From Cars to Buses: Using OCTA Ridership to Analyze the Emission Benefits of Bus Transportation

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As a Business Economics/ Earth Science double major, John Naviaux was very interested in financially practical approaches to solving environmental issues. His study of public transportation emissions synthesized his interests in economics and the environment. John's research calculates an economic value for the emissions savings of bus transportation, and is unique in being one of the first to rely on ridership data collected from the field. Along with this research, John has tried to use his undergraduate years to learn as much as possible about every possible subject. Pursuing his broad range of interests, he conducted a summer 2011 particle physics research project in Geneva, Switzerland.

Key Terms

- Emission Benefit
- Emission Efficiency
- Revenue Miles
- Ridership
- Unlinked Passenger Trips
- Weighted Ridership

Abstract

The emission benefits of public transportation are primarily realized during periods of high ridership. This research quantifies the emission benefits of buses by calculating the mile-weighted average ridership for the Orange County Transportation Authority (OCTA) bus system in Southern California. Ten routes were randomly selected, and data was collected on passenger counts, boardings, alightings, time of day, and distance between stops. The average ridership was calculated to be 14.49 riders per mile. Once non-revenue vehicle miles are accounted for, OCTA buses emit 20,000–51,000 fewer metric tons of CO_2 than an equivalent number of passengers would if they were transported by car. Using EPA valuations for the social cost of carbon, this decrease provides an annual savings of \$109,800–\$279,990 domestically, and \$724,200–\$1,846,710 globally. OCTA receives approximately \$480 million in subsides from state and federal sources each year, so an analysis focusing solely on CO_2 emissions must conclude that OCTA's emission benefits are not enough on their own to justify their subsidy. The emission benefits calculated for OCTA likely represent an ideal case. OCTA ranks 18th in the U.S. in number of passenger miles traveled and has completely switched its buses from diesel to natural gas fuels. Other bus systems using less emission-efficient fuels will provide an even smaller benefit.

Faculty Mentor

John Naviaux's thesis clearly shows that there are no significant CO_2 emissions benefits from moving a traveler from a personal automobile to an Orange County urban bus. This is a strong negative result since the Orange County bus fleet is among the cleanest in the world with almost all buses running on natural gas, and this shows that it will be difficult to reduce CO_2 emissions in the U.S. by simply getting more people to use urban mass transit. This thesis is an excellent example of the benefits of doing a good, thorough job on a "small" problem. The data collection is only feasible for a few bus lines, but by careful selection of these lines John was able to obtain important results.

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Introduction and Background

Transportation use is the single largest contributor to greenhouse gas emissions in California. In 2008, it accounted for 36.5% of the 477.7 million metric tons of CO_2 equivalent emissions in the state (CARB, 2010). Growing concern over climate change has caused federal and local governments in the U.S. to propose various strategies to curb emissions. One approach has been to increase funding for public transportation systems as a means to encourage their use (Callaghan, 2007). By carrying large numbers of people with each trip, public transportation systems have the potential to operate with low levels of emissions per passenger. Smaller vehicles' emissions are not as efficient in their emission levels precisely because their emissions are divided among fewer people. However, not every bus mile is driven by a vehicle in service, and there are times when public transit runs significantly below capacity. It is likely that their emission efficiency drops below that of smaller vehicles during these times of low ridership, but literature on this topic is lacking. By accounting for non-service miles and variations in ridership throughout the day we may more accurately assess the emission benefits of public transportation over cars.

At 53% of all unlinked passenger trips, buses are by far the most widely used form of public transportation in the U.S. (APTA 10). For this reason, bus emissions are used as a proxy for general public transportation system emissions. This paper compares tailpipe emissions from cars and the Orange County Transportation Authority (OCTA) to estimate the economic impact of moving individuals from personal vehicles to public transportation. Data was collected aboard ten randomly selected OCTA routes and used to create a profile of ridership fluctuations over the course of a day. This has been combined with route characteristic information and fuel economy data provided by OCTA to estimate average daily bus emissions. Economic comparisons may be made by contrasting bus emissions to EPA estimates of car emissions. I hypothesized that bus emission benefits would be minimal after adjusting for daily ridership fluctuations and non-service miles.

OCTA is an excellent candidate for analysis because of its relatively large size and its demonstrated commitment to reducing emissions. With a total 65,203,600 unlinked passenger trips in 2008, OCTA is the 18th largest bus agency in the United States (APTA, 2010). Buses have traditionally been equipped with diesel engines, but recent advances in technology have increased the competitiveness of alternative fuels, especially in urban buses. In a study comparing compressed natural gas (CNG) buses with diesel buses, the CNG engines reduced total hydrocarbon (THC) emission by 67%, nitrous oxides by 98%, and particulate matter (PM) by 96% while maintaining similar torque and power (Turrio-Baldassarria 68). OCTA recently finished replacing its older model fleet with buses running on either compressed natural gas (CNG) or liquid natural gas (LNG). OCTA has 557 buses, 52% of which used compressed natural gas at the end of 2009 (OCTA c, 2010). Today, all of OCTA's buses run on either CNG or LNG. Findings based on OCTA will represent an ideal scenario, as other agencies with fewer resources and using less emission-efficient fuels will provide smaller benefits.

