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Analyzing Traffic Engineering Applications in the Rhode Island Transportation System to Determine Potential Environmental Sustainability

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TABLE OF CONTENTS

FIGURES

Abstract

Transportation engineering is the application of technology and scientific principles to the planning, functional design, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods. Traffic engineering is a specific segment of transportation engineering that deals with the planning, geometric design, and traffic operations of roads, streets and highways, their networks, terminals, abutting lands, and relationships with other modes of transportation (Traffic Engineering, 2011). In the midst of this, there is concern for environmental compatibility, which continues to be of growing interest especially with regard to sustainable transportation. What can be done to work toward a more sustainable transportation system is a vital interest, and that is driving the desire to understand how traffic engineering applications can be viewed for their ability to provide a more sustainable transportation system.

This semester, I worked with Dr. Christopher Hunter to develop a research paper exploring how traffic engineering applications can be used to encourage environmental sustainability in Rhode Island. The rationale for the project is trying to gain a more quantifiable view of sustainability using available data. Emissions from vehicles give off pollution, which damage the ozone layer as well as reduce air quality. In addition, crude oil is being excessively used for gasoline and the supply left is dwindling. In exploring how traffic engineering can be used to encourage environmental sustainability, the focus was on congestion; Minimizing congestion reduces both pollution and the usage of gasoline, which encourages environmental sustainability. Safety was also taken into heavy consideration for the obvious reason of reducing

accidents and fatalities. However, an increase in safety and a decrease in accidents would also result in fewer instances of congestion.

A number of visionary ideas for the future will be discussed in this paper. The solution discussed in the most depth is the implementation of roundabouts. Research has shown that roundabouts reduce accidents and decrease congestion as compared to signalized and non-signalized intersections. Another such solution that will be discussed is the use of automatic tolls located at certain checkpoints in chronically congested areas during the "rush hour" to encourage people to stagger their commute and discourage the use of critical roadways for non-work/non-essential purposes during this time. Finally, variable/dynamic messaging signs will be mentioned briefly.

1. INTRODUCTION

Many definitions have been provided over the years for the terms sustainability, sustainable development, and sustainable transportation. The best definition I came about in my research was from a 1987 report for the United Nations World Commission on Environment and Development, which defined sustainable development as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (U.N. WCED 1987). Many people consider the publication of this report as instrumental in showing that a much more comprehensive approach was necessary to address the issue of sustainability (Clayton and Radcliffe 1996). In the years since 1987, awareness of sustainability has spread and it is an important consideration to address in any transportation project today.

The Texas DOT (TxDOT) lists five goals that address the three main components of sustainable transportation. These goals are to reduce congestion, enhance safety, expand economic opportunity, improve air quality, and preserve the value of transportation assets. The three components of sustainable transportation that these goals address are economic development, environmental stewardship, and social equity (TxDOT 2009). As mentioned, this paper will focus primarily on the benefits of roundabouts in addressing the first two goals set forth by the TxDOT: reducing congestion and enhancing safety. In addition, the concept of automatic tolling will be introduced. Suggestions will be made as to how the state of Rhode Island can utilize this type of tolling to decrease congestion, as well as provide funding that can then be used toward further tackling the issue of congestion. Variable/dynamic messaging signs are already in use throughout Rhode Island. Suggestions will also be made how these signs can be used to decrease congestion and make Rhode Island more environmentally sustainable.

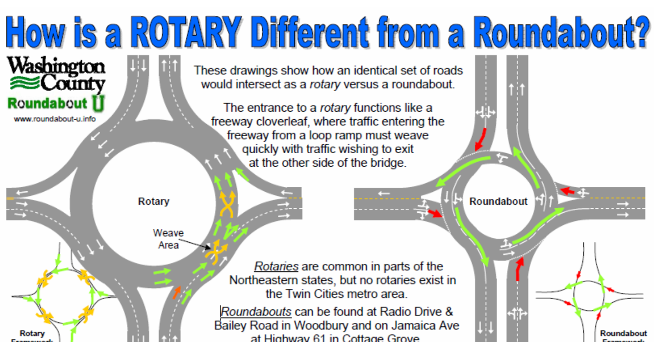
2. ROUNDABOUTS

Roundabouts are a modern engineering design that is very different than the typical traffic circle in the United States. In contrast to the old traffic circle, modern roundabouts are designed to handle high capacities. As a result, there are fewer delays and fewer accidents. According to Jacquemart, "the key guidelines are: (1) traffic in the circle has the priority and entering vehicles must yield, (2) a deflection at the entrance forces cars to slow down (tangential entries are not allowed), and (3) short flares at the entrance and wider circle are used to increase capacity" (411). The outside diameters of roundabouts typically vary from outside diameters of 50 ft to 300 ft. The major reasons that this method is a safer than a typical traffic circle or signalized/non-signalized intersection is the reduced approach speed and the simplistic nature of the roundabout. The only thing cars have to worry about is yielding to other cars, cyclists, and pedestrians.

2.1. Introduction to Roundabouts

As mentioned, the outside diameters of roundabout typically vary from 50 to 300 ft. Roundabouts between 50 ft and about 100 ft outside diameter are typically referred to as "mini-roundabouts." Often, the diameters of these smaller roundabouts are dictated by the turning radius of larger trucks (Jacquemart 411). Center islands are commonly incorporated into mini-roundabouts in such a manner that larger trucks can drive onto them if needed in order to execute a turn. The main purpose on these smaller roundabout is for traffic-calming purposes (Jacquemart, "Let's go round"). The outside diameters of single-lane roundabouts varies from 100 to 140 ft. Trucks are not able to mount the central island of these types of roundabouts. Multi-lane roundabouts typically vary from 120 to 200 ft (but can be up to 300 ft). These larger roundabout are typically designed and implemented for high capacity in safety, while also retaining the ability of traffic-calming (Jaquemart 411).

2.2. Rotary vs. Roundabout



Rotary	Modern Roundabout
It is typical to enter a rotary alongside traffic that is circulating in the inside lanes, like a freeway cloverleaf loop entrance where the ramp entrance lane continues under or over a bridge to the next exit.	Entering traffic must always yield to ALL traffic in the roundabout, regardless of which lane they are in, just like crossing a one-way road.
No intersections occur in a rotary, only adding and dropping of lanes. The right lane usually does not need to yield, but must find a gap to change lanes. The left entry lane must merge or yield before entering.	A roundabout is a series of "crossing intersections" where traffic entering the roundabout must **yield** the right of way to all traffic from the left.
The circle is usually not striped, though multiple vehicles may travel side by side. Lane changes occur after you have entered the circle.	The circle is striped as a spiral. Never change lanes in a roundabout. Choose your lane before entering, just like at a standard intersection.
Entering drivers who wish to circulate must change lanes while circulating and weave with vehicles trying to exit.	No lane changes occur within a roundabout. Except for vehicles that are turning right, entering a roundabout is a "crossing" movement.
A rotary is typically large, with entry speeds of 40 mph or higher.	A roundabout is generally small; speeds are rarely more than 25 mph.
Rotaries work well at low volumes, but very poorly under heavy traffic conditions. Most were designed in the 1940's or earlier.	Roundabouts are able to handle heavy traffic and are used for efficiency and safety. Roundabouts were developed in the 1960's.
Entry may be controlled by yield signs, merge signs, or no signs at all.	Entry is always controlled by yield signs for maximum efficiency.

Figure 1: How is a Rotary Different from a Roundabout (How is a Rotary, 2011)

The typical traffic-circles mentioned previously are commonly referred to as rotaries. Rotaries are not a recent concept by any means. In fact, the first rotaries came about before the invention of the automobile. The first rotary in the United States, know as a "gyratory," was installed in New York City in 1905 (Roundabouts Improve, 27). The vary majority of the rotaries in the United States were designed during or before the 1940's. A new technology, the roundabout, was first developed in the 1960's and has been gaining approval across the globe ever since (How is a Rotary, 2011). Comparisons between the unique characteristics on rotaries and roundabouts will be discussed in detail.

