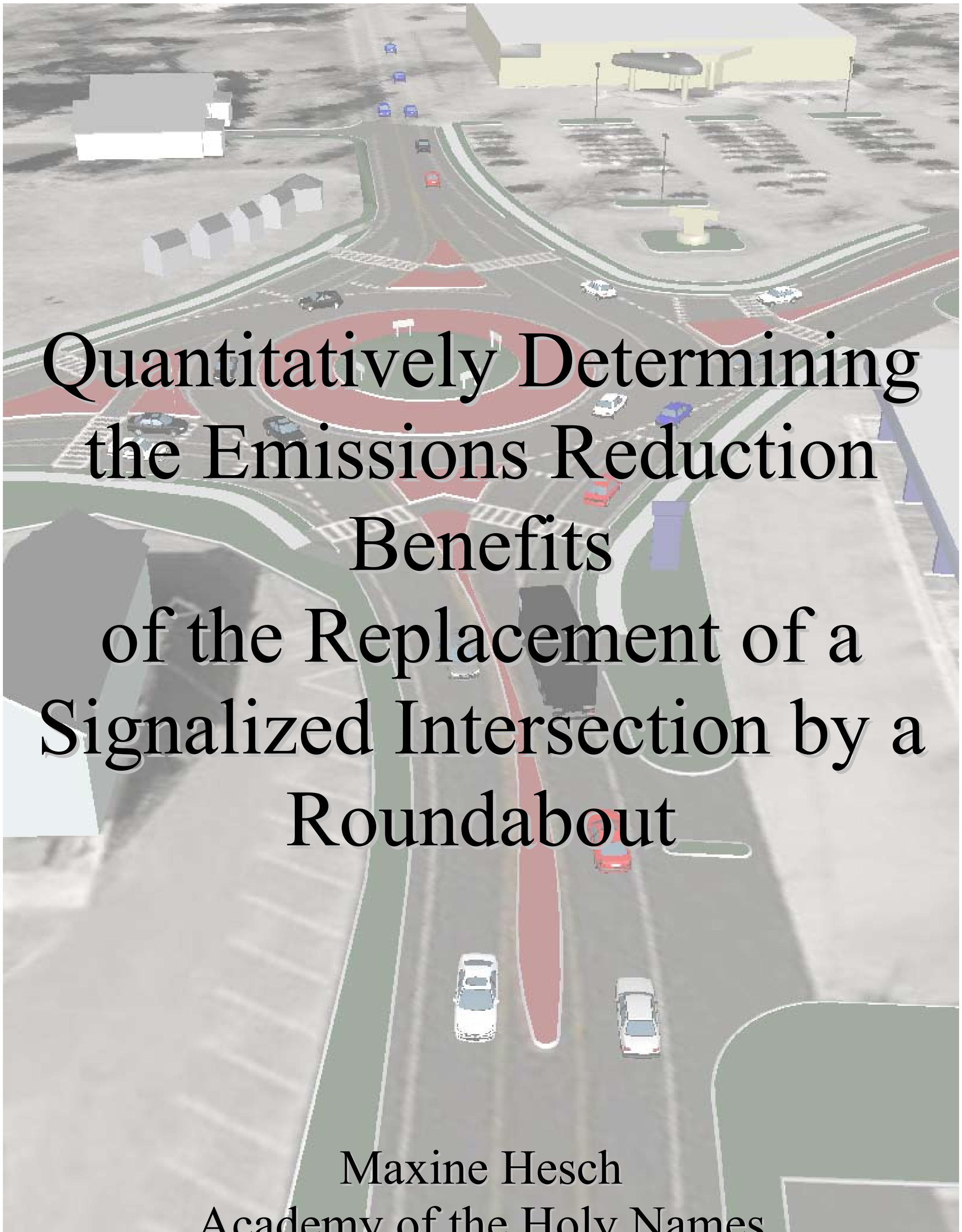

Quantitatively Determining the Emissions Reduction Benefits of the Replacement of a Signalized Intersection by a Roundabout