One of the most significant contributions to the literature that this research provides is a measure of mile-weighted bus ridership over the course of a day. This type of analysis had been independently recommended by other researchers, but had yet to be undertaken (Lin and Ruan, Chen, 2009). This paper also finds the minimum number of passengers needed for transportation by bus or by personal car to release an equal amount of CO_2 per person. Comparing this threshold to actual values for bus ridership allows for a more accurate estimate of the environmental costs and benefits of bus transportation.

Data and Methods

The goal of this paper is to accurately quantify the environmental impact, either positive or negative, of moving individuals from cars to buses. Cars, defined as light, four-person passenger vehicles, are compared to the bus operations of OCTA in California. Carbon dioxide emissions per mile are calculated by comparing the fuel used by OCTA buses to the hypothetical amount of fuel consumed had each passenger traveled the same distance by car. Calculations are made under the assumptions that the OCTA bus fleet runs solely on CNG and that cars receive the EPA estimate of 22.5 mpg for model year 2010 cars (EPA, 2010a). These are valid assumptions, as OCTA has transitioned to CNG buses, and government regulations are systematically increasing mpg and emission standards for light and heavy-duty vehicles (EPA, 2010b). It is expected that other transportation companies will also switch to CNG and LNG in the future (Callaghan, 2010).

Bus efficiency relies on transporting large numbers of people, so the emission profile of an individual is necessarily dependent on the total number of people on the bus at any one time. OCTA bus fare boxes collect data on boarding counts at each stop as passengers swipe their tickets. This allows for estimates of the popularity of each route and stop, but the ridership count cannot be determined without corresponding alighting data. This research is unique in that it incorporates actual passenger counts collected over a three-week period from selected OCTA bus routes. Data on route characteristics and fuel economy was also provided by OCTA (Trudell, 2011). With actual bus ridership information, it is possible to quantify the emissions of an individual on a bus versus the same individual taking a car. To my knowledge, no other researcher has collected ridership data in the field.

Route Selection and Route Characteristics

OCTA bus routes were randomly selected without replacement. OCTA provided average daily boarding data for all of its 77 routes from April-September 2010 (Trudell, 2011). The probability of selecting a route was weighted by the route's proportion of total daily boardings. Once a route was selected, it was removed from the sample and the relevant weights were recalculated. The corresponding route selections are presented in Table 1.

Table 1

Route Selection without Replacement

Selected Route	Service Area	Daily Boardings
33	Fullerton to Huntington Beach	2,050
47	Fullerton to Newport Beach	8,904
50	Long Beach to Orange	4,323
53	Orange to Irvine	8,483
55	Santa Ana to Newport Beach	5,479
57	Brea to Newport Beach	12,714
59	Anaheim to Irvine	2,794
64	Huntington Beach to Tustin	8,949
66	Huntington Beach to Irvine	8,092
143	La Habra to Brea	940

In large samples, this sampling method ensures that ridership data from these ten routes will converge on an unbiased estimate of total ridership for the entire OCTA bus system. Although OCTA only has 77 routes, it numbers them as follows: 0–99 "Local," 100–199 "Community," 200–299 "Intracounty Express," 400–499 "Stationlink," and 700–799 "Intercounty Express." Ninety-four percent of all passenger boardings occur on local routes. The routes selected for this research project accurately reflect this, as nine out of the ten are classified as "Local." Many of these local routes are in centralized areas and serve popular shopping locations. For example, routes 53, 57 and 64 serve the Mainplace Mall, Brea Mall, and Westminster Mall Areas, respectively. Although route 143 also serves the Brea Mall, the route is much farther removed from densely populated areas. The corresponding low boarding count is to be expected, as previous research stresses the importance of public transportation's proximity to an area's Central Business District (Glaeser et al., 2008).

Time-stamped boarding data provided by OCTA allowed the calculation of peak and off-peak boarding times for each of the selected routes. Each route takes on a bimodal distribution with peaks around 6–8 am and 3–5 pm. This corresponds with the peak/off-peak times written at each OCTA bus stop. Each stop lists different bus service frequencies for four different time periods: AM Peak 6–9 am, Midday 9 am–3 pm, PM Peak 3–6 pm, and Evening 6–11 pm. The daily boardings for route 59 are presented in Figure 1. Although route 59 has the most exaggerated peaks, each route follows a similar trend.