In a rotary, cars commonly (and are permitted to) enter the outside lane(s) of the circle while cars are traveling in the inside lanes. This poses a problem when the entering car wants to move to an inside lane or a circulating car wants to move to an outside lane. When this happens, weaving occurs within the circle. Primarily as a result of this weaving, rotaries only work well at low volumes; When they become congested during high traffic conditions, the weaving essentially brings a rotary to a standstill. A major property of rotaries is that no intersections occur within the circle. Any lateral movement desired must occur through changing lanes or weaving. Most often, a rotary is not striped. Entrance into the circle is often controlled by yield or merge signs, but sometimes no signs are present. Lastly, rotaries are typically larger than roundabouts and entry speeds often approach and exceed 40 mph (How is a Rotary, 2011).

In contrast, cars entering a modern roundabout must yield to all cars traveling within the circle. In contrast to rotaries and signalized/non-signalized intersections, roundabouts can handle a greater capacity (How is a Rotary, 2011). Roundabouts continue to function, even during periods of heavy traffic because circulating traffic always keeps moving (Modern Roundabout, 48). A number of intersections occur within a roundabout with lanes to the left always having the right-of-way over entering vehicles. Unlike rotaries, the circle is striped as a spiral and no lane changes or weaving is permitted. Yield signs are always present in a roundabout. Lastly, roundabouts are typically smaller than rotaries, with entry speeds typically at or under 25 mph (How is a Rotary, 2011).

2.3. Single-Lane Roundabout

Figure 2: One-Lane Roundabout (How to drive, 2011)

As mentioned previously, single lane roundabouts are typically constructed to have an outside diameter of 100 to 140 ft and include a non-mountable center island. The yellow sign shown in Figure 2 is called a "roundabout ahead" sign. This sign is accompanied by an advisory speed limit for the roundabout. For those unfamiliar with how to utilize a single lane roundabout, the key aspects will be discussed. As a vehicle approaches a roundabout, they must slow down and look out for pedestrians crossing the road in the crosswalk. After crossing the crosswalk and continuing to the yield sign and dashed yield line, a vehicle must look to the left to observe whether or not there are other vehicles inside the roundabout. If there are already vehicles in the roundabout, the entering vehicle must wait until there is a gap large enough to safety enter the roundabout. If there are no other vehicles circling in the roundabout, there is no need to yield, however speeds should still be reduced and vehicles should look out for pedestrians. After entering the roundabout, a vehicle should continue traveling in the circle until exiting on the desired road. A final precaution that should be noted is that vehicles circling in a roundabout should use their right-turn signal to indicate where they intend to exit and also look out for pedestrians upon exiting (How to drive, 2011).

2.4. Multi-Lane Roundabout

Figure 3: Multi-Lane Roundabout (How to drive, 2011)

The outside diameters of multi-lane roundabouts typically vary from 120 to 300 ft. Although similar in many ways, multi-lane roundabouts differ slightly from a single-lane roundabout. In addition to the "roundabout ahead" sign shown in Figure 2, multi-lane roundabouts include the black and white "lane choice" sign shown in Figure 3. The purpose of this sign is to inform vehicles that they must choose the appropriate lane before entering the roundabout. Having to choose which lane prior to entering a roundabout mirrors a traditional multi-lane intersection. In a two lane roundabout as shown above, vehicles in the right lane may only turn right or continue straight. Upon exiting the roundabout, a vehicle entering in the right lane should also exit in the right lane, as no lane changing is permitted. Vehicles in the left lane upon entering the roundabout may continue straight, go left, or make a U-turn, all while remaining in the left lane inside the roundabout and upon exiting. Just like with a single-lane roundabout, an entering and exiting vehicle must be cautious of pedestrians utilizing the crosswalk. Upon entering a two-lane roundabout, entering vehicles must yield to both lanes of traffic. Once a sufficient gap is present, a vehicle may enter the roundabout and continue without stopping to the desired exit, where a blinker will be used. Yielding is not required if there are no vehicles in the circle (How to drive, 2011).

For roundabouts with three or more lanes in each direction, the same principles apply as a two-lane roundabout with the acceptable turns in each lane indicated by a "lane choice" sign. Again, just like in a two-lane roundabout, every vehicle entering a roundabout with three or more lanes must enter and exit the roundabout in the same lane they entered.

2.5. Roundabout Capacity & Congestion Reduction

In comparison to typical signalized intersection, roundabouts have been shown to decrease average delays by more than 50%. On average, single-lane roundabouts allow about 2,500 vehicles per hour to utilize the circle per hour. Two-lane roundabouts are capable of allowing between 3,500 and 4,000 vehicles per hour. Three-lane roundabouts are capable of permitting approximately 6,000 vehicles to enter a roundabout per hour (Jacquemart 413). In general, the larger the diameter of a roundabout, the greater the separation of traffic is and the higher the capacity of the circle (Ourston, 1995). An example of a roundabout in use in the United States is the three and four lane roundabout in Long Beach, California. During the peak traffic hour, this roundabout handles 5,000 vehicles per hour with average delays of less than 5 seconds per vehicle (Jacquemart 413).

2.6. Twin River Roundabout Study

According to the Rhode Island Department of Transportation (RIDOT), the only study that has been conducted on a roundabout in Rhode Island is of the two-lane roundabout at the entrance to the Twin River Casino in Lincoln that was installed in late 2006. Pare Corporation (PARE) completed this study in November 2011. It compared the effectiveness of the two-lane roundabout by modeling it against both a signalized intersection with dedicated turn lanes and a one-lane-roundabout. The comparison between the signalized intersection and two-lane roundabout will be discussed. In addition, PARE analyzed crash data to determine the safety impacts of the installed roundabout.

Actual traffic counts collected in September 2011 were 30% less than PARE had predicted. One notable reason for this could be that greyhound racing no longer takes place. As a result, the 2011 existing volumes were less than the 2006 projected volumes. The average intersection delay projected for 2005 on a Friday night without an event was 17.7 seconds for a roundabout and 29.6 seconds for a signalized intersection. The average intersection delay projected for 2005 on a Friday night with an event was 24.2 seconds for a roundabout and 66.7 seconds for a signalized intersection. Lastly, the average intersection delay that existed for 2011 on a Friday night with an event was 10.0 seconds for a roundabout and 17.6 seconds for a signalized intersection. This analysis shows that delays are substantially less with a roundabout than with a signalized intersection. Reduced delay correlates to a decrease in congestion and an increase in environmental sustainability.

PARE also conducted a crash data comparison before and after roundabout implementation. From 2001-2006, there were 13 crashes that occurred at the intersection, 5 of which resulted in injury. This turns out to be an average of 2.6 crashes per year. From 2007 until the study was conducted, there were 16 crashes that occurred at the roundabout, none of which resulted in an injury. This turns out to be an average of 4 crashes per year. Although the crash rate is slightly higher after implementation of the roundabout, the severity of the injuries decreased dramatically. A major part of this can be attributed to slower speeds through the roundabout, which PARE determined to average 20mph through the roundabout, which has a posted speed of 15mph. In addition, the approach speed to the roundabout was determined to be 35mph after roundabout installation, as opposed to 41mph prior. The posted speed limit on Twin River Road is 35mph. Lastly, since the majority of the crashes since implementation have been from motorists failing to yield, it is possible that the crash rate will decrease in the future as drivers become more familiar with how roundabouts are supposed to function.

2.7. Safety

While the United States was once known as the least dangerous place to drive in the world, it is now 12th in the rate of road deaths per miles driven. In addition, the United States is 28th in per capita road deaths (Vanderbilt 6). While the United States is still a relatively safe place to drive, these statistics are disheartening. Studies have shown that around 40% of all injuries on the roadways occur at intersections (Antov 22). Clearly, improving the safety of intersections can significantly reduce the number of injuries on the roadways.