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Abstract

Roundabouts (circular intersections with relatively small diameters and deflected entrances) can be used to decrease vehicle delay time at intersections. The purpose of this study is to quantitatively determine the approximate magnitude of emissions reduction that can reasonably be expected from converting a failing signalized intersection to a roundabout, and to determine how the conversion of signalized intersections to roundabouts could contribute to the reduction of air pollutants in a specified geographical area.

aaSIDRA computer software was used to perform an analysis of a roundabout at a suburban New York intersection, where there is currently a traffic signal. The program estimated air pollution rates, delay times, and fuel consumption. This analysis was compared to the output from an aaSIDRA analysis of an improved version of the existing traffic signal. The two projections were compared to investigate the precise difference between the roundabout and the signal with regard to delay time, fuel consumption, and emissions.

Results showed that the roundabout reduced emissions, delay times, and fuel consumption at the intersection.

Introduction

With the current level of interest in the issue of global warming, it is becoming more and more apparent that air pollution is a growing problem in the United States. The Union of Concerned Scientists, along with many others such as former vice-president Al Gore, has expressed concern regarding the rapid degeneration of air quality. According to a study done by the Environmental Defense Fund, the US accounts for 45% of carbon dioxide emissions worldwide (Freeman). The EPA reported in March of 2006 that 27% of US greenhouse gas emissions from 1990-2003 were from the transportation sector (<u>Greenhouse</u> 1). This includes cars, trucks, SUVs, aircraft, buses, trains, and similar modes of transport. Similarly, data collected by the Energy Information Administration (an agency within the US Department of Energy) showed a decided increase in carbon dioxide emissions in the transportation sector between 1990 and 2004 (<u>Emissions</u>, xii).

Attempts have been made to stem this increase in harmful pollutants. The past few years have seen an increase in the number of electric or hybrid cars available, and automobile engines in general run much more efficiently than they did a few decades ago. Many areas encourage commuters to carpool, and suggest that residents attempt to minimize unnecessary trips.

There are efforts worldwide to cut down on greenhouse gas emissions, including the United Nations' Kyoto Protocol, which is an international effort to decrease the world's greenhouse gas emissions 5% by 2012 (United Nations). The United States did not ratify the Protocol, but many individual organizations and institutions within the country have set their own goals and incentives for emissions reduction. Seattle, Washington's Mayor, Greg Nickels, asked that all US mayors sign an agreement to (a) meet or surpass the Kyoto Protocol's 5% target, (b) urge the government (at both federal and state levels) to attempt to meet the Kyoto

Protocol's reduction suggestion for the US (7% reduction by 2012), and (c) support greenhouse gas reduction legislation in Congress (“Seattle”).

The US Department of Transportation's Congestion Mitigation and Air Quality (CMAQ) Improvement Program provides funding for transportation projects aimed at reducing emissions levels. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) legislation, signed into law by President Bush in 2005, continued the CMAQ program and supplied it with over $8 billion in funding through the year 2009. In addition, the Environmental Protection Agency's Clean Air Act requires states to create State Implementation Plans (SIPs) to detail the steps they will take to decrease their state's air pollutants by a certain amount.

In addition to improving vehicle characteristics and manipulating driver behavior, improving the efficiency of the transportation network is another way to reduce air emissions. When adapting infrastructure with an aim towards decreasing emissions levels, as for a State Implementation Plan or a CMAQ project, one of the primary considerations is reducing vehicle delay. It has been determined through multiple traffic modeling programs, including the USEPA’s MOBILE5, that cars generally emit more pollutants when they travel at lower average speeds (Williamson). It therefore follows that if delays were minimized (and average speed therefore raised) emissions would be reduced. This can be accomplished in a number of ways, including coordinating traffic signals (so that drivers do not encounter a number of red lights in a row) and converting signalized intersections to roundabouts.

