Impact Study

Conversion of

Three Signalized Intersections and

Three Stop-controlled Intersections

to

Modern Roundabouts

on Cleveland Street in Clearwater, Florida

National Roundabout Conference 2005 DRAFT

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Executive Summary

This study examines the impacts of converting three signalized intersections and three stop-controlled intersections to modern roundabouts.

Five areas of impact are examined: traffic impacts, safety impacts, environmental impacts, social impacts and cost impacts. To the extent practical, impacts are quantified. Where possible, impacts are also monetized.

Sixty-nine impacts are identified and evaluated: sixty-four in non-monetary terms and five in monetary terms.

The impacts expressed in monetary terms are factored into a comprehensive benefit-cost analysis resulting in a Net Present Value of $39,492,884and a Benefit/Cost Ratio of 34.5.

Analysis of the impacts expressed in non-monetary terms resulted in a Non-monetary Benefit/Cost Ratio of 44.

In the absence of a well established, authoritative precedent, this study also sets forth a comprehensive approach to identifying and examining the impacts of converting a conventional cross intersection to a modern roundabout.

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I. Introduction

A. Purpose of the Study

The purpose of this study is to enumerate and evaluate the anticipated impacts of converting six intersections to low-speed modern roundabouts.

The six intersections are along Cleveland Street in Clearwater, Florida, where Cleveland intersects with Lake Avenue, Duncan Avenue, Saturn Avenue, Corona Avenue, Aurora Avenue and Meteor Avenue, going from west to east. The first three intersections are signalized and the last three are 2-way stop controlled.

B. Precedence for the Study

There are well established and authoritative *warrants*[1] for installing traffic signals but not for removing signals, nor for prioritizing intersection improvements,[2] nor for placing modern roundabouts at new intersections, nor for converting existing signalized or stop-controlled intersections to modern roundabouts. In short, there is no well established procedure for converting a conventional cross intersection to a modern roundabout. This impact study sets forth a comprehensive approach to evaluating the impacts of converging a conventional cross intersection to a modern roundabout.

In performing this evaluation, this study is guided in part by three documents:

- *User Guide for Removal of Not Needed Traffic Signals*[3]

  This 1980 user guide suggests a procedure for replacing signal control with stop control. The *User Guide* provided the methodology used to evaluate removal of several traffic signals in Pinellas County during the 1990's, including the signal at Court Street and Lincoln Avenue, which was converted to stop control.

  The *User Guide* suggests a set of criteria for the removal of traffic signals to be replaced with stop control, and "the development of the criteria was based largely on the actual impacts resulting from traffic removals across the United States."

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[1] A *warrant* is a set of conditions prescribed by the Manual on Uniform Traffic Control Devices (MUTCD). The Millennium Edition (June 2000) of the MUTCD lists eight warrants for installation of a traffic signal and recommends a signal not be installed unless at least one warrant is met, and maybe not even then: "The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal." (Chapter 4C).

[2] *Hillsborough County Intersection Improvement Master Plan*, National Annual APWA Conference, San Diego, CA, Bernardo Garcia, PE, and John Seals, PE, August 2003

[3] *User Guide for Removal of Not Needed Traffic Signals*, JHK & Associates, FHWA Implementation Package FHWA-IP-80-12, November, 1980

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In keeping with the broader perspective the traffic engineering profession and society in general have developed since 1980, this impact study encompasses the1980 criteria within a broader range of considerations and, of course, is concerned with replacing the three signals with modern roundabouts, not stop signs.

- *The Florida Roundabout Guide*[4]

  This 1998 guide suggests a set of factors to consider when choosing and justifying locations for siting modern roundabouts. As with the 1980 *User Guide*, this 1998 guide document examines a smaller, narrower range of factors than this impact study. One of the contributors to the *Guide* is an author of the present study.

- *The Manual of Uniform Traffic Control (MUTCD)*[5]

  The 2000 Edition of the MUTCD essentially repeats the guidance of the *Florida Roundabout Guide*.

- *Roundabouts: An Informational Guide*[6]

  This 2000 guide constitutes a compendium of contemporary knowledge of modern roundabouts, oriented toward application in the United States.

