolina Department of Public Instruction (NCDOPI).

Table 5: Data inputs for DraftMOVES2009 Model

Input	Description	Data Source
Age Distribution	The percentage of the 30 age classes for each source type on the road in a given year. Each age class spans one model year, except for one which spans the 30th year and beyond.	School bus age distributions: NCDOPI Transit bus age distributions: NTD Remaining age distributions: NCDOAQ
Average Speed Distribution	The percentage of 16 speed bins that occur for each source type on each road type at every hour of the day. Each hour has a separate entry for weekdays and weekends. The speed bins are 5 mph, except the first one, which is only from 0-2.5 mph and the last one which is everything greater than 72.5 mph.	MOVES default
Fuel Supply	The percentage of the market share of various fuel formulation types for every month of the year.	MOVES default
Meteorology Data	The temperature and relative humidity for every hour of the day. There are 12 sets of these, one for every month, with the hourly data being averaged for the month.	NCSCO
Ramp Fraction	The percentage of ramps for each road type.	MOVES default
Road Type Distribution	The percentage of VKTs that are driven by each source type on each of the 5 road types. The road types are off-network (e.g. parking lots), rural restricted, rural unrestricted, urban restricted, urban unrestricted. Restricted essentially means freeways.	ITRE
Source Type Population	The number of vehicles for each source type. Examples of source types are personal automobiles, school buses, motorcycles, and long haul trucks.	ITRE & NCOSMB
Vehicle Type VMT	The number of VKTs that are driven using one of 6 HPMS vehicle type. An HPMS vehicle type is an aggregation of source types (e.g. instead of school buses, transit buses, and intercity buses being separate types they are combined).	ITRE & NCOSMB

Data sets for both the average speed distribution and the fuel supply could not be obtained. It was assumed that the distribution data for each county were not entirely different from those at the national scale so the defaults that were provided with the software for generalized national modeling were used.

Meteorological data were also necessary to run DraftMOVES2009. The data requirements in this instance are for monthly averages for each hour of the day of relative humidity and temperature. The State Climate Office of North Carolina (NCSCO) provided hourly data from December of 2008 – November of 2009 for

Durham County. These datasets were processed using an R script to calculate the monthly averages for each hour.

Road distribution data were the next set of data included. Projections of vehicle counts for many classes of roads in the area examined were provided by The Institute for Transportation Research and Education (ITRE) at North Carolina State University (NCSU) and were developed for the aforementioned LRTP. The road categories were much more detailed than required by DraftMOVES2009 and were aggregated to make the data compatible.

The next data import involved the counts associated with different source types (i.e. vehicle classes) in 2008. The counts for each type of vehicle were based on the same files that were used to determine the road distribution. In addition these source type distributions were for the current year. To create data for the future distribution, increases in the percentage of driving aged North Carolinians in a given year that were obtained from the North Carolina Office of State Management & Budget (NCOSMB) were multiplied by the size of the current fleets to crudely estimate increases in fleet size over time.

Caveats on Inputs

In regards to the age distributions, the model did not take into account changes to the age distribution that resulted from the Cash for Clunkers program (Godfrey 2009). In addition DraftMOVES2009 is not yet programmatically ready to consider motorcycles, so motorcycle data were not imported (Assessment and Standards Division 2009).

There could be a source of error due to using the default age source distribution and fuel types. Not including more specific fuel types are problematic and should result in differing levels of emissions being predicted. This is due to the fact that many fuel sources that could be used in the fuel (e.g. ethanol, electricity, etc) could further reduce or increase emission levels or certain pollutants from mobile sources depending on the type of fuel. For instance, it has been found that ethanol use decreases PM emissions, while increasing NOx emissions in heavy-duty diesel engines (Shi, Pang et al. 2006). In addition, less specific average speed distributions would result in the emission inventories being on the low side since average speeds tend to be lower in metropolitan areas due to congestion and this would result in increases in emission rates.

Finally, there was no way to determine how many of each vehicle class are short or long haul trucks, and there is no decision put into place as to how to accomplish this at the NCDAQ, so it was assumed that the percentage of short haul and long haul trucks was roughly akin to the percentage of gasoline and diesel fueled trucks and this was used to create these percentages (Godfrey 2009).

Results

All Vehicle Classes

The steady decrease in total emissions in each of the counties that were modeled is a very interesting discovery. In only 7 years, from 2008-2015, the model predicts that there will be reductions in the total PM and NOx emissions from mobile sources in Durham despite steady increases in the number of VKTs. A representative at the EPA that works on the DraftMOVES2009 model stated that these substantial reductions are largely due to changes in emission standards for long-haul vehicles that went into effect as part of the 2007 Heavy-Duty Highway Final Rule (Beardsley 2009).

These substantial reductions would mean that the region will not have great problems meeting criteria pollution standards, even if region continues to develop in such an automobile-centric, sprawling fashion. This is good news for air quality emissions in the region, though further research would certainly be necessary to determine if the reductions in NOx would have a substantial enough effect on reducing tropospheric O_3. However, CO_2 emissions continue to rise as time progresses for vehicle classes in total. As a result of the potential for increased stringency in criteria air pollutant standards, as well as the need to reduce CO_2 emissions, we will examine in more depth air pollution from light duty vehicles.

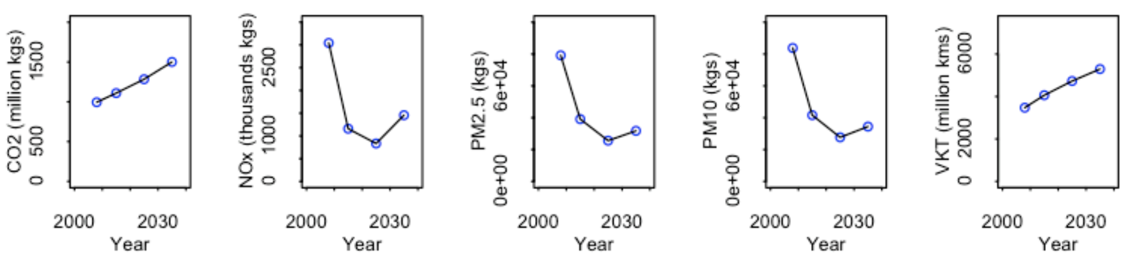

Figure 4: Baseline emissions for Durham County in 2008, 2015, 2025, and 2035

Light Duty Vehicles

The trends in CO_2 emissions from light duty vehicles follow those of the predicted VKTs almost perfectly as time progresses. The relationship between VKTs and NOx and time is a less clear, though NOx emissions from light duty vehicles are decreasing until 2025. Annual particulate matter emissions follow a similar pattern. It is the expectation that levels of total PM and NOx emissions from light duty vehicles are impacted largely by the mix of the ages of the vehicles in the fleet in any given year since pollution levels have historically decreased due to technology improvements (National Academy of Sciences 2006).