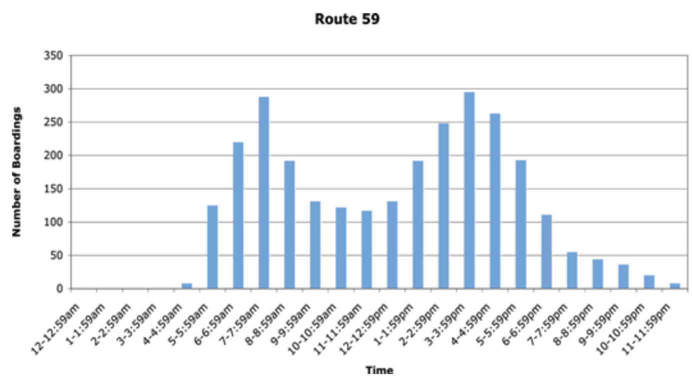

Figure 1

Daily Boarding Distribution for Route 59

Data Collection and Emissions Calculations

To collect data, I rode selected bus routes on weekdays at various hours. It should be noted that time constraints limited the days and hours that routes could be sampled. A large proportion of the data was collected on Monday and Friday from 7 am to 1 pm. The hours of sampling are not expected to bias the results, as boarding numbers during the morning and afternoon peaks are very similar (Trudell, 2011). It is acknowledged that Mondays and Fridays may have different ridership patterns as individuals prepare for work or the weekend. This issue may be resolved by further sampling. On each trip, passenger counts, boardings, alightings, location, and the time of day were noted whenever the sampled bus made a stop. The geographical coordinates of each bus stop were provided by OCTA. These were entered into Google Earth to find the total distance traveled by the bus as well as its stopping frequency (in miles). Google Earth is accurate to one tenth of a mile. Combining this information with the time of day at each stop allowed for the calculation of average bus speed for each route. Other studies have found this data to be useful in estimating NO_x, CO_2, and PM emissions. A bus with a higher average speed is, "likely to have less acceleration events and to spend more time in low emissions, low fuel consumption cruise mode" (Lambert, Vojtisek-Lom, et al. 9). Buses with lower average speeds likely emit more by accelerating and decelerating more often. Although this project focuses on CO_2 emissions, these route characteristics have been noted for future research.

To compare emissions, the fuel used by buses and by cars along a set distance was calculated. The number of bus passengers between each stop was divided by the average U.S. car occupancy to determine the number of cars that would be needed to transport the same number of people. Fifty percent of OCTA passengers use the bus to travel to work, so the 2009 National Household Transportation Survey estimate of 1.1 passengers per car was used[1] (OCTA, 2008). The Environmental Protection Agency (EPA) estimates the average model year 2010 car to achieve 22.5 mpg. This can be compared to the miles per gallon equivalent (mpge) of gasoline achieved by OCTA's CNG and LNG buses (EPA, 2010). A gallon equivalent of gasoline is defined as the amount of a fuel that contains the same amount of energy (measured in BTU), as a gallon of gasoline. OCTA LNG buses average 1.54 mpge (standard deviation 0.397), and CNG buses average 3.36 mpge (standard deviation 1.02). This information is used to calculate the CO_2 emissions per mile driven by cars and by OCTA buses.

The EPA calculates that each gallon of gasoline used by a car emits 19.4 lb of CO_2 (EPA, 2010a). Using the same methodology, the total CO_2 emission from a gallon equivalent of CNG was calculated to be 15.6 lb. The National Institute of Standards and Technology defines a gallon equivalent of gasoline to be 2.567 kg (5.660 lb) for CNG (NIST 2007). The calculations used were as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$2.567Kg\_CH_4 * \frac{1mol\_CH_4}{16.0g} * \frac{1000g}{Kg} = 160.4375mols\_CH_4$$

The molar ratio of CH_4 to CO_2 is 1 to 1, so:

$$160.4375mols\_CO_2 * \frac{44.0g}{mol} = 7.05925Kg\_CO_2 =$$

15.6lbs CO_2 per gallon equivalent CNG

1. NHTS Survey results available at http://nhts.ornl.gov/tables09/FatCat.aspx

The value of 15.6 lb CO_2 was derived under the assumption that CNG is composed solely of methane and that 100% of it burns in the reaction. Combining the collected data on bus ridership, distance between stops, miles per gallon, and emissions per mile allows a comparison between cars and buses.

One of the central assumptions of this research is that all bus riders would travel the same distances by car if the bus system were unavailable. Figure 2 demonstrates the impact on CO_2 emission as more individuals switch from buses to cars, with two different car emissions lines compared to emissions from CNG and Diesel buses. Bus CO_2 emissions lines were derived from data provided by OCTA on the fuel consumption of their fleet. The lines are flat due to the assumption that the weight difference from increased numbers of passengers does not affect gas mileage. Car emissions increase linearly as more vehicles are needed to transport the growing number of passengers.