C. Guiding Principle

A guiding principal for the present study is set forth in *A Policy on Geometric Design of Highways and Streets* (the *1994 AASHTO Green Book*): "Emphasis has been placed on joint use of transportation corridors by pedestrians, cyclists and public transit vehicles. Designers should recognize the implications of this sharing of the transportation corridors and are encouraged to consider not only vehicular movement, but also movement of people, distribution of goods, and provision of essential services."[7]

To this end, the present study encompasses not only the impacts and values traditionally considered but also emergency and commercial vehicles, the whole spectrum of users, the environment and society.

D. Need for the Study

The *User Guide for Removal of Not Needed Traffic Signals* explains the need for studies such as the present one by noting that:

"Traffic control devices are used at intersections to regulate the flow of conflicting traffic streams. Since the traffic signal provides the strongest form of at-grade intersection control,

[4] *The Florida Roundabout Guide*, 2nd Edition, Florida Department of Transportation, May 1998
[5] MUTCD Millennium Edition, June 2000
[6] FHWA Publication No. FHWA-RD-00-067, June, 2000
[7] *A Policy on Geometric Design of Highways and Streets*, Foreword, American Association of State Highway and Transportation Officials (AASHTO), 1994

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the general public has erroneously assumed traffic signals are a panacea for intersection operations and safety problems.

"Traffic signals now enjoy a high status among many segments of the public, elected officials, and public administrators. The popular belief, although often unsupported by evidence, is that signals somehow enhance traffic safety and improve traffic flow conditions. Given this popular bias, the practical reality is that signals are considerably harder to remove than to install. Additionally, the removal of a traffic signal often involves political and institutional considerations as well as technical factors.

"The purpose of the signal removal criteria and decision process is to provide … a strong technical and factual basis for reaching, supporting and defending final decisions."[8]

This counsel is offered by Christopher Kinzel: "For the American roundabout enthusiast, the present climate and future opportunities are exciting. More roundabouts are being studied, planned, designed and built in the U.S. than ever before, and a track record of success is being compiled that should fuel an even greater willingness on the part of public agencies to consider innovative applications for roundabouts. Care must be taken, however, to ensure that in the fervor to expand roundabouts' prevalence, inappropriate applications continue to be avoided. A thoughtful, analytical justification process should accompany the decision to install every roundabout."[9]

The present study examines the impact of six planned modern roundabouts as alternatives to other forms of traffic control existing at six intersections. The *Florida Roundabout Guide* notes that "Roundabouts have many advantages, most of which center on the limitations of the other three intersection control alternatives which include traffic signals, two-way stop control, and all-way stop control. The advantages are related to:

- improved intersection operation;
- lower accident rates and severity;
- lower costs; and,
- environmental factors."[10]

The present study examines these and other factors in detail.

E. Background and Context

Conversion of the six conventional cross intersections to low-speed modern roundabouts is part of the neighborhood vision created by 80 Skycrest residents participating in a traffic calming design charrette sponsored by the City of Clearwater in the summer of 2000. The six intersection conversions are part of their overall plan for their neighborhood, the Skycrest Traffic Calming Plan,[11] which includes traffic calming treatments at other locations in Skycrest.

[8] *Florida Roundabout Guide*
[9] *Roundabouts: The Evolution of Revolution*, Christopher Kenzel, P.E., writing in the July 2002 *Transport Line*, "A Technical Publication of HDR"
[10] *Florida Roundabout Guide,* p. 1-5
[11] The Skycrest Traffic Calming Plan is in Appendix ___ .

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The residents' purposes for converting these six intersections to modern roundabouts were to calm traffic, make the intersections safer and more friendly for all users, including pedestrians, bicyclists, children and older and handicapped users, and to gain the aesthetic enhancement landscaped roundabouts can bring to a neighborhood.

The Skycrest Neighborhood Traffic Calming Design Charrette is described further under *Social Impacts* in the section on *Social Origins of the Project* (p. 71).