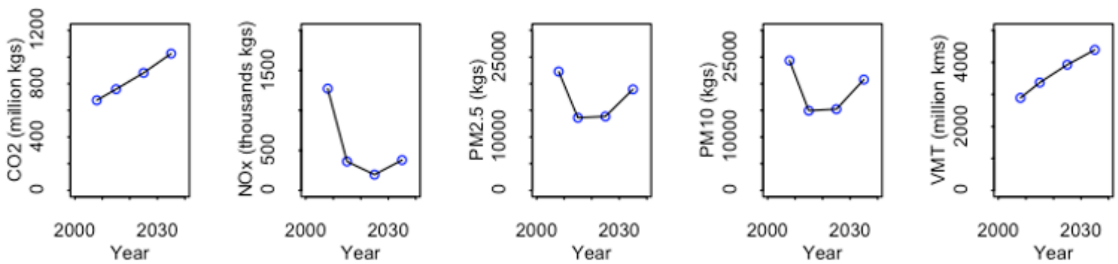

Figure 5: Baseline automobile emissions for Durham County in 2008, 2015, 2025, and 2035

Changes in Air Quality from VKT Reductions

Methods & Data

The data used to model how changes in VKTs impacted emissions was essentially the same as was used in the baseline emissions, the only difference being that VKTs from automobiles were reduced to model the effects of VKT reductions from light duty vehicles. Additional model runs were completed to examine VKT reductions of 10%, 30%, and 50% from the base level for 2008, 2015, and 2025. This was done under the expectation that an OLS model could be developed using the results from these model runs that would be applicable for determining the levels of pollution for any given year and VKT. The equation used for this purpose can be seen in Equation 1. This is essentially recreating the model in a form that allows for easier manipulation.

Equation 1: Simplified pollution emissions model

$$Pollution = \alpha \times dist + \beta \times year + \chi \times year^2 + \varepsilon$$

Results

Upon examining the results it was determined that a linear reduction in VKTs resulted in a linear reduction in each type of pollutant in any given year. This behavior can be observed in Figure 6.

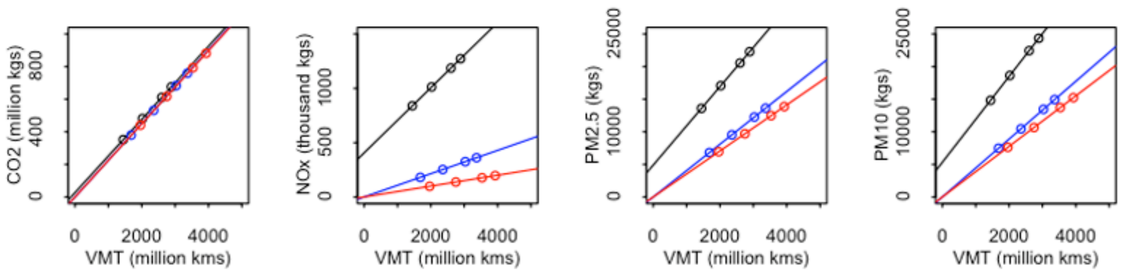

Figure 6: Changes in emissions in Durham County due to decreasing in VKTs in 2008 (black), 2015 (blue), and 2025 (red)

An OLS model was subsequently run on all of the data points obtained for each county and pollutant using VKTs, the year, and the $year^2$ as explanatory variables, with the year acting as a proxy for the model year distributions of the entire vehicle fleet. The resulting expressions appear to allow for reasonable approximations of pollution reductions in a given year based on VKTs and can be seen in Table 6.

Table 6: Formulas for the quantity of pollutants in kilograms, where distance is in millions of VKTs

Pollutant	Adj. R^2	Formula
CO_2 (millions)	1.0000	0.2247176 * dist - 783.1081 * year + 0.1937737 * $year^2$ + 791199.6
NOx (thousands)	0.9673	0.1279778 * dist - 24400 * year + 6.023556 * $year^2$ + 24600000
$PM_{2.5}$	0.9730	4.287469 * dist - 279629.7 * year + 69.17397 * $year^2$ + 283000000
PM_{10}	0.9731	4.701258 * dist - 304024.8 * year + 75.20878 * $year^2$ + 30700a0000

Potential Reduction Mechanisms

In this section several mechanisms to reduce VKTs will be discussed. Firstly, general assumptions about each reduction mechanism will be presented. This will be followed by information specific to each reduction mechanism.

General Assumptions

It is expected that these incentives will only include financial inducements for individuals that undertake the VKT reduction, since marketing costs would be similar across the mechanisms. It is also being assumed that certain individuals already receive a high utility from alternative commutes and, as a result, already undertake such commutes. These people are being excluded from the analysis.

There are some expectations about related services that would be required to create a functioning alternative commuting system in the region. The necessity of considering an emergency ride home program would be required to alleviate the disutility associated with fearing an emergency during the workday for nearly all of the mechanisms. Limited daily parking passes would also be necessary to allow workers a limited amount of flexibility to deal with inclement weather, the need to run personal trips during or after work occasionally, and other similar situations. Both of these programs currently exist and were included in the analysis.

Assumptions Specific to Reduction Mechanisms

Carpooling

Region wide, carpools on average contain 2.13 commuters and it was assumed that carpools for the sake of this analysis consist of that many people (Yasukochi 2010). The car being used in the carpool was assumed to be an average age and have average fuel efficiency. This mechanism was included in the survey instrument developed to analyze the choice model.

Vanpooling

Region wide, vanpools on average contain 10.4 commuters and it was assumed that vanpools for the sake of this analysis consist of that many people (Gleason 2010). Also vans are closer to light duty trucks resulting in the addition of one light duty gasoline vehicle per removal of every 10.4 automobiles. This mechanism was included in the survey instrument developed to analyze the choice model.

Busing

Bus commuting results in one automobile commute being removed from the inventory for every person that completes the switch. Also an addition of 1 hybrid bus will be added for every 32 automobiles removed. Hybrid buses are being used for this calculation since DATA's most recent bus purchases were Gillig Hybrid buses. This mechanism was included in the survey instrument developed to analyze the choice model.

Bicycling

When a commuter switches to a bicycle commute it results in the removal of one automobile from the inventory. However, bicycle commuting very likely follows a seasonal cycle with increases in the willingness to commute being highest during the more temperate spring and autumn months. Unfortunately analyzing this factor was beyond the scope of this project, so it was assumed that commuting patterns do not vary by season. There is a limit to how far people would be willing to commute using a bicycle that is far less than that of an automobile, but that will not be factored into this analysis. This mechanism was included in the survey instrument developed to analyze the choice model.

Walking

When a commuter switches to a walking commute it results in the removal of one automobile from the inventory. However, walking commuting very likely follows a seasonal cycle with increases in the willingness to commute being highest during the more temperate spring and autumn months. Unfortunately analyzing this factor was beyond the scope of this project, so it was assumed that commuting patterns do not vary by season. This mechanism was included in the survey instrument developed to analyze the choice model.