Roundabouts are circular intersections with relatively small diameters and deflected entrances, both of which tend to restrict vehicles to traveling at lower speeds. As a result of this low speed environment, vehicles entering the roundabout intersection are able to merge and travel through safely and efficiently without red lights interrupting the normal traffic flow. Highway corridors where roundabouts have been installed have been observed to have lower operating speeds, but also significantly lower stopped delay time than signalized corridors. Thus, the *average* speed (as computed from the distance divided by the time to travel through the corridor) is observed to be greater with roundabouts. The accident-reduction benefits of roundabouts are facts touted proudly by pro-roundabout organizations. However, until this study there has been no precise value placed on the amount of pollution or fuel consumption reduced by converting a signalized intersection to a roundabout.

Review of Literature

A study performed by Mandavilli, Russell, and Rys compared emissions levels before and after the installation of a roundabout and showed that "Modern roundabouts can improve traffic flow as well as cut down vehicular emissions and fuel consumption by reducing the vehicle idle time at intersections and thereby creating a positive impact on the environment" (Mandavilli 1).

Bergh, Retting, and Myers also provided information suggesting the benefits of roundabouts as compared to traffic lights (Bergh 2).

The Insurance Institute for Highway safety suggested that roundabouts could possibly reduce over 50% of traffic delays (Insurance).

Very few studies have been done to determine the exact emissions reduction capabilities of roundabouts. Shauna Hallmark of Iowa State University attempted to quantify the reductions benefit of replacing a signalized intersection with a roundabout. Her study utilized two different computer programs when only one was needed, claiming that aaSIDRA, since it was not the EPA-sanctioned emissions model, should not be used (Isebrands 3). In addition, in a personal correspondence Ms. Hallmark claimed that a deciding factor in selecting other programs over aaSIDRA was her belief that "the assumptions and rates for emissions in aaSidra [sic] are based on European values." When my mentor informed aaSIDRA's creator, Rahmi Akcelik, of this claim, Mr. Akcelik responded by saying that Ms. Hallmark was incorrect in her assumption, as the developers of aaSIDRA “compared some of SIDRA vehicle emission parameters with recent data from USA and found that they are reasonably close.” In addition, Mr. Akcelik’s study used *Australian* cars which are "larger than European cars". "Australia,” said Mr. Akcelik in an email, “is more like US and Canada than Europe (new country, large country, strong rural element, etc)."

Purpose

The purpose of this study is to determine the approximate magnitude of emissions reduction that can reasonably be expected by converting a failing signalized intersection to a roundabout. An intersection “fails” when it receives a Level of Service rating of F. Level of Service is a qualitative rating of the effectiveness of a roadway in serving traffic, in terms of operating conditions such as traffic flow. It uses an alphabetical scale from A to F with A being the best (free flow) and F being the worst (stopped traffic). For intersections, Level of Service is based on average delay (in seconds per vehicle). If there are delays greater than 80 seconds, the intersection receives a Level of Service of F.

An additional purpose is to quantitatively determine how much the conversion of signalized intersections to roundabouts could contribute to the reduction of air pollutants in a specified geographical area.