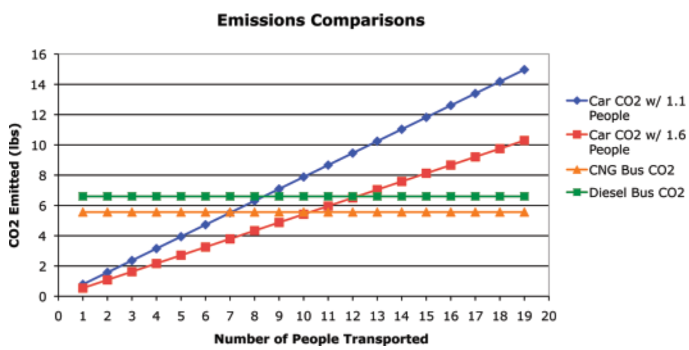

Figure 2

Bus-Car Emission Comparisons

Equations 1 and 2 were used to calculate emissions. In them, 22.5 is used for car mpg and 19.5 lb is used for CO_2 emissions per gallon. Diesel buses achieve 4.03 mpg and release 22.2 lb of CO_2 per gallon of fuel. CNG buses achieve 3.36 mpg and release 15.6 lb of CO_2 per gallon. It should be noted that bus emissions are multiplied by a factor of 1.198 while car emissions are multiplied by 1. This factor corrects for the miles driven by OCTA buses when not in service. Each weekday, OCTA buses travel 75,729.53 miles, of which 60,708.25 miles are revenue miles. 19.8% of miles traveled by OCTA buses are essentially "dead miles," as the buses emit CO_2 without transporting passengers. Buses must travel to and from their distribution centers, so these emissions are unavoidable. Since transportation agencies must still pay drivers and operation costs, they have an incentive to minimize the dead miles traveled each day. For this reason, it is assumed that the value of 19.8% represents the current minimum that a bus agency is able to achieve

$$Car\_Emissions = \frac{\#\_of\_People}{Riders\_Per\_Car} * \frac{Car\_Gallons}{Mile} * \frac{CO2\_Emissions}{Gallon} * 1\,Mile \quad (1)$$

$$Bus\_Emissions = (\#\_of\_People) * \frac{Bus\_Gallons}{Mile} * \frac{CO2\_Emissions}{Gallon} * 1.198\,Miles \quad (2)$$

without sacrificing service quality. Looking back to Figure 2, the intersections of emission lines indicate the number of passengers a bus would need to have to emit less CO_2 per person than if those passengers had taken cars. Table 2 summarizes this information.

Table 2

Required Bus Passengers to be Superior to Cars

	Cars w/ 1.1 Riders	Cars w/ 1.6 Riders
CNG Bus	7.1	10.3
Diesel Bus	8.4	12.2

Two values are used for possible car ridership. 1.1 is the average ridership for cars traveling to work, while 1.6 is the average U.S. car ridership (NHTS). Once non-service miles are accounted for, a CNG bus requires an average of 7.1 passengers for it to release less CO_2 emissions per person than if those passengers had taken cars. With this value in mind, it is possible to analyze the OCTA bus system.

Results

Over the total 24.5 hours in which OCTA buses were sampled, more than 470 stops were observed. Figure 3 overlays the mile weighted average bus ridership for the OCTA system on the unweighted data points. To calculate the weighted trendline, the collected data was organized by the time of day and divided into 15-minute groups. A weighted ridership value was then calculated for each period according to Equation 3, in which Total_Distance is the distance traveled by all sampled routes during the 15-minute period being weighted. For example, all route data collected from 8:30 am to 8:44 am were placed in the 8:30 am group. Data from 8:45 am to 8:59 am were placed in the 8:45 am group, etc. In a large sample, this should converge to the average ridership for the OCTA system. However, there are large spikes in the data, especially after 1:00 pm. As noted previously, time restrictions limited the majority of route sampling to be from 7:00 am from 1:00 pm. Averages calculated after 1:00 pm are assumed to be not as accurate.

$$Weighted\_Ridership = \sum \frac{(Riders * Distance\_Traveled\_from\_Stop)}{Total\_Distance} \quad (3)$$

Recalling that CNG buses require an average of 7.1 passengers, Figure 3 shows that OCTA buses are largely superior to cars. The dashed line represents the ideal level of 7.1 passengers. OCTA buses stay above this threshold for the majority of sampled times. There does not appear to be significant variation in ridership between peak and off-peak times. This is likely due to the fact that OCTA reduces bus frequency during times of low ridership to maintain constant boardings per vehicle hour ratios. Buses that run every 15 minutes during peak times may only run every 45