Other Alternative Mechanisms

There are a whole host of other alternative commutes that could be considered when analyzing reductions. Some of the more popular ones, such as telecommuting or reduced day work week, involve reducing the number of days that the individual physically commutes to work. However, since the ability to telecommute or function on a reduced work week is dependent on such factors as the type of work being performed, the social dynamic of the office, and internal security issues we will not examine them as options in the mode choice model (Mokhtarian and Salomon 1996). Another form of alternative commuting that is being excluded from the analysis is the use of a motorcycle or moped. This is because DraftMoves2009 does not include the ability to model most emissions from motorcycles so approximations will have to be included for this change in the emissions inventory.

Transportation Mode Choice Model

In this section a transportation mode choice model was developed to determine how many users could potentially switch to the aforementioned mode choices and under what incentives would be required.

Methods & Data

Survey Data

Several potential data sources were explored for use in this research. These included an annual transit demand survey produced due to a Durham County ordinance, a travel diary survey implemented by a transportation consulting firm, and a self produced contingent valuation email survey. First the pros and cons of each of these data sources were discussed followed by a focus on the data set that was eventually chosen for further analysis.

The first source that was explored was the annual Commute Trip Reduction Program (CTRP) survey produced by Durham County. In 1999 the Durham County Board of Commissions passed a Commute Trip Reduction Program ordinance that required, among other things, that every employer in Durham County that employed more than 100 persons were required to implement an annual standardized survey to examine commuting behavior (Article V). Results from the surveys completed in 2007 and 2008 contained geocodable addresses for 6038 and 5365 records respectively (Triangle Transit Commuter Resources Department 2008). However, this survey was not implemented using a random sample, is limited to only large employers, very likely exhibits a strong self selection bias, and contained no demographic variables. Due to these factors this source was discarded.

The second source that was explored was a travel diary survey conducted in 2005-2006 by the transportation consulting in conjunction with ITRE, on behalf of the two MPOs, NCDOT, and Triangle Transit, to model transit demand in the region. This data set had the benefits of being region-wide, implemented using proper random sampling techniques, and inclusive of demographic information. However, trip data are only available at the Traffic Analysis Zone, a geographic area created by the U.S.

Census Bureau the size of, or larger than a Census block. This made it problematic to discern how survey respondents could commute by foot, bike or bus. In addition no clear economic factors were examined making the development of any mode choice model problematic. Due to these factors this source was discarded.

Because of the flaws with these two data sets it was determined that that the most appropriate solution would be to implement a contingent valuation survey. In undertaking this approach commuters could be directly asked how much they are willing to accept in benefits to switch to various forms of alternative commutes. This survey instrument allowed all of the relevant demographic information to be obtained as well as detailed information about the resident's location. Unfortunately, this approach has its drawbacks as well, namely that extrapolation to the population of the region could be flawed and there may be bias introduced by the fact that some types of employees do not check their email as regularly. Despite the flaws with this approach this was the best way to obtain the necessary information to develop the mode choice model during the brief time period available for the data collection.

Prior to releasing the survey a small focus group was conducted with five local residents, one of which was employed by Duke University. This was determined to be an appropriate group of people to conduct a focus group with since only two questions on the survey were specific to employees of the University, while the remaining questions could be answered by any automobile commuter. The focus group received an email with a link to the survey just as members of the sample eventually would and were asked to fill out the survey with additional text areas at the bottom of several pages to ask about any recommendations for, or problems with, the preceding section. This process resulted in a few minor changes to the wording of survey questions and the inclusion of two additional questions.

The survey began by asking whether or not the subject regularly commuted, alone in an automobile, and to the same site. If they did meet these criterion, they were asked questions about their current commute and if not they were taking directly to a thank you page. The crux of the survey instrument was 10 dichotomous choice questions in which subjects were asked whether or not they would walk, bike, bus, carpool, or vanpool to work for a certain amount of monthly tax-free benefits. The amounts asked were \$100, \$150, \$200, and \$250. Each subject received one of the five values at random for the entire survey. Beyond this basic demographic information was collected, including a home address or a nearby street address, which would be geocoded using an Internet resource found at batchgeocode.com. The survey instrument that was used can be found in Appendix B.

The names and email addresses of 478 employees of Duke University and Hospital that were holders of parking permits that expired in 2011 were provided by Duke Parking and Transportation Services for use as a sample. Of these, 452 of these (94.6%) were deliverable email addresses. Half of the sample received their first contact on the afternoon of Friday, February 19, 2010 and the remaining received their first contact on the morning of Monday, February 22, 2010. This split was implemented to determine if any considerations should be paid when sending out a follow up contact. There was only a slight difference in response rates to the initial email, so all recipients that had not completed the survey, including those that had started it and stopped midstream, received a reminder email. The reminder email was delivered on the morning of Thursday, February 25, 2010 to 305 addresses. The survey was closed at 5pm on Monday, March 1, 2010.

In total 209 persons (46.24%) responded to the survey. However, 84 (40.19%) of the responses were immediately dropped from usage because they were considered unusable for a variety of reasons (see Table 7 for details).

Table 7: Responses dropped from inclusion in analysis of the survey results

Reason	Count	Percentage
Did not work five days a week	48	23.41%
Did not work at the same site daily	7	3.41%
Did not drive to work alone	13	6.34%
Did not reach the dichotomous choice questions	1	0.49%
Did not answer a key demographic question	12	5.85%
Resided outside of the Greater Triangle Region	3	1.46%
Total	**84**	**40.98%**

A geographic distribution of the survey respondents can be viewed in Figure 7. It does appear that origins of the commute are centered in and around the city of Durham, with the majority of commuters beginning the journeys from locations near Interstates and other arterial highways. This appears to correspond with the distribution of commuters with destinations in the City of Durham found in Figure 8.