Methods / Materials

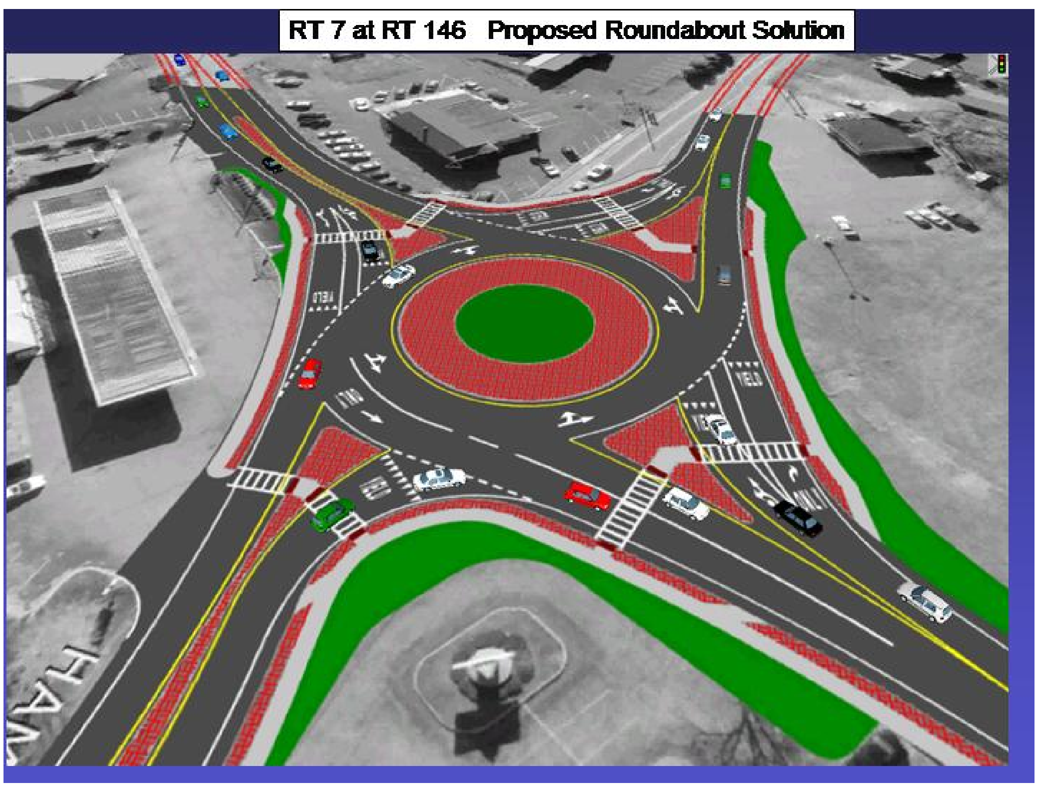
To achieve the purpose of this study, the approximate magnitude of emissions reduction from roundabout conversion for a specific geographical area had to be determined. Once that was attained, an estimation could be made of how a roundabout could contribute to that area’s goal.

The intersection evaluated in this study is located in Rotterdam, New York (Schenectady County) at the intersection of Routes 7 and 146. Currently, the major movement during the intersection's PM peak hour (westbound Route 7) operates at Level of Service F, with typical delays over 3 minutes. Due to this fact, as well as a high accident rate, the New York State Department of Transportation (NYSDOT) has studied various improvement options for reconstruction. NYSDOT has had much success using roundabouts as replacements for failing signalized intersections. In fact, in August of 2006, NYSDOT implemented a new design policy requiring that roundabouts be the preferred option for intersection reconstruction (Schips). Thus, NYSDOT has decided to replace the signal at Routes 7 and 146 with a modern roundabout.

Following are two figures depicting the intersection as it is now (*Figure 1*) and a computer simulation of the proposed roundabout (*Figure 2*).

Figure 1: Routes 7 and 146, Rotterdam, New York

Figure 2: Computer Illustration of Roundabout



The first step in determining the reduction in fuel consumption, delay, and emissions following this conversion was to perform a computer analysis of a roundabout at the intersection by using aaSIDRA. aaSidra is a computer software program created by Australian Rahmi Akcelik which can analyze an intersection (a signalized intersection or a roundabout) and estimate, among other things, air pollution emission rates. The DOT's traffic count information was entered into aaSIDRA, as were data specifying the size of the proposed roundabout, width and number of lanes, and other required information. These details were entered by my mentor and represent the actual design parameters for the proposed roundabout. aaSIDRA generated a report projecting, among other information, projected emissions levels for hydrocarbons, carbon monoxide, nitrogen oxide, and carbon dioxide. It also calculated the amount of fuel consumption at the roundabout.

aaSIDRA was then used to analyze an ideal version of the existing signal (i.e. the existing signal with added lanes to achieve the desired level of service). Again aaSIDRA provided a report about emissions levels and other characteristics. The two projections were compared to investigate the precise difference between the roundabout option and signalized option with regard to delay, fuel consumption, and emissions.