Roundabouts are a device that can seriously improve the safety of roadways in the United States. These devices are able to move traffic safely through an intersection due to slower speeds, fewer conflict points, and easier decision making than typical signalized/non-signalized intersections (Roundabouts, 2010).

2.7.1. Conflict Points

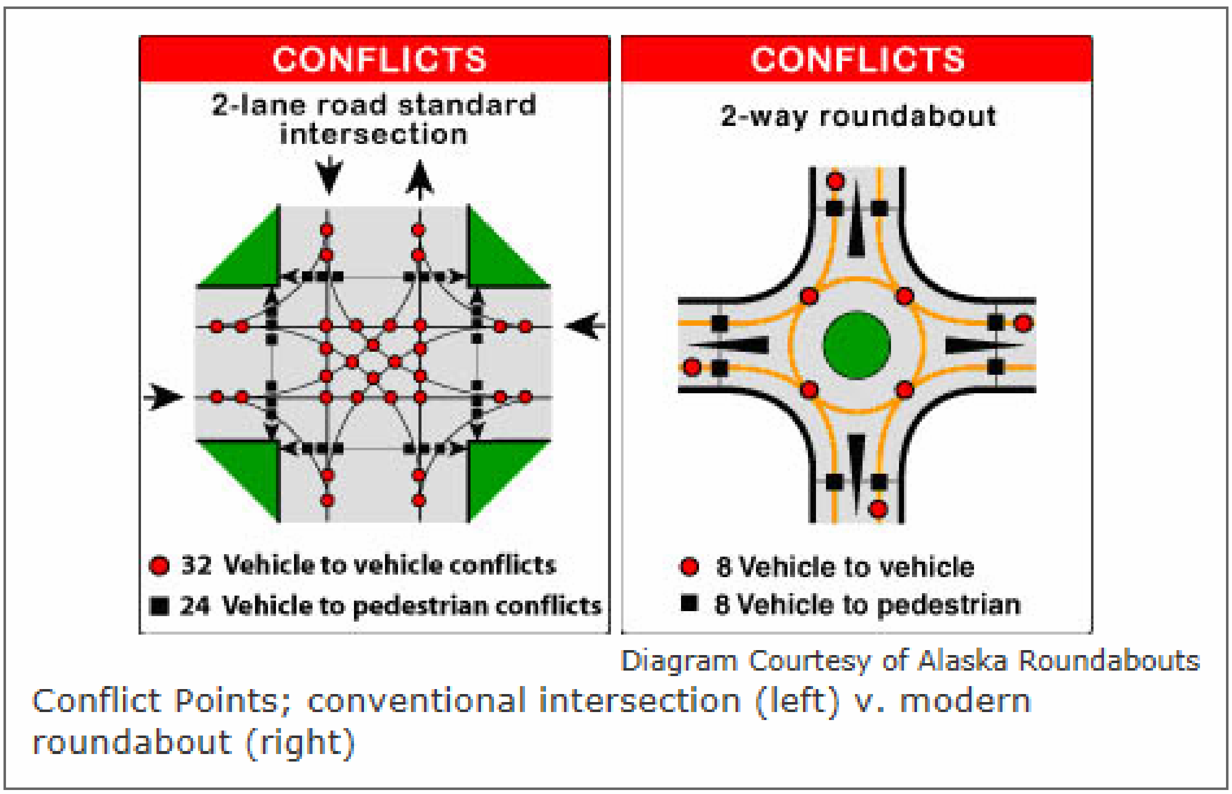


Figure 4: Conflict Points (Safety Benefits, 2011)

The above Figure 4 shows the dramatic difference in the number of conflict points between a standard 2-lane standard road intersection and a 2-way roundabout. Although this figure only compares the intersection of two-lane roads, the same number of conflict points are present regardless of the number of lanes. Each collision point is a location where traffic crosses paths. Traffic is defined as vehicles, bicyclists, and pedestrians (Safety Benefits, 2011). As indicated on this figure, the number of vehicle to vehicle conflict points are reduced from thirty-two to eight (75% reduction) by converting a conventional intersection into a modern roundabout. In addition, the number of vehicle to pedestrian conflict points are reduced from twenty-four to eight (67% reduction). This decrease in the number of conflict points definitely is a major reason for the substantial increase in safety that has been shown at roundabouts.

2.7.2. Studies

A number of studies have conclusively determined that roundabouts are much safer than conventional intersections. The Insurance Institute for Highway Safety (IIHS) completed a study in March of 2000 of twenty-four intersection converted to roundabouts from signalized/non-signalized intersections (Safety Benefits, 2011). The results of this study showed a 90% decrease in fatal crashes, a 76% reduction in injury crashes, a 30-40% reduction in pedestrian crashes, and a 10% reduction in bicycle crashes (Roundabouts, 2010).

A study conducted of 181 roundabouts in The Netherlands before-and-after construction indicated a 51% decrease in total accidents, a 72% decrease in injury accidents, an 89% decrease in pedestrian injuries, and a 30% decrease in bicycle injuries (Jacquemart 411). The results of another before-and-after study of 73 roundabouts in Victoria, Australia showed that total injuries decreased by 74% and pedestrian accidents were reduced by 68% (411). FHWA also conducted a study of 19 intersections converted to roundabouts and found that for single-lane, total crashes were reduced by 51% and total injuries decreased by 73%. For multi-lane, total crashes decreased by 37% and total injuries were reduced by 51% (Roundabouts Improve, 28).

The two most comprehensive studies found were conducted by the Maryland State Highway Administration (MSHA) and the Minnesota Department of Transportation (Mn/DOT), respectively. MSHA conducted a study of thirty intersections that were converted to modern roundabouts. The results of this study were a decrease in annual crashes from 4.05 per year per intersection to 1.11, which is a decrease of 73%. More importantly with regards to safety, the number of annual crashes resulting in injuries per intersection dropped from 2.31 to 0.35, which is a reduction of 85%. Lastly, the total crash rate reported per million vehicles entering fell from 1.36 for conventional intersection to 0.27 after conversion to modern roundabouts (Safety Benefits, 2011). The study conducted by the Mn/DOT at a particularly problematic stop-controlled intersection that was converted to a modern roundabout found some dramatic results.

Location	Implementation Date	Before				After				Reduction in Crashes/Year		
		Months	Total Crashes	Injury Crashes	Angle Crashes	Months	Total Crashes	Injury Crashes	Angle Crashes	Total Crashes	Injury Crashes	Angle Crashes
State Highway 13 and County Road 2	Aug-05	36	19	14	18 (1-fatality)	24	3	2	0	76.2%	78.7%	100%

Table 1: Summary of crash reductions after conversion to a roundabout intersection

Figure 5: Mn/DOT Roundabout Case Study (Minnesota Roundabout, 2011)

In the thirty-six months before the conversion to a modern roundabout, the total number of crashes was 19, the total injury crashes was 14, and the total angular crashes was 18 with one fatality. In the twenty-four months after the conversion, the total number of crashes was 3, the total injury crashes was 2, and the total angular crashes was zero. Converting these crashes to percentages shows that the total number of crashes decreased by 76.2%, the total injury crashes decreased by 78.7%, and the total angular crashes decreased by 100% (Minnesota Roundabout, 2011).

2.8. Implementation

Roundabouts have been gaining approval throughout the world since their first implementation in the 1960's. Their use is especially prevalent throughout Europe, where tens of thousands have been constructed. However, only about 3,000 have been built in the United States (What goes around, 37). A number of reasons that contribute to the hesitancy of building roundabouts in the United States will be discussed.

2.8.1. Hesitancy in the United States

Although roundabouts have been shown to successfully to drastically increase both capacity and safety, the United States has been hesitant to construct roundabouts. A survey was conducted in Santa Barbara, California before and after the construction of a roundabout in the city. Before construction, the survey showed that the public attitude with regards to the roundabout was 23% very negative, 45% negative, 18% neutral, 14% positive, and 0% very positive. However, after the roundabout was implemented for about six months, the public attitude had shifted dramatically. The post-construction survey indicated that the public attitude was 0% very negative, 0% negative, 27% neutral, 41% positive, and 32% very positive (Jacquemart 20). The results of this survey give an example of the hesitancy in the United States to the construction of roundabouts. However, this survey also shows the dramatic change of opinion once the public see how successful roundabouts really are, contrary to their original opinions that roundabouts do not work.