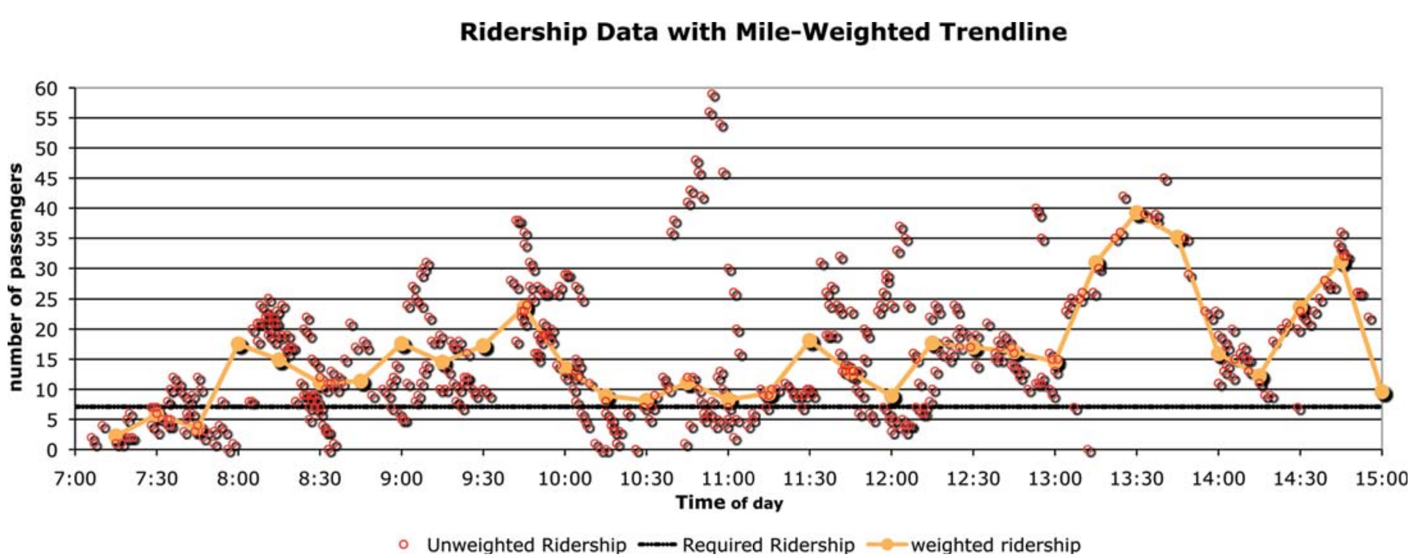

Figure 3

Weighted Average Bus Ridership

Table 3
Summary Route Data

Route	Average Stopping Frequency (Miles)	Average Stopping Frequency (Minutes)	Average Speed (MPH)	Total Time on Bus (minutes)	Total Car CO_2 (lbs)	Total Bus CO_2 (lbs)	Total Sampled Distance (miles)	Total Inefficient Miles	Inefficient Miles as % of total
33	0.5	2	18.48	30	78.36	40.39	8.7	0.00	0.00
47	0.6	2	22.55	68	136.78	82.18	17.7	4.70	26.55
50	0.5	3	14.22	76	311.65	63.61	13.7	0.00	0.00
53	0.4	2	18.46	88	163.98	96.11	20.7	8.80	42.51
55	0.6	2	19.64	43	107.70	58.04	12.5	3.70	29.60
57	0.4	2	13.57	60	132.86	60.82	13.1	1.20	9.16
59	0.7	3	19.42	357	644.99	415.07	89.4	42.20	47.20
64	0.3	2	11.16	111.5	364.88	82.64	17.8	0.00	0.00
66	0.3	2	12.29	93	223.32	79.39	17.1	2.10	12.28
143	0.8	3	15.43	42	58.16	48.75	10.5	6.70	63.81
Average:	**0.5**	**2**	**16.39**						
Total:					**2222.67**	**1027.00**	**221.20**	**69.40**	

minutes during off-peak times. Summary statistics for the sampled routes are presented in Table 3.