The following are figures depicting the values for emissions and fuel consumption for the roundabout and improved signal.

Figure 3: Hydrocarbon Emissions by Approach

Approach	Emissions at Signal (kg/h)	Emissions at Roundabout (kg/h)
South	0.215	0.16
East	0.389	0.236
North	0.173	0.16
West	0.198	0.165

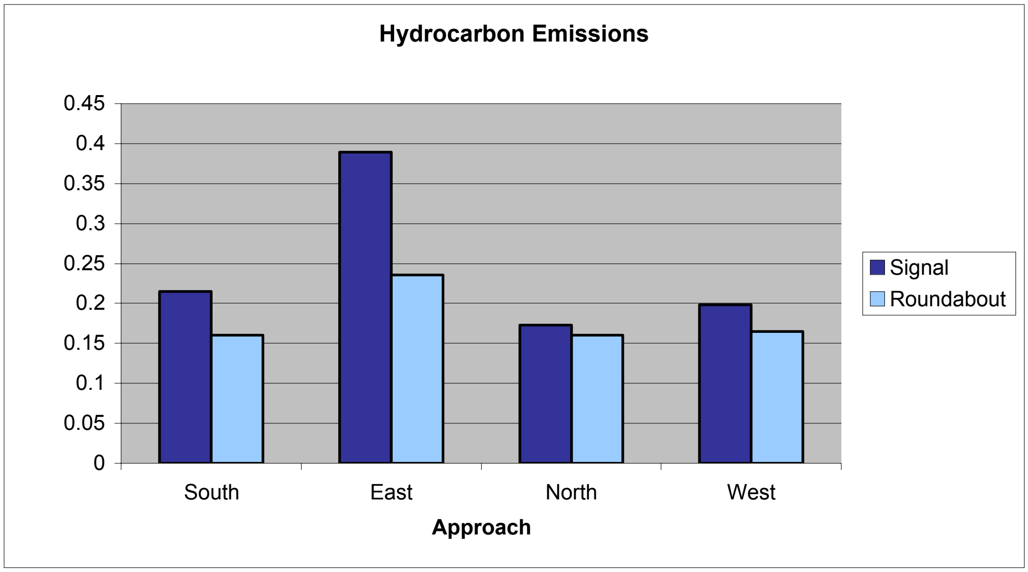


Figure 4: Carbon Monoxide Emissions by Approach

Approach	Emissions at Signal (kg/h)	Emissions at Roundabout (kg/h)
South	9.86	8.09
East	17.66	11.85
North	8.14	8.13
West	9.31	8.34