F. Definition of Modern Roundabout

A modern roundabout is a circular intersection with a central island that prevents vehicles from passing through the intersection in a straight line. Modern roundabouts are common in Europe, the United Kingdom and Australia and began appearing in the United States beginning in 1994.

Modern roundabouts are not the same as the older, large *rotaries* and *traffic circles*, often greater than 300' in `diameter, such as those built in New England and New Jersey earlier in the last century. As the FHWA roundabout *Guide* states, "Those designs enabled high-speed merging and weaving of vehicles. High crash experience and congestion in the circles led to rotaries falling out of favor in America after the mid-50's."[12]

The characteristics that distinguish a 1-lane modern roundabout are:[13]

- Vehicles entering a roundabout on all approaches must yield to vehicles already in the circulating roadway; there is a yield sign at each entrance to the roundabout. (*Traffic circles* sometimes use stop control or signal control, or give priority to entering vehicles.)

- Circulating vehicles are not subject to any other right-of-way conflicts. Once a vehicle enters the circulating lane, it has priority over vehicles approaching on the entrance lanes. (Some traffic circles impose control measures within the circulating roadway.)

- Modern roundabouts have raised splitter islands on all approaches, part of the deflection scheme and an essential safety feature to separate traffic moving in opposite directions and provide refuge for pedestrians.

- No parking is allowed on the circulating roadway.

- No pedestrian activities take place on the central island.

- The speed at which vehicles are able to negotiate the circulating roadway is kept under control because the geometry of a modern roundabout deflects their path first to the right to enter the roundabout, then to the left to circulate around the central island, then to the right again to exit the roundabout.

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[12] *Roundabouts: An Informational Guide*, p.2
[13] *The Florida Roundabout Guide*, 1998 Edition, Florida Department of Transportation, p. 1-3

Additionally, like all of five Clearwater's existing modern roundabouts, the six planned roundabouts incorporate another design feature for speed control: *negative superelevation*. That means the circulating roadway is not banked *into* the curve—as superhighways are, in order to assist high-speed traffic—but rather is banked the other way. A 2% slope down to the *outside* of the circulating lanes provides both drainage and a driver sensation of higher than actual speed, which causes the driver to drive more slowly for a comfortable ride.

Sloping the circulating roadway away from the central island also makes the central island more visible to approaching drivers, another safety feature.

The figure below illustrates three ways of designing roadway cross slopes, depending upon the application.

Figure 1. Roadway Cross Slopes

Sloped on Both Sides	Superelevation	Negative Superelevation
[Insert diagram of ordinary crowned roadway profile]	[Insert diagram of banked roadway curving left.]	[Insert diagram of circulating lane curving left. Label 2%]
Straight roadway, crowned for drainage	High-speed curve, banked to assist high-speed traffic and provide for drainage	Modern roundabout circulating lane, sloped away from the central island to keep vehicle speeds down by increasing the sensation of turning, and also provides drainage

An example in contrast with the above list of roundabout characteristics is St. Armand's Circle in Sarasota, Florida. This is a large traffic circle anchoring an upscale shopping district. It has parking on the circulating lanes, a park for pedestrians on the central island, a stop sign within the circulating lanes, and one leg gives priority to entering traffic—all features *not* found at modern roundabouts.

The figure below illustrates the difference between an older rotary and a modern roundabout.

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Figure 2. Modern Roundabout Compared to Old Rotary

[Insert photo of modern rbt under construction within huge rotary.]

Photo of modern roundabout under construction within the old rotary it will replace

The figure above shows how much smaller a modern roundabout is than the older rotary it is replacing. The significant differences in entry and exit geometries are readily evident. The large size and tangential entry/exit geometries of the older rotaries contributed to their high speeds, frequency and severity of crashes and frightening user experience.

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II. Traffic Impacts

This section examines the traffic impacts of converting the six existing intersections to modern roundabouts.

All six of the existing intersections are conventional cross intersections. The *Florida Roundabout Guide* states that "There are many locations in the state that could benefit from the installation of a roundabout as an alternative to the more conventional intersection control methods."