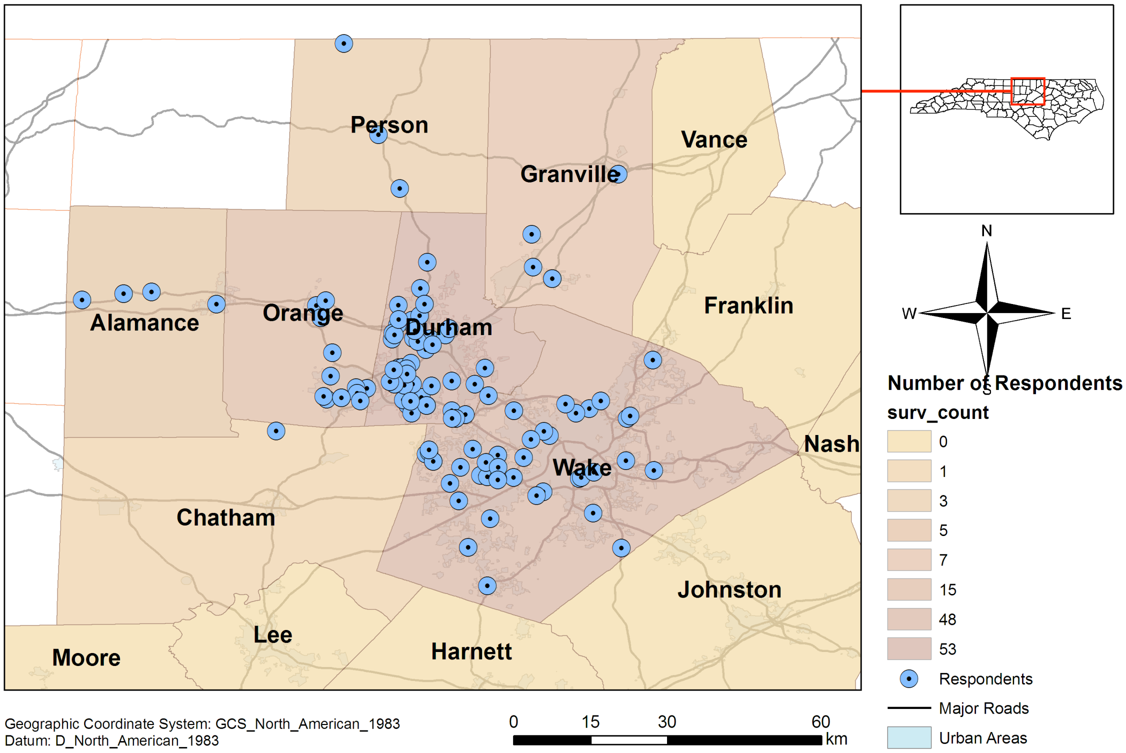

Figure 7: Location of survey respondents commute origins in the Greater Research Triangle

In addition to the simple calculations the three categorical demographic variables had to be transposed. The income variables were changed to the midpoint of the range that corresponded to the income category, excepting categories 15, which was set to $200,000 because of its open-ended nature, and category 16, which was set to being a missing value (De Vaus). Age groups were also converted using the midpoint of the range, except no arbitrary decisions involving the tails of the distributions were necessary in this case. Since conversion of the education categories were extremely arbitrary, a dummy variable was calculated for persons that had completed a Bachelor's degree or higher.

Table 8: Summary statics of key survey response variables

Variable	Median	Mean	Min	Max
Morning commute time (min)	25	25.03	2	60
Evening commute time (min)	25	28.85	2	90
Commute length (kms)	23.34	26.80	0	75.64
Morning commute congestion (1-5)	3	3.44	1	5
Evening commute congestion (1-5)	3	2.69	1	5
Knew about daily passes (1 - yes)	0	0.32	0	1
Knew about emergency ride (1 - yes)	0	0.19	0	1
Gender (1 - male, 0 - female)	0	0.25	0	1
Household size	2	2.38	1	6
Commuters in household	2	1.59	0	4
Age group (U.S. Census standard)	7	-	5	13
Education level (U.S. Census standard)	5	-	2	8
Income level (U.S. Census standard)	6	-	1	15

Finally, approximations for the fuel economies for the primary automobile provided by the respondents were looked up in an online database created by the Department of Energy and the Environmental Protection Agency (Department of Energy and Environmental Protection Agency 2010). Combined fuel economy estimates were used and in the case where multiple engine configurations existed for a particular car model the averages of all fuel economies for the models with automatic transmission were used.

Table 9: Summary statics of key modifications of survey response variables

Variable	Median	Mean	Minimum	Maximum	Count
Average commute time (min)	25	27.18	2	67.5	121
Average commute congestion (1-5)	3	2.65	-47	5	121
Dependents	0	0.81	0	5	121
Age	32	36.18	13	62	121
Finished Bachelor's degree (1 - yes)	1	0.79	0	1	121
Income	65,000	77,070.71	10,000	200,000	99
Fuel economy (kpl)	9.35	9.45	0.00	17.86	115
Informed (0-2)	0.00	0.50	0	2	121

Commuteshed Data

Two commutesheds were to be looked at in the course of this study. One is that of people that have workplace destinations within the City of Durham, the second being those that commute to Duke University and Duke Hospital. This subpopulation is being examined since the random sample of the survey was developed as a random sample of these persons.

Given that the sample contacted in the survey is a random sample of the population of the 18,695 parking permit holders at Duke, it is being assumed that the sample and therefore the responses are a representation of the population as a whole (Harden 2010). These 18,695 parking permit holders are a subset of the total population of the approximately 29,304 Duke employees that commute to locations within the City of Durham.

Data concerning the total population of person's that commute to a destination within the Durham city limits was obtained from LED OnTheMap and based on 2007 numbers (more recent data was not available for North Carolina). This data was downloaded at the census tract level of precision. Given very distant survey results had been excluded from the analysis, only tracts that had their centroids within 65 kilometers of the city limits were included. This area included all of the geocoded survey results that were remained. There were a total of 79,952 persons in the commuteshed and 43,010 (53.78%) of them began their commutes outside of the Durham city limits (U.S. Census Bureau 2007).