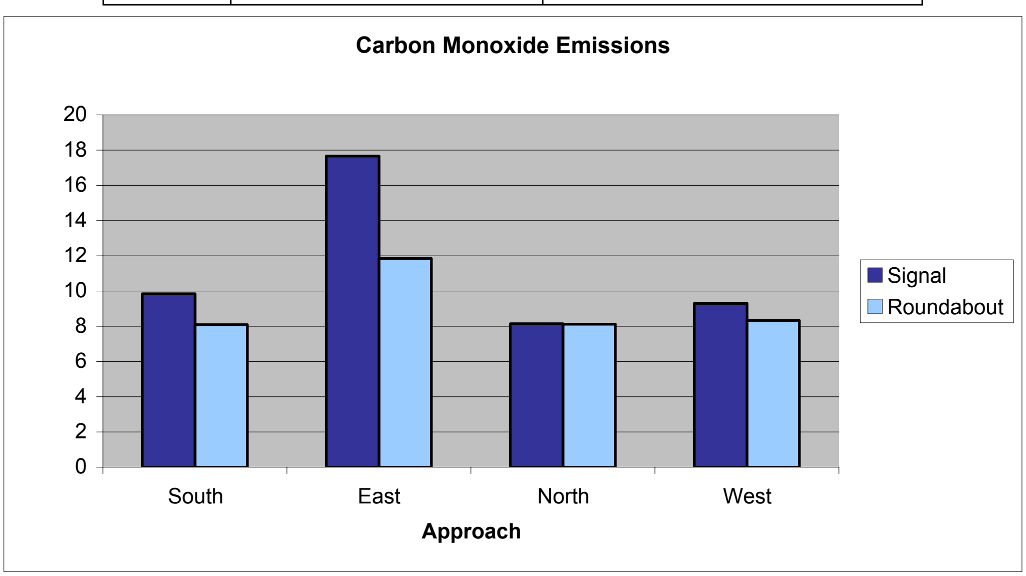


Figure 5: Nitrous Oxide Emissions by Approach

Approach	Emissions at Signal (kg/h)	Emissions at Roundabout (kg/h)
South	0.292	0.247
East	0.501	0.361
North	0.249	0.245
West	0.279	0.251

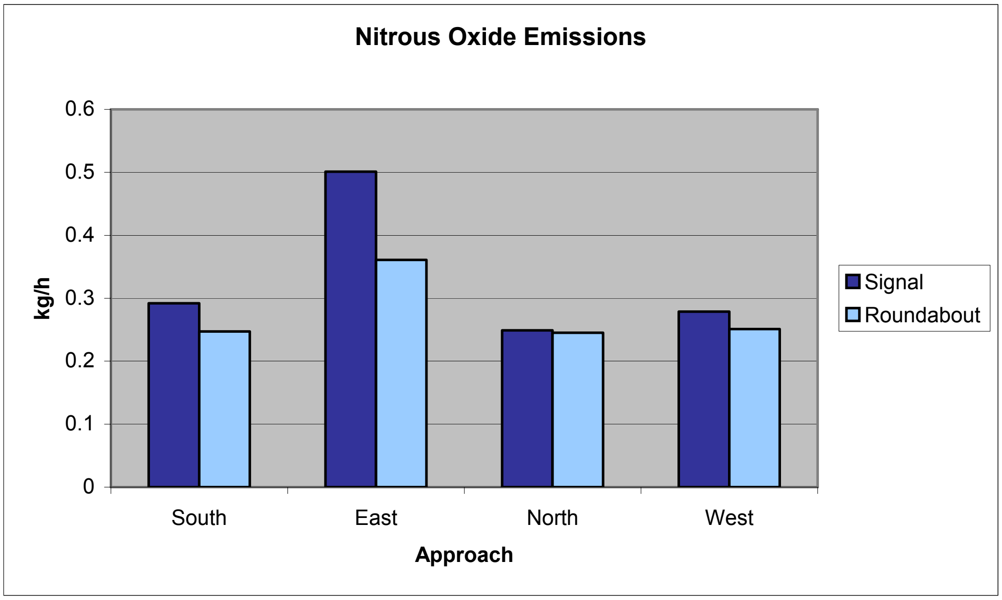


Figure 6: Carbon Dioxide Emissions by Approach

Approach	Emissions at Signal (kg/h)	Emissions at Roundabout (kg/h)
South	126.9	100.3
East	218.6	147.8
North	106.9	99.3
West	119.4	102.6