Another survey of a number of state transportation agencies found that thirty-five (80%) had not yet built any roundabouts and were not in the process of constructing any. A number of reasons were given for not building roundabouts. 37.1% responded that they were not sure drivers will get used to them, 34.3% were not sure if they worked efficiently, 17.1% were not sure if they were safe, 14.3% were hesitant to building them because they are not part of the AASHTO guide, and 14.3% were concerned about liability (Jacquemart 20). However, implementation of roundabouts have shown that drivers will get used to them, they work more efficiently than typical signalized/non-signalized intersection, and they are safe. Possibly inclusion of roundabout construction into the AASHTO guide will encourage state agencies to be less hesitant to build them, as well as decrease their fears of liability.

Other reasons given through other surveys indicate other reasons against the construction of roundabouts. These reasons include that roundabouts cannot give priority to the major route, difficulty of providing adequate guide signing, uncertainty about appropriate applications, politicians and public want traffic lights, concerns with modeling operational efficiency, additional right-of-way is needed for construction, and they are awaiting more widespread use of roundabouts (Jacquemart 20). To quote Jacquemart:

> In the United States, a handful of traffic engineers are trying to introduce the modern roundabouts to the American landscape, and a few modern roundabouts have been built in California, Colorado, Nevada, Maryland, Vermont, and Florida. They have been well received by the professional community and by the public. However, the introduction of this new type of intersection is facing resistance by many traffic engineers. Among the reasons that have been mentioned are that American drivers are not used to this type of intersection and that they get confused or make mistakes in the circle. The examples of several countries with very different driving cultures (Great Britain, France, Switzerland, etc.) and the limited experience in the United States have shown that all these drivers

overcome the "confusion" and that the roundabouts perform efficiently and safely in different environments. (412)

Clearly, there is severe and widespread hesitancy against the construction of roundabouts in the United States. However, if this hesitancy could wane and people could trust the numerous studies that shown the enormous benefits of roundabouts, the capacity and safety of roads in the United States would increase significantly and congestion would decrease. Rhode Island should take the lead and construct roundabouts at troublesome signalized intersections, as roundabouts have been shown to be very effective at decreasing congestion while also improving safety. In taking the lead in the construction of roundabouts, Rhode Island would also be taking the lead in encouraging sustainable transportation.

3. AUTOMATIC TOLLING

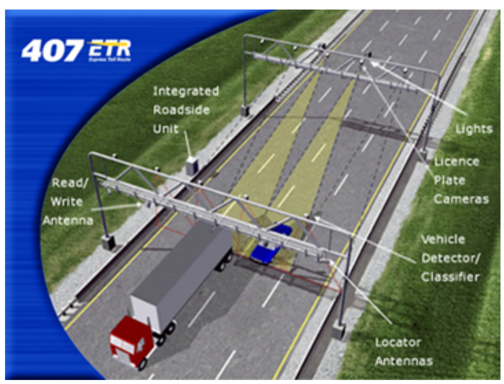


Figure 6: Canada's 407 ETR for ETC (407 Express Toll Route)

Automatic tolls or electronic toll collection (ETC) are used as a way to collect money for the use of roadways that need constant maintenance. A typical "old-fashioned" toll both consists of a gate and an operator, who opens the gate after the toll is collected from the vehicle. The operator can process about 350 vehicles per hour (*Intelligent* 8-1). Automatic coin machine lanes can process about 600 vehicles an hour, while a combination of an operator and an automatic coin machine can process about 900 vehicles per hour. Typical ETC lanes have the capability to process up to 1,200 vehicles per hour. The setup for this toll is still separate lanes booths and a toll booth, but with automatic tolls. However, with the advanced utilization of electronic toll and traffic management (ETTM), vehicles can be processed up to the capacity of the lane at over 2,000 vehicles an hour (*Intelligent* 8-1). This is due to the fact that separate booths are not required for the automatic toll to be recorded. Therefore, there is no need for a gate to be opened or closed so that traffic can be left to flow freely at open road speeds.

Examples exists as to how these type of tolls have been have already been implemented in Canada and Poland. The system that exists in Canada is the Canada 407 Express Toll Route (ETR), pictured in Figure 4 above. The ETR is a closed-access toll route, meaning that there are gantries at every entrance and exit (Kamarulazizi). The gantries are equipped with cameras, laser beam scanners and DSRC devices to identify the vehicles as they pass under the gantry. As a vehicle pass under the DSRC device detects the transponders that can be purchased on monthly or yearly leases, if no transponder is found the cameras then can identify those vehicles. The cameras are equipped with optical character recognition to clearly see what the license plate number so, the fee of using the ETR is paid by all who use the route. The laser scanners are used to classify the vehicles into classes. There are different fees for what class is using the system. The heavier classes have a higher surcharge compared to a light passenger vehicle. The gantries also act like checkpoints to identify when as vehicle enters and exits the system. This is used to assess the millage fee of how far the vehicle traveled in the system. Poland uses a similar system with the exception that their system is gated and a transponder is required to enter the system.

The ETC system in Poland also uses GPS to track the exact distance that the vehicle travels on the highway, instead of the gantry checkpoints.

3.1. Rt. 95 Congestion

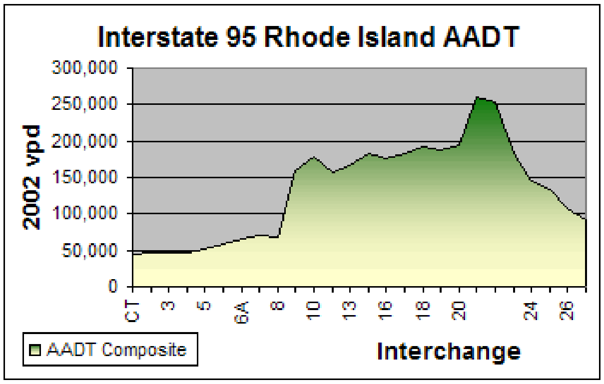


Figure 7: AADT at Every Exit along I-95 in Rhode Island (Interstate-Guide)

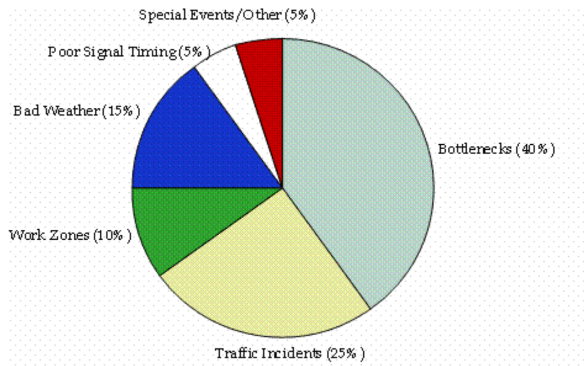


Figure 8: The Sources of Congestion: National Summary (Traffic Congestion)

As in any state, automatic tolling can be used most successfully as a means to decrease congestion in Rhode Island if implemented on chronically congested areas on major highways. One of the most chronically congested areas of Rhode Island is Rt. 95 as it passes downtown Providence. As a result, this location will be examined in detail as a possible location for an automatic toll to be implemented.