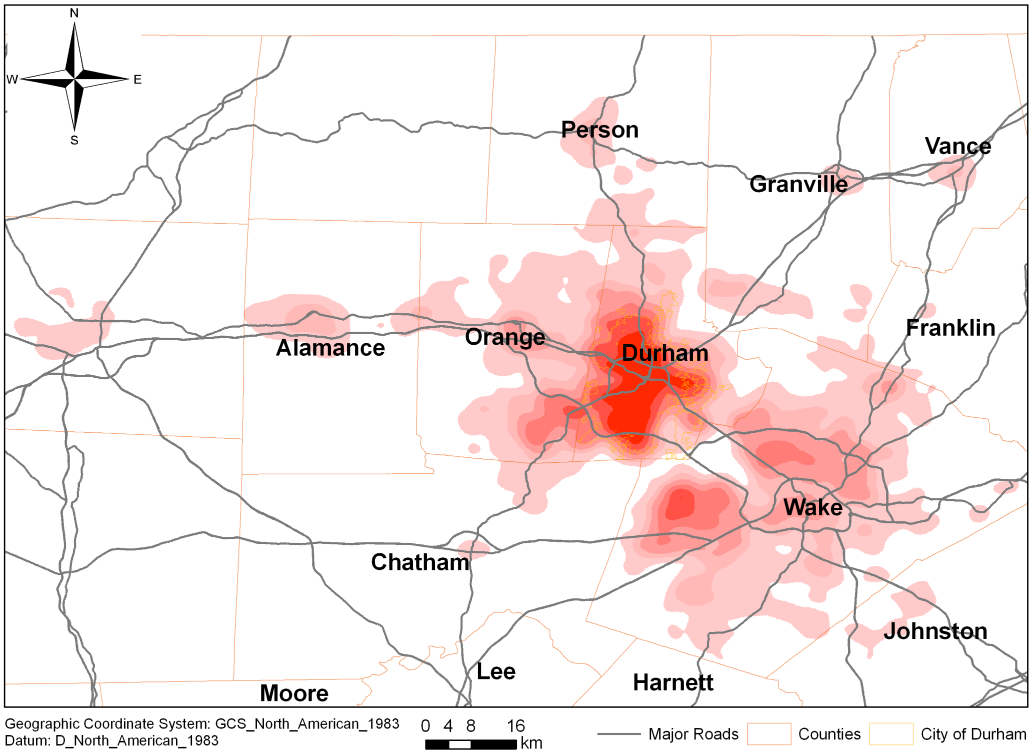

Figure 8: Commuteshed for the City of Durham, NC

In the aforementioned CTRP survey there were 11,598 respondents to workplace destinations within the City of Durham. Of these respondents, 9,401 (81.06%) of the respondents stated that they primarily commuted to work alone in their automobile (Triangle Transit Commuter Resources Department 2008). If the assumption is made that the mode choice of the 11,598 respondents is representative of 79,952 commuters that have a workplace destination within the Durham city limits, it is expected that approximately 64,810 of the commuters regularly drive alone.

There are several notes that should be mentioned when examining population of total Durham commuters. Firstly, the population of employees of Duke makes up 36.7% of the total population of commuters to the City of Durham. Secondly, the hub of the bus network is centered in downtown Durham. This would mean that people that commute downtown could be more likely to be willing to accept a commute by bus with a lower benefit value than persons that commute to Duke University and Hospital. Finally, there are some potential distortions in the demographics that make up of the sample. For instance Durham's population is equally distributed among males and females, but the survey respondents were 26.4% male and 73.6% female. On the other hand, all of the statistics that could be found were for the population of Durham as a whole, not just of people that commute into it, so an outright acceptance of this distortion may not be justified as well.

Models

Using the survey responses 10 regressions were run to determine the effects of the bid on the mode choice. In five of these the bid was the only dependent variable in the regressions. A review of the literature found that another approach that has been used is log-transforming the bid values in the regression, which can be done under the assumption that no one has a compensating variation, the additional amount of money required to compensate a person for a change in quality, that is negative (Ready and Hu 1995). The other five regressions have the log-transformed bid value as the only dependent variable.

It is only necessary to regress mode choice on the bid, or log-transformed bid, variable because "random assignment of bids ensures that the bid variable is not correlated with omitted covariates and the coefficients on the bid variable will not contain an omitted variable bias (Boyle, MacDonald et al. 1998)". To prove the random distribution of bids ANOVA tests were conducted on gender, income, completion of a Bachelor's degree, household size, number of commuters, commute distance, average congestion, and average commute time.

Results

ANOVA Results

None of the ANOVA tests exhibited a statistically significant difference in regards to the examined covariate and the bid value. This provides evidence that the statistical model used to analyze the impact of the bid value follows the identifying assumptions. The full results can be found in Appendix D.

Impact of Bids

The coefficients obtained from the regressions that used the bid as an explanatory variable can be seen in Table 11 and with the log transformed bid as an explanatory variable in Table 12. The patterns of significance were the same across both sets of regressions, though the coefficients obviously were of differing magnitude.

The coefficients for carpooling and vanpooling are not statistically significant. It is very likely that the bids were set too high to develop a more accurate effect on the probability of carpooling or vanpooling. This assertion is supported by the values present in Table 10, which show very high rates of acceptance for carpooling and vanpooling as an option.

Table 10: Percentage of respondents that were willing to change mode

Variable	Count	Percentage	Answered	Variable	Count	Percentage	Answered
Not Willing	24	19.83%	121	**Bus**	47	38.84%	121
Walk	9	7.44%	121	**Carpool**	79	65.29%	121
Bike	18	14.88%	121	**Vanpool**	73	60.33%	121

The lack of a significance of the bid on walking and biking as a mode choice would also be logical since so few respondents chose this as a mode anyway and so few respondents live within walking and biking distance. Only 5 persons live within

8km of work, which is quite a substantial walk. More people do live in bicycling distance, but it is still the minority. The average commute distance is 24 miles, a very substantial bike ride. In this case, the idea that the bids were set too low to compensate people for their very large travel times would be a likely suggestion.

This leaves the impact of the bid value on the decision by the respondent to select to bus to work. This is the only bid result that was statistically significant. This would imply that the range in benefits from $100-$250 were sufficient to determine the marginal effects of the bid value.

Table 11: Results of logit regressions with bid as an explanatory variable

	Logit (Pr(1) = Car)	ES	Logit (Pr(1) = Walk)	ES	Logit (Pr(1) = Bike)	ES
Bid	-0.004594	(-)	-0.0044064	(+)	-0.0067191	(+)
Constant	-0.6127039		-1.777041		-0.6209644	
N	121		121		121	
Prob > chi2	.0607 *		0.4496		0.1218	
Pseudo R2	.1663		0.0089		0.0235	

	Logit (Pr(1) = Bus)	ES	Logit (Pr(1) = Carpool)	ES	Logit (Pr(1) = Vanpool)	ES
Bid	.0062577**	(+)	.0039131	(+)	.0036102	(+)
Constant	-1.497326***		.0276694		.0419813	
N	121		121		121	
Prob > chi2	0.0456**		0.2267		0.2614	
Pseudo R2	0.0245		0.0095		0.0081	

Table 12: Results of logit regressions with the log-transformed bid as an explanatory variable

	Logit (Pr(1) = Car)	ES	Logit (Pr(1) = Walk)	ES	Logit (Pr(1) = Bike)	ES
log(Bid)	-.6488071	(-)	-.7524443	(+)	-1.067432	(+)
Constant	1.897512		1.286018		3.649141	
N	121		121		121	
Prob > chi2	0.2918		0.4198		0.1218	
Pseudo R2	0.0092		0.0102		0.0235	

	Logit (Pr(1) = Bus)	ES	Logit (Pr(1) = Carpool)	ES	Logit (Pr(1) = Vanpool)	ES
log(Bid)	1.066307 **	(+)	.6081014	(+)	.5655723	(+)
Constant	-5.842931 **		-2.389733		-2.211266	
N	121		121		121	
Prob > chi2	0.0380**		0.2457		0.2773	
Pseudo R2	0.0264		0.0088		0.0076	

Economic Analysis

In this section the potential policy of compensating users for switching from commuting in an automobile alone to commuting via a public transit option were examined. The option of taking the bus is the only option being examined since, as was seen in the preceding section, it was the only mode choice where the impact of the bid level on decision making was significantly different from zero.

To determine whether the policy solution is reasonable the marginal avoided damages from pollution were calculated. The commuter's choice was considered the unit on the margin. These marginal damages will then be equated to the marginal willingness to accept compensation for the change in mode choice. Finally, the number of commuters that would switch at the given compensation level was estimated using the logit model developed from the survey results and, in turn, the total pollution reduction was determined.