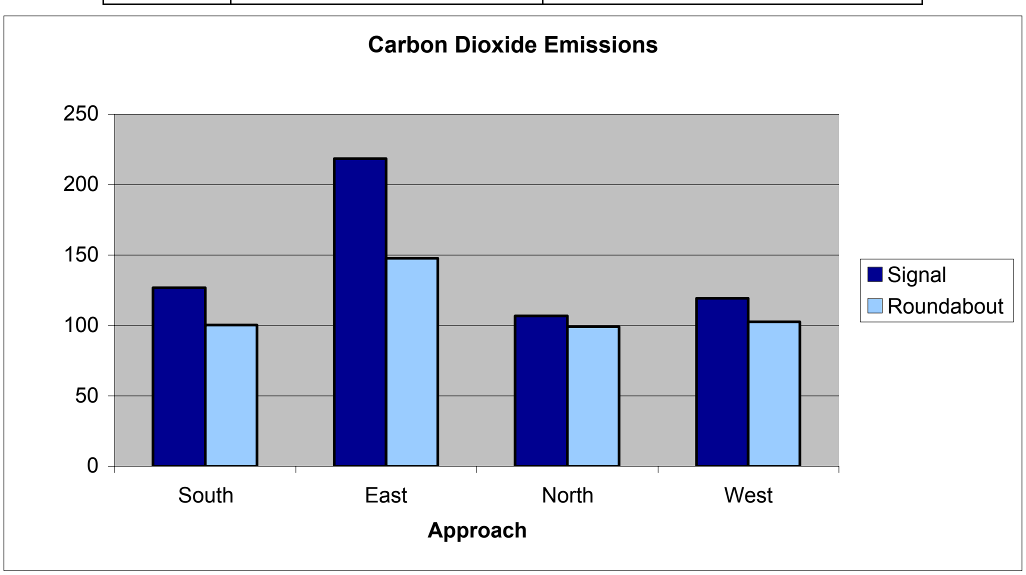


Figure 7: Fuel Consumption by Approach

Approach	Consumption at Signal (L/h)	Consumption at Roundabout (L/h)
South	50.6	40.1
East	87.2	59
North	42.7	39.7
West	47.7	41