Emission calculations are dependent on the distance traveled and the number of passengers transported by each route. Total Car CO_2 is calculated using the "traveling to work" average value of 1.1 passengers per car as opposed to the national average of 1.6. Total Bus CO_2 is calculated assuming that all buses run on CNG and does not take dead miles into account. Both of these assumptions bias the results slightly in favor of bus travel. Total Inefficient Miles is defined as the distances traveled by each route with fewer than eight passengers (the required amount to be superior to cars, rounded the nearest whole person). Note that there is large variation among routes. Certain routes, such as Route 64, were superior to cars each time they were sampled. On the other hand, Route 143 released only marginally fewer emissions than hypothetical cars traveling the same distance. Also note the frequency with which buses made a stop. On average, sampled buses stopped every 2 minutes after having traveled roughly 0.5 miles. These are approximate values, as distances were rounded to the nearest tenth of a mile and times were rounded to the nearest minute. Although stopping frequency was not incorporated into the emission calculations for this paper, it becomes relevant when applying the results of this paper to buses running on fuels other than CNG/LNG. Particulate matter emissions from diesel buses are closely tied to stopping frequency, so this has been noted for future research.

OCTA System Ridership

Figure 4 presents the average mile weighted and unweighted ridership for each sampled route. This information is summarized in Table 4. The two measures do not differ as significantly as suspected. Note that standard deviations tend to be quite large. This is likely due to the fact that buses travel through areas of both low and high popularity along their routes. Large variations are seen in the data as buses pick up and drop off large groups of people. This spatial variation in ridership is well known, and was recently mapped out by OCTA.[2] Since OCTA is aware of this issue, it is assumed that they are willing to sacrifice some degree of efficiency to provide service to customers in more distant areas. I hypothesized that ridership values along shorter segments would have much smaller standard deviations. This is an area for future research.

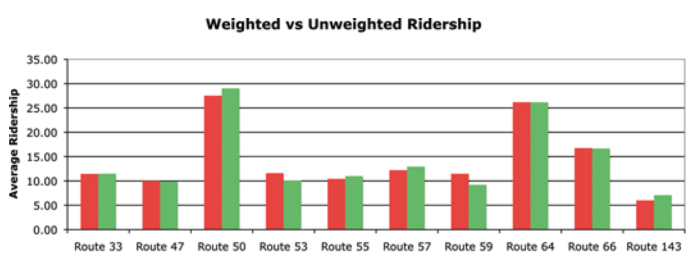

Figure 4
Weighted vs Unweighted Ridership

To calculate a meaningful value for the ridership of the OCTA system as a whole, an additional weight must be

2. http://www.octa.net/TransitSurvey/Reports.aspx

Table 4

OCTA Ridership Results

Route	Mile Weighted Ridership	Unweighted Average Riders	Standard Deviation (Unweighted Average)
33	11.48	11.44	2.53
47	9.86	10.00	4.43
50	29.02	27.53	7.85
53	10.11	11.60	7.81
55	10.99	10.43	8.99
57	12.94	12.21	4.72
59	9.20	11.47	7.97
64	26.15	26.18	10.85
66	16.66	16.75	8.95
143	7.07	6.00	3.96

Table 5

Weights Used to Find Average Ridership

Route	% of Scheduled Miles	% Miles Sampled ofTotal	Weight (% Scheduled)/ (% Sampled)
33	0.0487	0.0393	1.2377
47	0.1589	0.0800	1.9854
50	0.0764	0.0619	1.2332
53	0.0983	0.0936	1.0502
55	0.1175	0.0565	2.0795
57	0.1897	0.0592	3.2030
59	0.0788	0.4042	0.1950
64	0.0954	0.0805	1.1852
66	0.1107	0.0773	1.4323
143	0.0257	0.0475	0.5416

developed for each route to account for over/under sampling. For example, Route 59 comprises 89.4 of the total 221.2 sampled miles. A weighted average based on the total sampled miles would converge to the average ridership of Route 59. Some routes also run more frequently, so a relevant weight should reflect this. Ultimately, the weight for route *i* was calculated using Equation 4.

$$Weight_i = \frac{Proportion\_of\_Scheduled\_Miles_i}{Proportion\_of\_Sampled\_Miles_i} \quad (4)$$

For example, Route 59 accounts for 7.88% of the total scheduled miles for all ten routes. However, it accounts for 40.42% of the total sampled miles. Thus, the weight for Route 59 is 0.1950. Weights are presented in Table 5.

Equation 5 was used to calculate an average OCTA system ridership of 14.49 riders per mile, with a standard deviation of 6.35. This is above the threshold of 7.1 riders per bus to be superior to cars.

$$System\_Ridership = \sum \frac{(Mile\_Weighted\_Riders) * (Proportion\_Weight)}{(Sum\_of\_Proportion\_Weights)} \quad (5)$$

Economic Analysis

Buses in the OCTA system travel 60,708.25 revenue miles each weekday, 34,676.96 miles each Saturday, and 29,908.11 miles each Sunday. This means that OCTA buses transport passengers approximately 19.1 million miles each year and emit (19.1 million miles*1/3.36 gpm*15.6 lb CO_2 per gallon*1.198) = 106,236,929 lb CO_2 = 48,188 metric tons of CO_2. Using the average bus ridership of 14.49, transporting the equivalent number of people by cars would emit from 67,999 (with 1.6 riders per car) to 98,907 (with 1.1 riders per car) metric tons of CO_2. Assuming every passenger would have traveled by car if there were no bus system, OCTA prevents the release of 20,000 to 51,000 metric tons of CO_2 each year.