Value of Pollution Damages

Most types of pollution damage do not have a specific market value associated with them, which is why they are characterized as unpriced externalities. Some pollution, though, can be priced via emissions trading systems. But those pollutants that are traded on markets, such as NOx, have a variety of distortions, such as speculation and improperly set caps, preventing the true economic value of pollution reduction from being known. As a result, the best option to examine the economic opportunity cost of pollution reduction is to employ a nonmarket valuation technique such as averting behavior, hedonic analysis or contingent valuation. However, such an analysis would be well beyond the scope of this project, so the values were transferred from previous research in the field. A paper by Muller and Mendelsohn provided estimates of the marginal value of damages caused by the criteria air pollutants being examined in this paper and these values can be seen in Table 13.

The price for CO_2 was based on a literature review conducted by Richard Tol, in which he reviewed 28 published studies that included 103 estimates for the marginal damage of CO_2. In it several values per ton of CO_2 were presented, a few of which were used in this analysis and are reprinted in Table 13. Since, there is so much variability in the potential price of CO_2 all of these values were explored in this analysis. Additionally, though the damages associated with the three criteria pollutants that were looked at are small in magnitude compared even with the smaller potential values for CO_2 damages they were included in the total price of damages throughout the rest of the paper.

Table 13: Damages of Pollution in $ per kilogram and per annum for an average SOV commuter (Tol 2005; Muller and Mendelsohn 2007)

Source	Damages/Kg	Damages/Year	Total Damages/Year
CO_2 (Median)	0.0154	56.05	56.67
CO_2 (Mean/Peer-Reviewed)	0.0551	200.17	200.78
CO_2 (Mean/All)	0.1025	372.31	372.93
CO_2 (95% percentile)	0.3858	1401.16	1401.78
PM2.5	1.9842	0.46	
PM10	0.3307	0.14	
NOx	0.2205	0.03	

To calculate the change in VKTs that resulted from the decrease of one commute the mean commute length one way from the survey data was used as the estimate for the half of the reduction in VKTs due to one commute. Since the survey specifically asked whether the respondent would undertake such an alternative commuter four days a week, the doubled mean value was multiplied by 4, then by 52 weeks per year to determine the annual VKT reductions for a person that had entered into the program. This calculation was developed under the assumption that vacation days, holidays, sick days, and days in which daily parking passes were used occurred on average once per week. It is possible that the survey respondent was not taking all of this into account with their answers resulting in the calculation being high.

It was determined that this person, on average, would now drive 6240 fewer kilometers annually. Using the formulas presented in Table 6 calculations were made for the level in decrease of pollutants as the result of this change. The damage values presented in Table 13 were then used to calculate the resulting averted damage costs, with the results displayed in the same table.

Equation 2: Logit based mode choice equation using bid

$$\Pr(Bus = 1) = 1/(1 + e^{-0.00626*bid+1.497326})$$

Equation 3: Logit based mode choice equation using log(bid)

$$\Pr(Bus = 1) = 1/(1 + e^{5.843\text{-lg}(1.066*bid)})$$

The coefficient obtained from the logit regressions were used to develop two equations for the probability of a change in mode choice. The one developed using the bid as an independent variable can be seen in Equation 2 and the one developed using the log-transformed bid in Equation 3. Using several bid values based on the values of pollution presented in Table 13, as well as a value that approached 0 to represent the status quo, the probabilities of switching to the bus were determined. The results of these calculations are shown in Table 14.

Table 14: Likelihood of change based on Equation 2 and Equation 3 and the total value of pollution damages at varying values of CO_2 damages

	$/Month	Equation 2	Equation 3
CO_2 (Median)	5.52	18.80%	1.68%
CO_2 (Mean/Peer-Reviewed)	19.57	20.18%	5.71%
CO_2 (Mean/All)	36.36	21.93%	10.11%
CO_2 (95% percentile)	136.67	34.48%	29.71%
Status Quo	0.00	18.28%	0.00%

As one can see from Table 14, the equation that used the bid as the dependent variable is not an appropriate choice. This functional form does not result in the expected behavior as the bid value approaches $0. However the equation based on the log-transformed bid does exhibit the expected behavior. As the bid approaches

$0 the likelihood does as well, since the status quo is that these people are unwilling to bus under current circumstances.

The probabilities based on Equation 3 were then applied to the total populations of Duke and Durham bound commuters to calculate populations that would make a mode choice switch and the aggregate level of pollution reductions that could occur. The annual pollution from bus travel was subtracted from the reductions. The annual distances were assumed to be the 1/32 of those from the automobile since 32 people could fit onto a bus. The pollution emitted per hybrid bus was based on the pollution emitted by hybrid buses in Orange County, CA from a report produced by the National Renewable Energy Laboratory (Chandler and Walkowicz 2006). It was assumed that the additional buses are hybrids because DATA have begun purchasing hybrids when they purchase new buses and would continue to do so.

Table 15: Reductions in VKTs and pollution at various policy levels under a logit model

Commuters to the Duke University:				Reductions (kgs, except VKTs)				
	$/Month	Likelihood	Pop.	VKTs	CO_2	NOx	PM2.5	PM10
CO_2 (Median)	5.52	1.68%	314	5,074,685	844,646	648	22	24
CO_2 (Mean/Peer-Reviewed)	19.57	5.71%	1,067	17,244,234	2,870,183	2,202	74	81
CO_2 (Mean/All)	36.36	10.11%	1,890	30,545,081	5,084,016	3,901	131	144
CO_2 (95% percentile)	136.67	29.71%	5,554	89,760,519	14,940,014	11,464	385	422

Commuters to the City of Durham:				Reductions (kgs, except VKTs)				
	$/Month	Likelihood	Pop.	VKTs	CO_2	NOx	PM2.5	PM10
CO_2 (Median)	5.52	1.68%	1,089	17,599,785	2,929,362	2,248	75	83
CO_2 (Mean/Peer-Reviewed)	19.57	5.71%	3,701	59,813,411	9,955,526	7,639	256	281
CO_2 (Mean/All)	36.36	10.11%	6,552	105,889,615	17,624,589	13,524	454	498
CO_2 (95% percentile)	136.67	29.71%	19,255	311,188,117	51,795,096	39,744	1,334	1,463

Caveats

There may be some flaws in the model, some of which can be discussed based on the results expressed in Table 16. Due to the high level of "yes" responses and the lack of lower level bids being included in the survey, this distribution exhibits many of the symptoms of a fat-tail problem (Ready and Hu 1995). This has likely to have been partially alleviated by the choice of the log-transformed bid functional form, but it is problematic that reliance was necessary based upon functional form choice.