In recent years, the congestion in the Providence Metropolitan area has become a major problem. Studies have shown that daily traffic over the 1-95 Viaduct through Providence is approximately 230,000 (Langevin). In addition, a 2002 study showed that the maximum AADT over 1-95 in Rhode Island topped out at 261,000 between Exit 22/U.S. 6 east and U.S. 44/Smith Street (Interstate-Guide). That same 2002 study showed that there was a large jump between the

Exit 8/Rt. 2 to Exit 9/Rt. 4 segment (68,700 AADT) and the Exit 9/Rt. 4 to Exit 10/Rt. 117 segment (158,900 AADT). Traveling northward from this point, the AADT remains above 157,000 for every segment of Rt. 95 until after the interstate passes through Providence. The Exit 24/Branch Avenue to Exit 25/Rt. 126 segment has an AADT of 144,800, the Exit 25/Rt. 126 to Exit 26/Rt. 122 segment has an AADT of 133,700, and the Exit 26/Rt. 122 to Exit 28/Rt. 15 segment had an AADT of 107,300 as the congestion around the Providence Metropolitan area begins to dwindle rapidly north of downtown Providence/Pawtucket (Interstate-Guide).

While the congestion in the Providence metropolitan area is already bad, it is only expected to get worse. While slightly outdated, a study was conducted by the Texas Transportation Institute's that showed that while populations in metropolitan areas only grew by 22% on average between 1982 and 1997, the average traffic delay experienced increased by an incredible 235% (Hogan). This study also indicated that, in the Providence/Pawtucket area, while the actual percent change in population was 9.1% (actual population growth of 75,000), the percent change in driving was 62.1% (perceived population growth of 512,225). While this data is again slightly outdated due to the construction of the IWAY, a 2002 study showed that the 1-95 at the 1-195 interchange was the 14th worse bottleneck in the United States, with 15.34 million annual hours of delay (Traffic Congestion). To put this delay in perspective, the worst bottleneck in the United States was 27.144 million annual hours of delay U.S. 101 in downtown Los Angeles. While this congestion has greatly been relieved due to the IWAY, it is an indicator of the number of vehicles traveling through the Providence Metropolitan area during peak hours. As a final example of the tremendous number of cars using 1-95 through Providence, the same study that showed a maximum AADT in Providence of 261,000 showed that the maximum AADT anywhere along the whole of 1-95 was 299,600 where 1-95 passes through New York

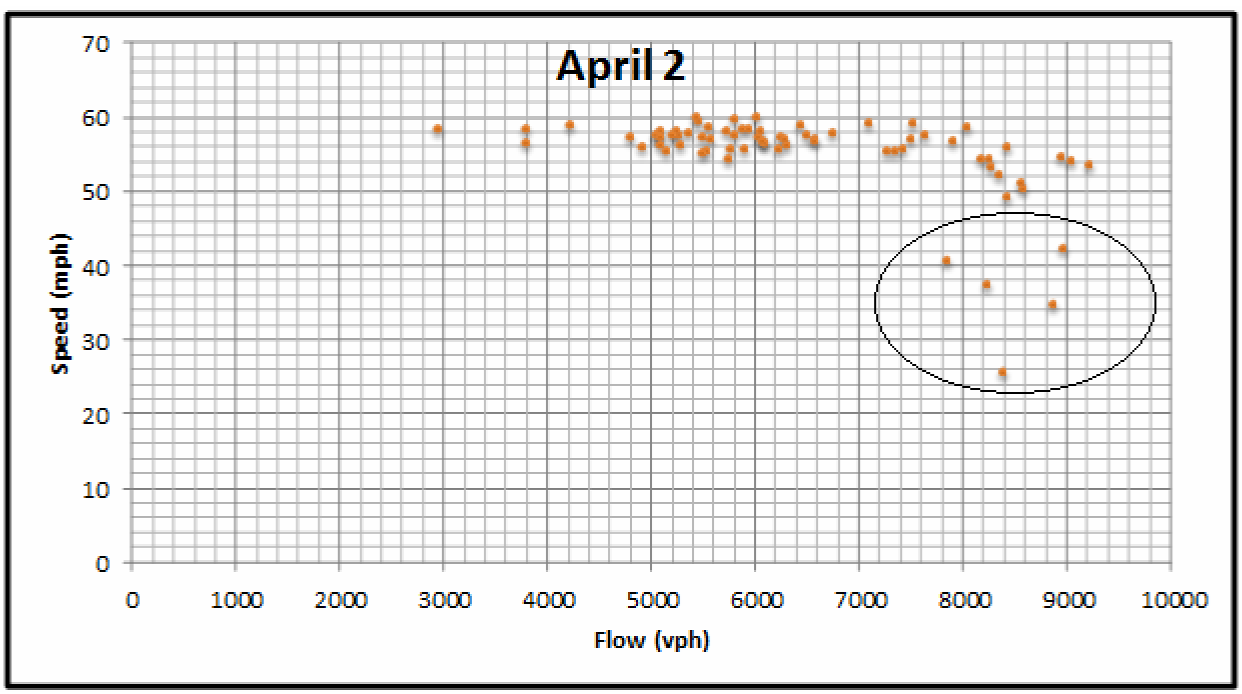
City (Interstate-Guide), where congestion is known to be extremely great. While the Providence Metropolitan area is much smaller than many metropolitan areas around the country, the congestion problem is very real. As mentioned, the goal of this paper is to present solutions to encourage environmental sustainability by relieve congestion on the roadways. The main source of congestion that traffic engineering applications can attempt to minimize is bottlenecking. Figure 1 above shows the different factors that cause congestion, indicating that 40% of all congestion occurs as a result of bottlenecking. The main time when traffic engineering applications can be utilized to decrease congestion are during the chronically congested peak hour periods.

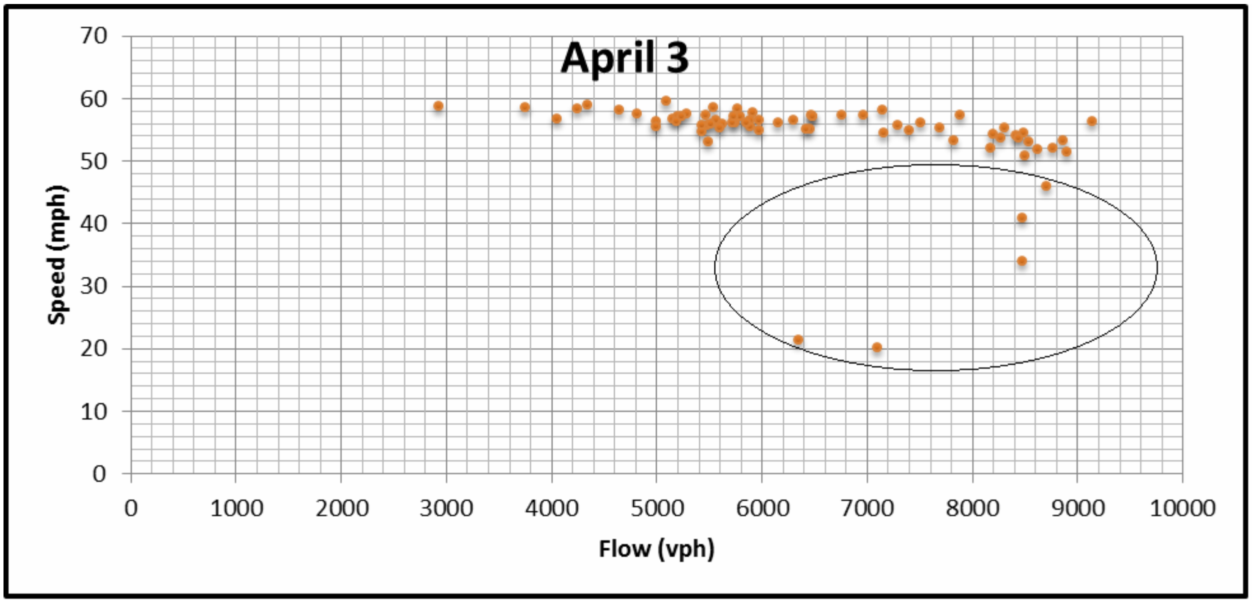
In a system such as the I-95 section between exits 10-26 that has a tremendous amount of congestion and traffic, the installation of typical ETC with separate lanes would not be an effective way creating the money necessary for maintenance and revenue. Such a device would contribute to the congestion problem. Therefore, a more sophisticated ETTM system without toll booths should be instituted in the Providence Metropolitan area.