"Social cost of carbon" is a term defined by the EPA as "an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year." This includes, among other things, changes in human health, agricultural productivity, and the value of ecosystem services (US 2). In 2009, the EPA and the Department of Transportation collaborated to ensure consistent estimates of the social cost of carbon. They averaged three integrated assessment models and found a domestic cost of $5 per metric ton of CO_2 and a global cost of $33 (in 2006 dollars). Converting to 2010 dollars yields costs of $5.49 and $36.21, respectively. The domestic cost is meant to reflect the value of damages in the United States, while the global cost is meant to reflect damages worldwide (US, 2010). Applying these values to OCTA's bus operations implies a sav-

Table 6

Bus/Car Breakeven MPG

	Car w/ 1.1 Riders	Car w/ 1.6 Riders	Car w/ 2 Riders
Superior to CNG Bus	46.18 mpg	31.75 mpg	25.40 mpg
Superior to Diesel Bus	38.92 mpg	26.76 mpg	21.41 mpg

ings of $109,800–$279,990 domestically, and $724,200–$1,846,710 globally each year.

The EPA states that the "annual emissions of a typical passenger vehicle should be equated to 5.5 metric tons of carbon dioxide equivalent" (www.epa.gov). Average OCTA ridership is higher than the required threshold of 7.1, so every individual that moves from cars to buses provides a net emission benefit regardless of the time of day. Using the EPA's estimate, the removal of a single car from the road saves approximately $30.20 locally and $199.16 globally in emissions. OCTA's 2010–2011 budget is $1.2 billion, of which 40% ($480 million) comes from state and federal sources (OCTA a). Using the upper limit of emission savings, an additional (480,000,000–1,846,710)/199.16 = 2.4 million cars would have to be removed from the road to completely cover OCTA's subsidy with its benefit to the environment. As car fuel economy standards rise, buses become a less attractive way to reduce emissions. The U.S. Department of Transportation recently estimated that new Corporate Average Fuel Economy (CAFE) regulations for model year 2011 vehicles will raise the industry-wide combined average to 27.3 mpg (DOT, 2009). Although CAFE compliance is calculated in a lab rather than in highway conditions, it still represents a commitment to increasing fuel economy standards. This inspired a calculation of the mpg a car would need to achieve in order to emit less CO_2 per person than buses. The bus average ridership of 14.49 was used for the comparison (Table 6).

Increasing the number of people that are transported by car appears to reduce the emission advantages of buses dramatically. At the national average of 1.6 riders per car, the new mpg standards could make transportation by car more environmentally friendly than by diesel bus. At 2 riders per car, both CNG and diesel buses will ultimately release more CO_2 per person than if those individuals had taken a car. Cars carrying 1.1 individuals still are not close to being superior to buses. It should be noted that increasing average car ridership from 1.1 to 2 represents a significant change. A possible policy implication would be for local governments to provide additional incentives for carpooling and increasing vehicle fuel efficiency.

Conclusions and Discussion

Data from ten randomly selected routes collected over a three-week period reveals that OCTA system ridership averages 14.49 people per mile. Although this is greater than the average of 7.1 passengers per mile required for buses to be more emission efficient than cars, I find that investing in buses is a very cost-inefficient way of reducing CO_2 emissions. The OCTA bus system is currently preventing the release of 20,000 to 51,000 metric tons of CO_2 each year by providing an alternative mode of transportation to cars. This saves society an estimated $109,800–$279,990 annually. Once the global impact of CO_2 is considered, the value of these savings rises to $724,200–$1,846,710. If we assume that the state acts to maximize the welfare of society, then the subsidies that state and federal governments provide may be viewed as reimbursement to local agencies for their external benefits. With this in mind, the values of OCTA's emission savings are not solely enough to justify the transportation agency's $480 million subsidy. This is partially due to the EPA's relatively low valuation of the social cost of carbon. Other papers have incorporated estimates of $200 per ton of carbon or higher in their analyses (Johansson, 1999). Even using the upper bound of emission savings though, CO_2 would need to be valued at over $9,400 per metric ton to cover OCTA's state and federal subsidies.

If one's primary goal is to reduce or offset CO_2 emissions, there are cheaper alternatives than investing in public transportation by bus. However, it is undeniable that buses provide an incredibly valuable service to their users. By providing inexpensive transportation, they improve the local economy and allow individuals greater access to different jobs. According to a 2008 OCTA bus survey, the mean income of OCTA bus riders is $31,800, and 60% of riders do not own a car. Without state and federal subsidies, it is unlikely that OCTA would be able to provide affordable services to the low-income areas that benefit most from a bus system.