Table 16: Sample sizes and "yes" responses for the willingness to accept busing

Bid	Sample Size	Yes (Before)	Percentage	Yes (After)	Percentage
100	36	10	27.78%	10	27.78%
150	23	8	34.78%	8	34.78%
200	26	14	53.85%	14	53.85%
250	36	17	47.22%	15	41.67%

As a second problem, it is possible, to some degree, the survey respondents did not take the exercise seriously, responded with yes responses as strategic misrepresentation, or responded with a lack of complete information (Daniel 1994). The high bid values and inclusion of biking and walking probably lead to the first problem, some survey respondents even provided feedback relating to this effect. The second of these issues is also quite likely since survey respondents, though they were informed that the policy presented in the survey was not something that was being implemented, they may have wanted to influence the process anyway to result in a higher level of benefits. The third issue is also a large possibility since it was not made clear as to the fact that the people that participated in the program would or would not have to purchase bus passes, give up their parking pass, or undertake other actions related to the other mode choices. This lack of clarity as to the assumptions being presented to the survey takers very likely had a large impact on the flaws in the distribution.

Conclusion

The results of the analysis herein suggests providing compensation for commuters to undertake alternative commutes could cause them to switch modes in large numbers. However, framing such a program under the guise of reducing air pollution may be a bit naïve. Duke commuters have the opportunity to receive substantial benefits for taking the bus rather than driving already and when looking at 2008 survey data do take the bus and other forms of alternative transit at a slightly higher rate than the general population of commuters of Durham. However, the level of monthly benefits that Duke currently provides for buses is quite high compared to the marginal damages averted by an average commuter undertaking an alternative commute. Policies made at the federal level that target heavy duty diesel vehicles, including buses, are already having such a substantial impact on reducing criteria air pollutants, which have relatively small marginal damages in the first place, so they are included, but have very little economic impact. Furthermore, it is only at very high prices per kilogram of CO_2 that even the current discounts for commuters that use the Triangle Transit, DATA, or CAT start to substantially reduce air pollution. When lower values are used, in particular ones that are conventionally thought of to be a price for CO_2 under a cap-and-trade regime, the changes are almost imperceptible.

However, for every commuter that no longer drives to work alone approximately 3,500 kilograms of CO_2 are not emitted. As a result, it would be wise to examine policies that lower the opportunity costs for commuters to undertake alternative commutes such as increases in bus routes and availability, striping more bicycle lanes, etc. By providing a public good through alternative transportation infrastructure improvements the WTA payment can essentially be made to multiple people at the same cost of simply paying the one person to switch. Of course, for an employer to do this they would have to collaborate with other nearby employers, which is unlikely, so this needs to come from the state, regional, and local governments and planning organizations. Though the opportunity costs expressed by the survey respondents may have been high due the various shortcomings in the survey instrument these costs are still quite substantial. It will only be if the various opportunity costs associated with undertaken commutes become high that people will take different types of commutes.

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Appendix A (Acronym Dictionary)

Acronym	Definition
BRT	Bus Rapid Transit
CAA	Clean Air Act
CAMPO	Capital Area Metropolitan Planning Organization
CAT	Capital Area Transit
CRLP	Constrained Long Range Plan
CTP	Comprehensive Transit Plan
CTRP	Commute Trip Reduction Program
DATA	Durham Area Transit Authority
DCHC MPO	Durham/Chapel Hill/Carrboro Metropolitan Planning Organization
EPA	Environmental Protection Agency
ESC	Employment Security Commission of NC
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
ISTEA	Intermodal Surface Transportation Efficiency Act
ITRE	Institute for Transportation Research and Education
LRTP	Long Range Transit Plan
LUTRAQ	Land Use/Transportation/Air Quality
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
NCDAQ	North Carolina Division of Air Quality
NCDOPI	North Carolina Department of Public Instruction
NCDOT	North Carolina Department of Transportation
NCOSBM	North Carolina Office of State Budget and Management
NCSCO	State Climate Office of North Carolina
NCSU	North Carolina State University
NOx	Nitrous Oxides
NTD	National Transit Database
OLS	Ordinary Least Squares
STAC	Special Transportation Advisory Committee
TIP	Transportation Improvement Plan
TT	Triangle Transit
USGS	United State Geological Survey
VKT	Vehicle Kilometer Travelled
VOCs	Volatile Organic Compounds

Appendix B (Survey Instrument)

Contact Email

Subject Line: Tell Us About Your Commute
Body:
${m://FirstName} ${m://LastName},

You have been chosen from a random sample of Duke parking permit holders to take part in a brief survey about your daily commute to Duke University. The survey should take approximately fifteen minutes to complete. This survey is part of a research project by Joseph Jakuta, a Masters student at the Duke University. Your feedback is very important for the success of this project. Upon completion of the project no further contact will occur, unless requested.

To take the survey follow this link: ${l://SurveyLink?d=Take the Survey}. Thanks for your time.

Sincerely,
Joseph Jakuta

Reminder Email

Subject Line: Re: Tell Us About Your Commute
Body:
${m://FirstName} ${m://LastName},

I just wanted to take a moment to remind you that you have been chosen from a random sample of Duke parking permit holders to take part in a brief survey about your daily commute to Duke University. You are also receiving this email because records show that you had not yet completed the survey. Apologies if you have completed it and I was unable to remove you from the email list in time.

Follow this link to complete the survey: ${l://SurveyLink?d=Take the Survey}.

The survey should take only **15** minutes to complete. Your feedback is very important for the success of this project. Due to time constraints, all submissions must be in by **5pm on Friday, February 26th**.

This survey is being conducted for my Master's Project at Duke University. Upon completion of the project no further contact will occur, unless requested.

If you have started, but not completed, the survey the link should take you to where you left off. If you have not yet begun the survey you will be taken to the beginning.

To take the survey follow this link: ${l://SurveyLink?d=Take the Survey}.

Thanks again for your time,
Joseph Jakuta

Survey Instrument

The purpose of the study is to determine whether residents of the Research Triangle that drive to work alone are willing to take less convenient commutes if offered a monthly benefit in their paychecks. This study is theoretical and no such program is directly being considered. This study is being conducted by Joseph Jakuta, a graduate student at the Nicholas School of the Environment at Duke in conjunction with Triangle Transit.

You will be asked several questions about your current commute work, followed by questions in which you will say whether you would undertake a type of commute (e.g. bus, carpool) for a certain amount of money, and finally questions about yourself.

You are free to choose whether or not you participate in this survey. You can also skip certain questions, or stop the survey at any point. However, providing all of the information does allow us to develop the best picture of commuters.

If you have any questions please contact jmj22@duke.edu with the subject line "Duke Commuter Survey."

Do you agree to continue this survey?

* Yes [1]
* No [0]

Your Current Commute

Do you regularly travel to work five days a week?

* Yes [1]
* No [0: if no continue to the end of the survey]

Do you regularly travel to the same work site five days a week?

* Yes [1]
* No [0: if no continue to the end of the survey]

Do you primarily drive to work alone in a car?

* Yes [1]
* No [0: if no continue to the end of the survey]

How many minutes (on average) does your commute take by car in the morning?

____

How many minutes (on average) does your commute take by car in the evening?

____

Approximately, how many miles is your commute (one-way)?