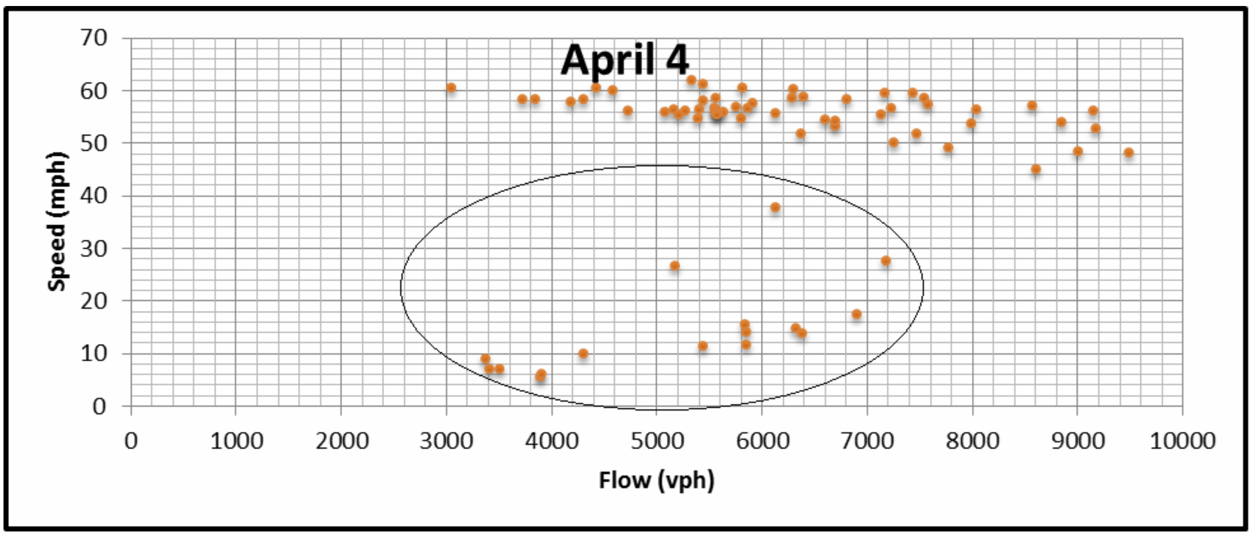
3.2. Thurbers Avenue Data

Data obtained on Interstate 95 just south of Branch Avenue for the entire day of Tuesday, December 13, 2011 gave a total northbound volume of 81,098 vehicles. The 2002 mentioned previously indicates that the AADT on Rt. 95 from Broad Street to Exit 18/Allens Ave./Thurbers Ave. has an AADT of 183,900 (Interstate-Guide). Assuming the directional split is 50/50, the northbound volume for the 2002 study would be 91,950. These numbers therefore make sense, as there are both relatively close to one another. Analyzing the data from Thurbers Avenue shows that while the traffic volumes are higher in the morning hours, the traffic speed is lower in the afternoon/evening hours. As this paper is looking to minimize congestion, the traffic speeds are of greater concern. Higher flows in the morning are not as much of an issue as lower volumes in the afternoon if they do not cause traffic speeds to decrease as much. From 8:00am until 8:25am, traffic speeds are below 30mph, but remain above 24mph. The only other time in the morning traffic speeds are below 30mph is from 8:50am until 8:55am when the speed is 25mph. In the afternoon, traffic speeds vary between 8mph and 25mph from 4:40pm until 5:50pm. Before and after this time, traffic speeds remain above 30mph. Although analysis was only conducted on traffic data for one day, traffic speeds are clearly more of a problem in the afternoon.

A location was also looked at on Rt. 95 just south of Thurbers Avenue from 6am-noon on April 2-4, 2012. The relationships of speed vs. occupancy, speed vs. flow, and flow vs. occupancy were analyzed. Of most interest were the graphs of speed vs. flow and flow vs. occupancy. The graphs of speed vs. flow from April 2-4, 2012 are depicted on the graphs below:







Some consistent conclusions can be made from these three days of data. Initially, speed remains relatively high and decreases very slowly as flow increases. However, once the flow reaches a critical value, congestion occurs (as indicated by the outlined ovals above). The theoretical speed vs. flow relationship, depicted in Figure 9 on the next page, suggests that this should be the case. Once the flow reaches a critical value, the speed reduces in addition to the flow. This is the case in highly congested stop-and-go traffic. Therefore, the goal for the Providence Metropolitan area should be to keep flows on Rt. 95 from this critical value. As long as flows do not reach this value, speeds should remain relatively high and congestion should remain minimal.