Assumptions

Several assumptions were made throughout the course of this project. Ridership data was collected primarily on weekdays from 7 am to 1 pm in January 2011. It is likely that ridership varies seasonally over the course of the year and on weekends. However, data provided by OCTA indicates that bus frequency is regulated to maintain an average of 15 boardings per revenue vehicle hour regardless of the day. The analysis also assumes that all bus riders would otherwise travel a similar distance by car if the OCTA system were unavailable. This biases emission benefits in favor of buses, as only 60% of passengers that take the bus own a car (OCTA b). Additionally, only four-person passenger cars are considered in emissions calculations, and they are all assumed to achieve 22.5 mpg. In reality, there are a variety of different vehicles on the road at all times with large differences in fuel economy. The value of 22.5 mpg was used to make the results of the paper more applicable to future analyses. In calculating the mpg a car would need to achieve in order to be on par with bus emissions, only car mpg is allowed to vary while bus mpg remains fixed. This underestimates the emission advantages of buses in the future. Advances in technology will likely improve mpg for buses as well as cars. Finally, it is assumed that emissions of particulate matter and NO_x are insignificant enough to be ignored for both cars and buses. For the most part, CNG is burned very cleanly and the assumption holds. These emissions cannot be ignored for diesel buses, though. PM emissions especially can be very detrimental to air quality and human health, so the emission benefits of diesel buses are likely very low.

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Works Cited

[APTA] American Public Transportation Association. "2010 Public Transportation Fact Book: 61st Edition." Washington, DC: American Public Transportation Association. (2010). Available at www.apta.com.

Callaghan, Lisa. "Funding Bus Rapid Transit in the U.S." Report for the Transportation Research Board. 2007. 1–18.

[CARB] California Air and Resource Board. "Trends in California Greenhouse Gas Emissions fro 2000 to 2008 – by Category as Defined in the Scoping Plan." California Environmental Protection Agency: Air Resource Board. May 2010.

Chen, Cynthia, Jason Chen, and James Barry. "Diurnal pattern of transit ridership: a case study of the New York City subway system." Journal of Transport Geography 17 (2009): 176–186.

[DOT] Department of Transportation, National Highway Traffic Safety Administration. "Average Fuel Economy Standards: Passenger Cars and Light Truck Model Year 2011." 2009. Accessed online February 28, 2011 at http://www.nhtsa.gov/fuel-economy.

[EPA a] Environmental Protection Agency (a). (November 2010). "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010." Office of Transportation and Air Quality.

[EPA b] Environmental Protection Agency (b). (May 2010). "EPA and NHTSA to Propose Greenhouse Gas and Fuel Efficiency Standards for Heavy-Duty Trucks; Begin Process for Further Light-Duty Standards: Regulatory Announcement." http://www.epa.gov/otaq/climate/regulations/420f10038.htm. Accessed January, 2011.

Glaeser, Edward L, Matthew E. Kahn, and Jordan Rappaport. (2008). "Why do the Poor Live in Cities? The Role of Public Transportation." Journal of Urban Economics 63. 1–24.

Johansson, Bengt. "The Economy of Alternative Fuels when Including the Cost of Air Pollution." Transportation Research Part D 4 (1999) 91–108.

Lambert, D. C., M. Vojtisek-Lom, et al. (2002). "Evaluation of on road emissions from transit buses during revenue service." Buffalo, NY, Clean Air Technologies.

[NIST] National Institute of Standards and Technology. "NIST Handbook 44: Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices." 2007. http://ts.nist.gov/weightsandmeasures/h44-07.cfm.

[OCTA a] Orange County Transportation Authority. "Annual Budget: Fiscal Year 2010–2011."

[OCTA b] Orange County Transportation Authority. "OCTA Bus Satisfaction Study Summary of Results." Jan. 2008.

[OCTA c] Orange County Transportation Authority. "Bus Transit: Fast Facts." Jun 2010. Trudell, Phyllis, Gordon Robinson, Bill Habibe, Jorge Duran, Brian Hoang. Email Correspondence. Jan 2011.

Turrio-Baldassarria, Luigi, Chiara Laura Battistelli, Luigi Conti, Riccardo Crebelli, Barbara De Berardis, Anna Laura Iamiceli, Michele Gambino, and Sabato Iannaccone. "Evaluation of Emission Toxicity of Urban Bus Engines: Compressed Natural Gas and Comparison with Liquid Fuels." Science of the Total Environment 355 (2006): 64–77.

[US] United States Government. Interagency Working Group on Social Cost of Carbon. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866." Feb 2010.