____

On a scale of 1 to 5, how congested is your morning current commute (1 being stop and go, 5 being nearly car free)?
1 2 3 4 5

On a scale of 1 to 5, how congested is your evening current commute (1 being stop and go, 5 being nearly car free)?
1 2 3 4 5

What is your car's make (e.g. Ford, Toyota)?

____

What is your car's model (e.g. Explorer, Corolla)?

____

What is your car's model year (e.g. 1995)?

____

Which lot do you park in?

____

Do you ever commute to work in any of the following ways?

* Walking [1]
* Bicycling [2]
* Motorcycling [3]
* Busing [4]
* Carpooling [5]
* Vanpooling [6]
* I Always Drive Alone [7]
* Other [8]

Alternative Commute

The next five questions will ask you if you would be willing to commute using a different mode if offered a given amount of money as a tax-free addition to your paycheck. Some may seem absurd (such as walking to work if you live 20 miles away or busing to work if you do not live near a bus route) so answer "no."

Would you be willing to [walk, bike, bus, carpool, vanpool: repeated for each option] to work at least four days a week if you received a monthly benefit of [$100, $150, $200, $250: random]?

* Yes [1]
* No [0]

You may not have known that Duke offers a limited number of daily parking passes to alternative commuters for cases when they need to commute via car. In addition Duke works with Triangle Transit to provide emergency ride home services to alternative commuters. Knowing about these services please answer the following five questions.

Would you be willing to [walk, bike, bus, carpool, vanpool: repeated for each option] to work at least four days a week if you received a monthly benefit of [$100, $150, $200, $250: random]?

* Yes [1]
* No [0]

Prior to this survey, did you know about alternative commuters' access to a limited number of daily parking passes?

* Yes [1]
* No [0]

Prior to this survey, did you know about alternative commuters' access to emergency rides home through Triangle Transit?

* Yes [1]
* No [0]

About yourself

What city/town do you live in?

____

What is your zip code?

____

What is your gender?

* Male [1]
* Female [0]

How many people live in your household including yourself?

____

How many people live in your household and work outside of the house including yourself?

____

What is your age?

____

What is the highest level of education you have completed?

* Less than High School [1]
* High School / GED [2]
* Some College [3]
* 2-year College Degree [4]
* 4-year College Degree [5]
* Master's Degree [6]
* Doctoral Degree [7]
* Professional Degree (JD, MD) [8]

What is your combined annual household income?

* Less than $20,000 [1]
* $20,000 - $29,000 [2]
* $30,000 - $39,000 [3]
* $40,000 - $49,000 [4]
* $50,000 - $59,000 [5]
* $60,000 - $69,000 [6]
* $70,000 - $79,000 [7]
* $80,000 - $89,000 [8]
* $90,000 - $99,000 [9]
* $100,000 - $109,000 [10]
* $110,000 - $119,000 [11]
* $120,000 - $129,000 [12]
* $130,000 - $139,000 [13]
* $140,000 - $149,000 [14]
* More than $150,000 [15]
* I'd prefer not to say [16]

Earlier in this survey, you provided your city and zip code to us. While this information is useful to us, more precise location data gives us an even more accurate picture of commuting patterns. In this question, we are providing you the option to give us your address or a nearby intersection to your home if you feel comfortable doing so. We stress that the data in this survey is only used for research purposes. If you share your address, you will not be added to any mailing lists or receive any contact from anyone because of your participation. Your privacy is very important to us. If you would prefer not to provide any additional location data for your commute, we completely understand and thank you for participating in the survey.

What is your street address?

____

Would you feel more comfortable providing a nearby intersection?

____

Thank You

Thank you very much for completing the survey. Your feed back will be very helpful in completing this research. Again if you have any questions please email jmj22@duke.edu with the subject line "Duke Commuter Survey."

Appendix C (ANOVA Results)

Table 17: ANOVA Results Across Bid Levels

Number of obs	121			R2	0.0032
				Adj	-
Root MSE	60.40			R2	0.0052
					Prob >
Source	**Partial SS**	**df**	**MS**	**F**	**F**
Gender	1379.07	1	1379.07	0.38	0.5399
Residual	434199.44	119	3648.73		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.1302
				Adj	
Root MSE	60.07			R2	0.0059
					Prob >
Source	**Partial SS**	**df**	**MS**	**F**	**F**
Income	56696.57	15	3779.77	1.05	0.4142
Residual	378881.94	105	3608.40		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.0038
				Adj	-
Root MSE	60.39			R2	0.0046
					Prob >
Source	**Partial SS**	**df**	**MS**	**F**	**F**
Completed Bachelor's	1656.45	1	1656.45	0.45	0.5016
Residual	433922.07	119	3646.40		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.0371
				Adj	-
Root MSE	60.39			R2	0.0048
					Prob >
Source	**Partial SS**	**df**	**MS**	**F**	**F**
Household Size	16143.89	5	3228.78	0.89	0.4934
Residual	419434.62	115	3647.26		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.0058
				Adj	-
Root MSE	61.10			R2	0.0285
					Prob >
Source	**Partial SS**	**df**	**MS**	**F**	**F**

# of Commuters	2512.58	4	628.14	0.17	0.9542
Residual	433065.93	116	3733.33		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.2405
				Adj	-
Root MSE	65.13			R2	0.1685

Source	**Partial SS**	**df**	**MS**	**F**	**Prob > F**
Commute Miles	104757.08	42	2494.22	0.59	0.9690
Residual	330821.43	78	4241.30		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.0856
				Adj	
Root MSE	59.63			R2	0.0203

Source	**Partial SS**	**df**	**MS**	**F**	**Prob > F**
Average Congestion	37301.28	8	4662.66	1.31	0.2452
Residual	398277.23	112	3556.05		
Total	435578.51	120	3629.82		

Number of obs	121			R2	0.1932
				Adj	-
Root MSE	63.56			R2	0.1128

Source	**Partial SS**	**df**	**MS**	**F**	**Prob > F**
Average Commute Time	84147.24	33	2549.92	0.63	0.9309
Residual	351431.28	87	4039.44		
Total	435578.51	120	3629.82		

Appendix D (Land Use Logit Results)

Table 18: Results of logit regression run on land use variables in the Greater Research Triangle Region

Logistic regression		Number of obs	=	47949
		LR chi2(10)	=	2005.3800
		Prob> chi2	=	0.0000
Log likelihood	-3845.3967	Pseudo R2	=	0.2068

urb02	**Coef.**	**Std. Err.**	**P>|z|**
for91***	3.6661	0.3890	0
agbar91***	3.7856	0.3913	0
wet91***	2.9982	0.4346	0
dmaj_road***	-12.2750	1.3025	0
dall_road***	-149.6387	19.8614	0
ned***	0.0026	0.0009	0.006
slp	0.0039	0.0024	0.103
for_perc **	-1.3631	0.6057	0.024
urb_perc ***	7.5486	0.6153	0
ab_perc *	-1.2268	0.6596	0.063
_cons ***	-6.8660	0.6461	0