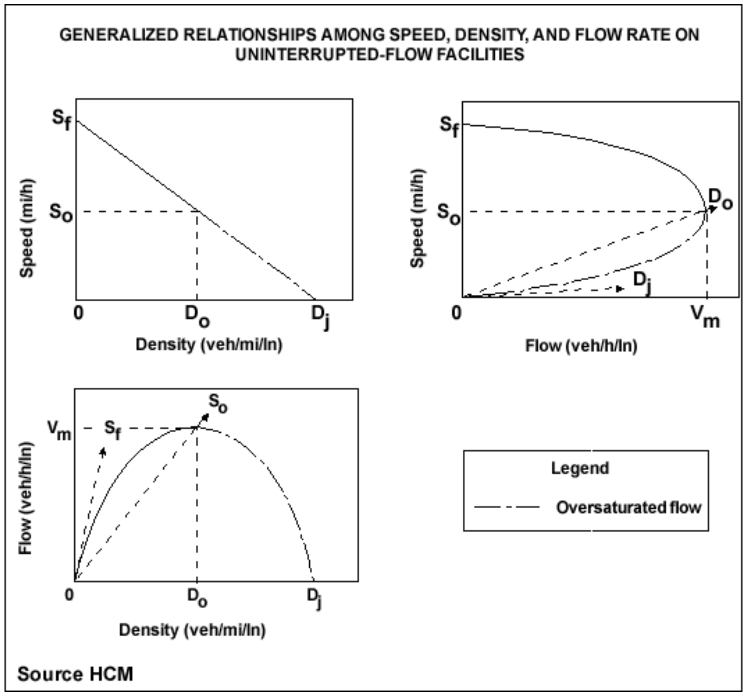
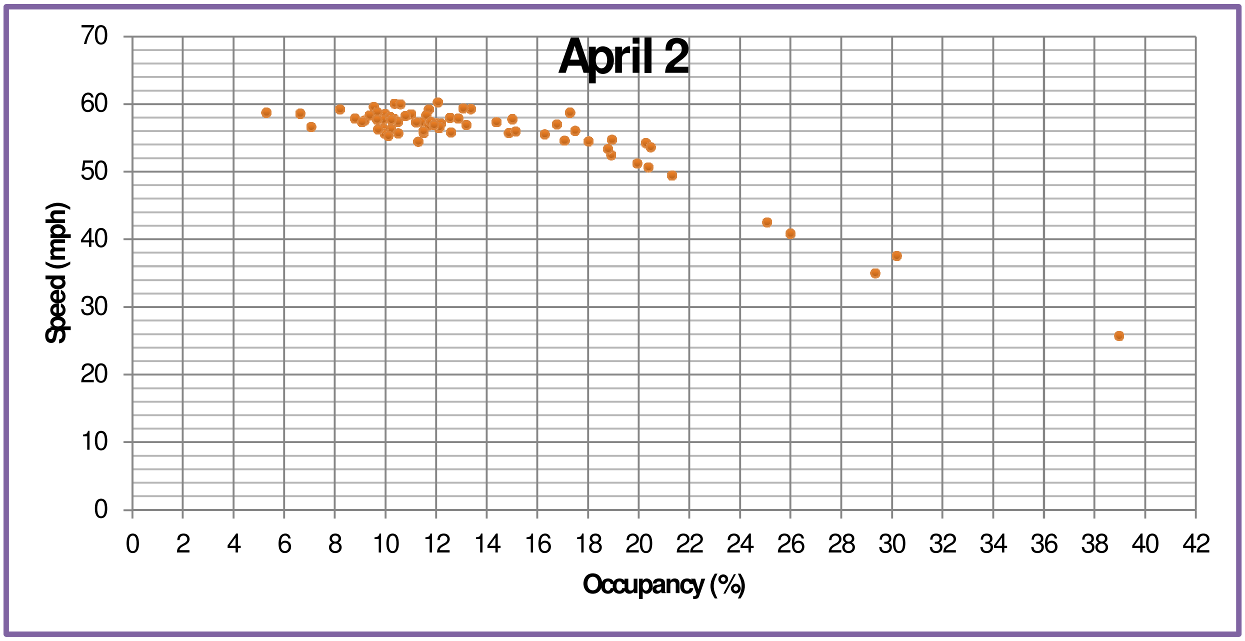
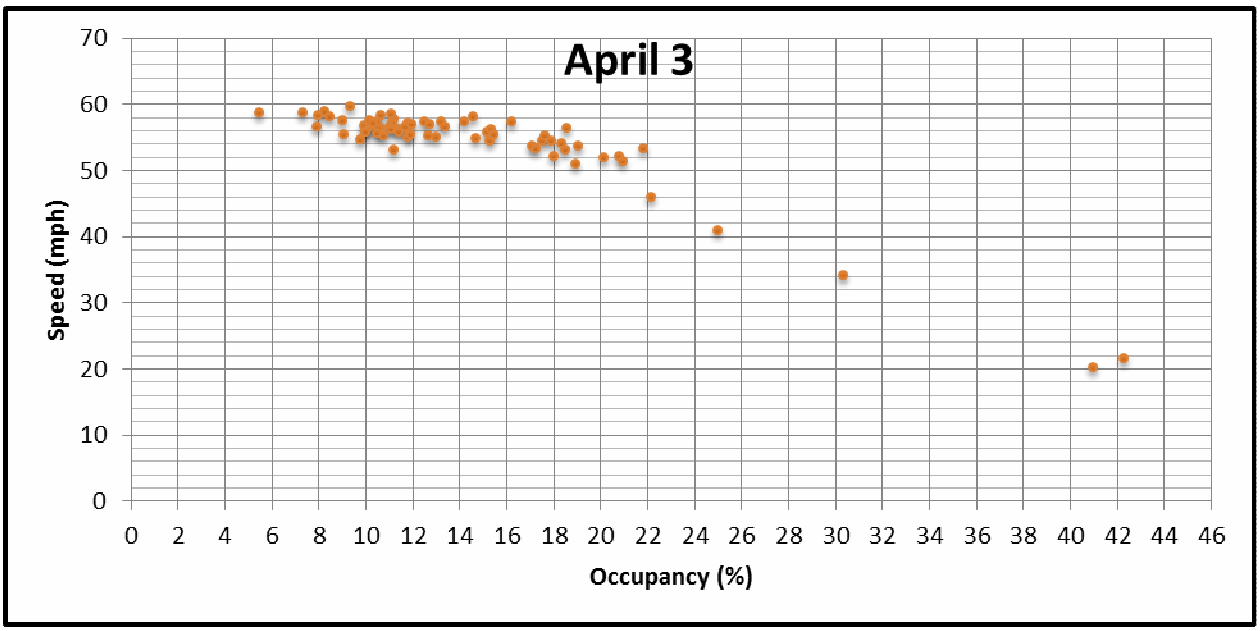
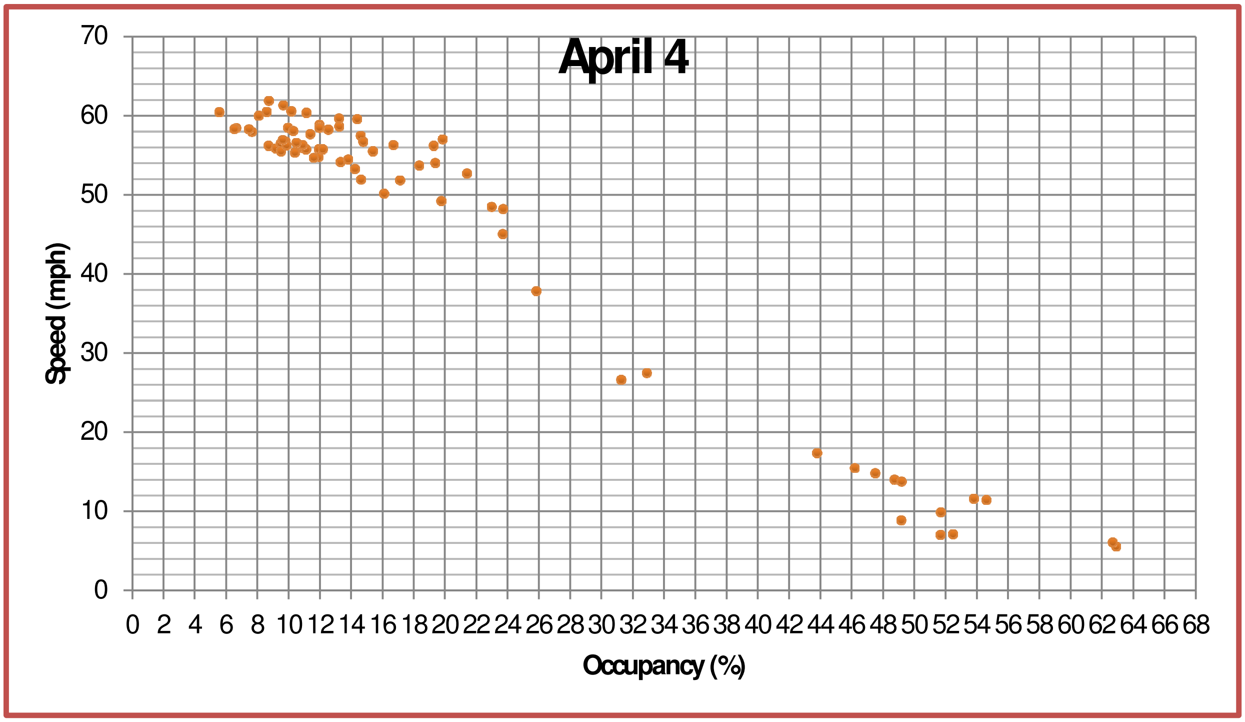


Figure 9: Generalized Relationships Among Speed, Density, and Flow Rate (HCM)

Next, the relationship between speed and flow will be explored. The graphs of speed vs. flow from April 2-4, 2012 for the same location are depicted on the three graphs located on the next two pages:


April 2
Speed (mph)
Occupancy (%)
0
10
20
30
40
50
60
70
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42


April 3
Speed (mph)
Occupancy (%)
0
10
20
30
40
50
60
70
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46



The speed vs. occupancy curves developed for the location on Rt. 95 is shown to follow the same linear relationship as the generalized speed vs. density curve as depicted in Figure 9 (occupancy is a surrogate value for density). All three graphs are consistent is showing that as the occupancy increases, the speed decreases. Depending on what the desired minimum speed to maintain on Rt. 95 is, the objective of an automatic toll would be to keep the occupancy below the corresponding value.