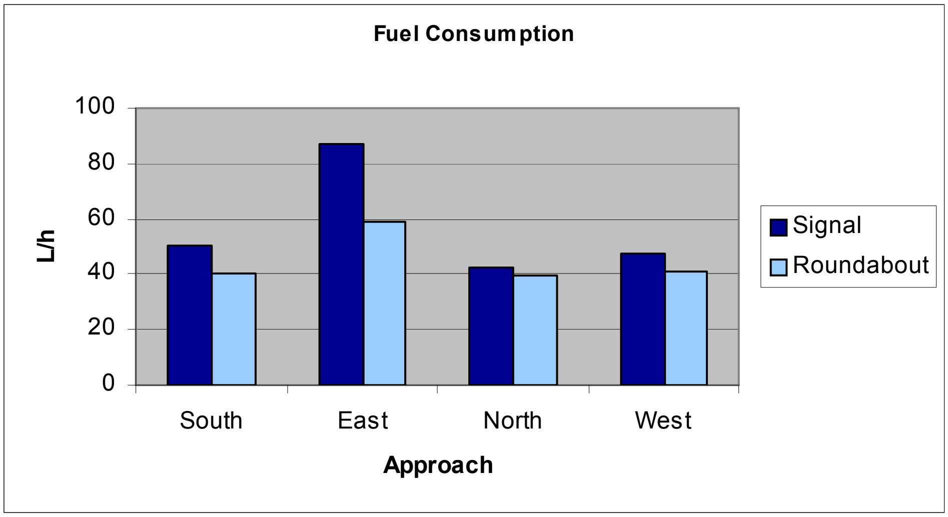


Figure 8: Summary of Decrease in Pollutants

Pollutant	Approach	Signal Production (kg/h)	Roundabout Production (kg/h)	Difference (kg/h)	% Decrease
CO2	South	126.9	100.3	-26.6	20.96
	East	218.6	147.8	-70.8	32.88
	North	106.9	99.3	-7.6	7.11
	West	119.4	102.6	-16.8	14.07
	Intersection Total	571.9	450.0	-121.9	**21.31**
NOX	South	0.292	0.247	-0.045	15.41
	East	0.501	0.361	-0.14	27.94
	North	0.249	0.245	-0.004	1.61
	West	0.279	0.251	-0.028	10.04
	Intersection Total	1.320	1.104	-0.216	**16.36**
CO	South	9.86	8.09	-1.77	17.95
	East	17.66	11.85	-5.81	32.9
	North	8.14	8.13	-0.01	0.123
	West	9.31	8.34	-0.97	10.42
	Intersection Total	44.97	36.41	-8.56	**19.03**
HC	South	0.215	0.16	-0.055	25.58
	East	0.389	0.236	-0.153	39.33
	North	0.173	0.16	-0.013	7.51
	West	0.198	0.165	-0.033	16.67
	Intersection Total	0.975	0.721	-0.254	**26.05**

Figure 9: Summary of Intersection Level of Service (LOS) and Delay Times

Parameter	Signal	Roundabout
Intersection LOS	D	B
Worst Movement LOS (LOS at the time of the intersection's worst performance)	E	B
Average Delay (s)	37.9	10.7
Total Vehicle Delay (vehicle hours/hour)	38.28	6.85

Conclusion

As shown, there are significant reductions from the roundabout for all parameters, ranging from a 16.36% reduction in nitrous oxide to a 26.05% reduction in hydrocarbons compared to the traffic signal. In my mentor's opinion, no other single intersection improvement could have achieved such significant reduction in delay and the corresponding reduction in emissions and fuel consumption.

At its peak hour, the roundabout reduces carbon monoxide at the intersection by 8.5 kg/h. Peak hour (the time during which most of an intersection's traffic passes through) is generally regarded to represent about 1/10th of the daily volume. That makes the daily reduction of CO approximately 85 kg/day.

Having acquired a quantitative estimate for the amount of pollution reduced, the data could be compared to the State Implementation Plan data for Onondaga County, New York, which is a region with similar characteristics to Rotterdam. Onondaga has a SIP goal of reducing from 495 tons of CO per day to 372 tons per day between 2003 and 2009. That means reducing 123 tons over six years, or 20.5 tons per day per year. This data was acquired in an email communication from Patrick Lentlie of the New York State Department of Transportation

Environmental Analysis Unit's Air Analysis Section   The Rotterdam roundabout would reduce approximately 0.0936 tons per day, which is 0.456% of Onondaga's daily reduction goal. Therefore, simple multiplication shows that ten roundabouts would each day contribute 4.56% of the SIP goal.

Future Research

This study showed that roundabouts decrease delay time, fuel consumption, and emissions at an intersection when compared to a traffic light. It follows, then, that transportation agencies in the United States should institute programs to increase the number of roundabouts being used to replace failing signals. Such agencies, as well as others involved in development, should be made aware of the fact that a signal which meets design criteria will produce up to 26.05% more emissions than a roundabout at the same location.

In addition, carbon dioxide is not currently a regulated emission, despite its negative impact on the environment. This and other greenhouse gases should be regulated on the state and national level. Precisely *how* to regulate those would be the topic of a different study.

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ABOUT THE AUTHOR

The author of this paper, Maxine Hesch, is a senior at the Academy of the Holy Names in Albany, NY (grad. Spring 2007). Maxine began her research in the 8th grade as a simple study of the correlation between traffic light length and automobile carbon monoxide emissions. Students were given the option of continuing in the Science Research program throughout high school. Maxine elected to take the course for the full four years. Her continued research led to information about the delay reduction properties of roundabouts. Science Research students are required to have a mentor and Tom Kligerman, a civil engineer in NYSDOT's Office of Design, agreed to serve as Maxine's mentor for this project.

Maxine recently earned an award for the presentation of this paper at the Upstate New York Sub-Regional Junior Science and Humanities Symposium.

Maxine completed work on this project in March 2007.