3.3. Proposed Implementation of an Automatic Toll

Based on the analysis of Thurbers Avenue, I am proposing an automatic toll collection station with a $2 automatic toll between Exit 22/U.S. 6 east and U.S. 44/Smith Street, where the highest AADT on Route 95 of 261,000 was recorded, between 4:30pm and 5:30pm on weekdays. Since traffic speeds began to be severely affected at 4:40pm, having automatic tolls beginning 10 minutes previous will encourage drivers to get off the highway before congestion occurs. While traffic speeds remain low until 5:50pm, I feel that it is impractical and defeats the purpose of an automatic toll if it is used for more than one hour. While people may have some flexibility in their schedules, asking them to stay off the highways for an incredibly long amount of time will likely result in them not being able to schedule around the toll. In addition, if vehicles avoid the highways until 5:30pm, the hope if that traffic speeds will be higher than in the data collected after this time. The success of this tolling will then be analyzed to see if the automatic toll is having an effect on reducing congestion. Based on these results, the toll can be adjusted. A variable toll could also be implemented. In this situation, tolls would only be charged when the number of vehicles on the road reaches a certain threshold, or incremental tolls could be charged. Lastly, the success of this pilot automatic toll may lead to similar tolls on other chronically congested areas of Rhode Island in the future, such as Rt. 146 and Rt. I-95.

4. VARIABLE/DYNAMIC MESSAGING SIGNS

Variable messaging signs (VMS) is defined as signs that electronically or mechanically vary a display as traffic conditions warrant (*Intelligent* B-9). Essentially, dynamic message signs (DMS) are the same thing. According to the RIDOT, there are currently 15 overhead DMS signs in Rhode Island, which display important travel information (Traffic Management). In addition, the RIDOT reports that there are currently more than 20 smaller VMS signs located throughout the state. Unlike the overhead DMS signs, however, these VMS signs are located on the side of the road. I am proposing to at least double the number of DMS and VMS signs in Rhode Island, bringing the total to 30 and approximately 40, respectfully, in order to hopefully relieve congestion.

Variable/Dynamic messaging signs serve to increase the volume of cars capable of using the whole system by either encouraging drivers to drive in a certain manner or use other routes. Again, as mentioned, the goal is to allow the greatest volume of vehicles access to the transportation system without congestion/bottlenecking. The aim is to increase supply, with supply being the capacity of the transportation system. Yet again, the goal is to decrease congestion, specifically bottlenecking even if travel speeds need to be reduced in order for this to occur.

As mentioned, I am proposing an increase of 15 DMS's and 20 VMS's. In conjunction with implementing these new signs, we are proposing that a video image processor (VIP) be included at every new DMS and VMS location. A VIP analyzes video images to determine the changes that occur between frames. In the Providence area, each VIP system should be equipped with two cameras, a microprocessor-based computer to process the images taken, and software to interpret and analyze the images into traffic flow data (*Intelligent* 14-6). Interaction with the TMC will then be required to determine the message the signs should have on them.

4.1. Variable Speed Limit Signs

Variable speed limit (VSL) signs are one type of DMS. These signs may be used to alter speed limits based on real time traffic or weather condition (InterPlan). VSL signs can be changed manually or by remote from a TMC. As technology advances, the VSL signs can become more accurate as more information is known about how badly the downstream portion of the road is congested and also in deciding how the speed limit should vary for the upstream portion of the road. The whole idea of VSL signs is to give the congestion more time to dissipate and alleviate the bottleneck affect. In Providence, In addition to the installation of 15 additional

DMS signs proposed, I am proposing that 5 VSL signs be implemented each mile on both Rt. 95 North and Rt. 95 South from 3 miles downstream of the most congested section until 1 mile upstream from this section.

Studies have shown the effectiveness of variable speed limit signs. According to a study conducted by the Washington State Department of Transportation (WSDOT), the placement of VSL signs have shown to be a great improvement on roadway safety. The WSDOT placed 14 VSL signs along the westbound section of I-90. These signs were placed with the hopes of increasing safety and keeping traffic moving when a bottleneck situation occurs. The results of this study were that VSL signs decrease congested-related collisions by 30% or more (WSDOT I-90). The results of another study conducted on the I-495 Capital Beltway around Washington, D.C. determined that variable speed limit signs can delay the onset of congestion and help produce more rapid recovery from congestion (Sisiopiku, 2009). Reducing the rate of accidents with the utilization of VSL signs will reduce the amount of congestion while simultaneously making the roadways safer.

5. COSTS AND BENEFITS

A number of subsystems are needed in order to construct a proposed toll plaza in downtown Providence. An electronic toll reader has a capital cost of $3,500 per lane ($14,000 each way for 4 lanes such as Route 95) and O & M of $350 ($1,400 total each way). One high speed camera is required per 2 lanes. Therefore the capital cost is $7,500 ($15,000 total each way) and O & M costs are $750 ($1,500 total each way). The cost of installing electronic toll collection software and structure are $7,500 and $12,500, respectively. Toll administration hardware is also required, and the capital costs is $12,500 while the O & M cost is $1,250.

Lastly, toll administration software, which includes local databases and national database coordination, includes a capital cost of $60,000 and O & M of $6,000.

In terms of DMS and VMS signs, only the cost for VMS signs could be found. Therefore, we calculated DMS signs as being the high end cost and VMS being the low end. The cost of installing DMS signs is assumed to be $120,000 each or $1,800,000 for all 15 we are proposing, not including the VSL signs. The O & M costs are approximately $6,000 each per year or $90,000 total. The cost of installing VMS signs are $48,000 each or $960,000 for 20. The O & M are $2,400 or $48,000 total.

I am proposing that a total of 10 VSL signs be installed on Rt. 95. We are assuming the higher end cost because this cost includes a static speed sign, speed detector (radar), and display system. Therefore the capital costs are estimated at $5,000 each ($50,000 total).

For roundabouts, there is typically no technology that is involved. The only cost incurred will be during the construction project when the roundabout will be implemented.

As mentioned earlier, we are proposing that a toll of $2 be charged between 4:30pm and 5:30pm on the most congested section of Route 95 (which has an AADT of 261,000) on weekdays. As a rough underestimate of the amount collected from the tolls per year, we assumed 1/24th of this AADT value, and multiplied by $2, 5 days/week, and 52 weeks/year. The result was an estimated $5,655,000 per year would be collected from the implantation of an automatic toll plaza on Rt. 95.

6. COST ANALYSIS

Totaling up all of these costs results in capital costs of $2,960,500 and O & M costs of $151,050 per year. As mentioned, the estimated revenue from the toll booths is $5,655,000 per year. According to this analysis, the proposed plan to use traffic engineering applications to encourage environmental sustainability by decreasing congestion is very cost effective. The tolls collected in the first year would more than cover the capital costs.

7. CONCLUSIONS

As we move further into the 21st century, environmental sustainability remains a critical issue. Increasingly, it is integral that sustainable transportation programming is encouraged as transportation contributes nearly 29% GHG emissions in the United States ("Transportation's Role," 2010). This report illustrates how Rhode Island should take the lead in encouraging sustainable transportation through the use of traffic engineering applications. Roundabouts, automatic tolls, and variable/dynamic tolls are all traffic engineering applications discussed in this paper due to their potential ability to encourage environmental sustainability by reducing congestion and increasing safety.

With regards to roundabouts, studies have shown the severe hesitancy to install these devices despite proven success. Roundabouts have been shown be have less congestion than signalized or stop-controlled intersection. In addition, they have been shown to reduce accidents and improve overall safety of our roadways. Rhode Island has the opportunity today to replace a number of chronically congested intersections throughout the state with roundabouts. Hopefully the success of such an endeavor would reduce the hesitancy throughout the United States and encourage widespread construction of roundabouts.

Automatic tolling has been has implemented in various locations worldwide. This paper details the issue of congestion in the Providence Metropolitan area. While before and after studies would need to be conducted, all indications suggest that implementing an automatic toll in the city would be successful in alleviating congestion.

Lastly, with regards to dynamic/variable messaging signs, studies have proven their success in reducing congestion. While some signs are currently in use throughout Rhode Island, increasing the number of signs in addition to introducing variable speed signs will likely reduce congestion as well as increase safety.

These proposed traffic engineering applications are just an initial look at how to best address the growing issue of environmental sustainability from a transportation engineering point of view. Continuing to strive for a more sustainable transportation system will remain a vital interest in the future, and will continue to drive the desire to understand how traffic engineering applications can be viewed for their ability to not only provide a more sustainable transportation system, but a sustainable future.

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