Three of the existing six intersections are signalized. The *Highway Design Manual* states that "many have the misconception that traffic control signals installations provide the solution to all traffic problems. This is not true. Traffic control signal installations typically reduce the overall capacity[14] of the intersection, delay motorists, and often increase the frequency of rear-end accidents."[15]

Although the charrette vision specified the six planned modern roundabouts for their traffic calming safety benefits, the *Guide* also notes that "Roundabouts can efficiently handle particular intersections with decreased delay[16] and greater efficiency than traffic signals."

The *Guide* further notes that "Traffic signals cause unnecessary delay for many reasons," including:[17]

- The need to provide a minimum green time to each movement in every cycle creates time intervals in which no vehicles are entering the intersection.
- The "lost time" associated with startup and termination of a green phase detracts further from the amount of time that is available for moving traffic.
- Left turns that take place from shared lanes impede the other movements in the shared lanes unnecessarily.
- Heavy left turns, even from exclusive lanes, require dedicated phases that rob time from the major movements and increase the total time lost due to startup and termination of traffic movements.
- Many signal violations occur at higher speeds, leading to severe crashes.

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[14] *Capacity* is "The maximum rate of flow at which vehicles reasonably can be expected to trafverse a point on a lane or road during a specified period under prevailing traffic, roadway and signalization conditions; usually expressed as vehicles per hour. From the *Florida Roundabout Guide* Glossary

[15] *Highway Design Manual*, Revision 39, Section 11.3.1.3, March 15, 2002

[16] *Delay* is the additional travel time experienced by a vehicle or pedestrian with reference to a base travel time (e.g. the free-flow travel time). From *Glossary of Road Traffic Analysis Terms,* Rahmi Akçelik, August 2002.

[17] *The Florida Roundabout Guide*

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- Permitted left turns and right turns on red introduces additional conflicts. The single most challenging aspect of conventional intersection design for older drivers is performing left turns during the permitted signal phase (steady green ball).[18]

- Signals are mechanical devices that occasionally fail and provide no control during power failures.

Modern roundabouts overcome all of these disadvantages. There is no sequential assignment of right-of-way and therefore no wasted time. Left turns are not subordinated to through traffic. Because the signal is nonexistent, so are signal violations (red light running). Because vehicles enter under yield control instead of stop control they have lower headways and higher capacities. Loss of power makes no difference since there are no electrically-powered control devices to fail.[19]

A. Impact on Traffic Flow

This section examines the impact on traffic flow of converting the existing six cross intersections to modern roundabouts.

1. Free flow

Because the form of traffic control is the yield sign at entry, a modern roundabout allows traffic to flow through the intersection without stopping whenever there is no conflicting circulating traffic; that is, to flow freely through the intersection. In contrast, a traffic signal presents the red ball to two approaches at all times, and that traffic must stop and cannot turn left or go through, even in the absence of any other traffic. With the moderate traffic volume[20] at these intersections, much of the off-peak traffic will flow freely through the roundabouts.[21]

At the three 2-way stop-controlled intersections, traffic already flows freely on the through street, Cleveland Street, but all side street traffic must stop. To make a left turn or through movement, side street traffic must wait at the stop sign until gaps in both directions of Cleveland Street traffic occur simultaneously. Side street traffic will experience improved flow with the roundabouts, particularly at peak hours.

2. Computer modeling software

The engineering field has successfully reduced many forms of engineering analysis to methodologies embodied in software and makes heavy use of modeling software to evaluate existing systems and predict the performance of planned systems. In the United Stares, the performance methodology for the analysis of conventional

[18] Older driver challenges are examined further in the sections on Older Users (p. 39) and Older Pedestrians (p. 50).

[19] *The Florida Roundabout Guide*, 1998 Edition

[20] *Traffic volume* is the number of vehicles passing a given point on a street during a specified period of time. From *Glossary of Road Traffic Analysis Terms,* Rahmi Akçelik, August 2002.

[21] Even with the much greater volumes at the Clearwater Beach Entryway Roundabout, most vehicles experience free flow most hours of the year. The major exception is during Spring Break, especially daytime on Spring Break weekends, when a 2-mile parking lot queue extends through the roundabout.

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intersections is described in detail in the Highway Capacity Manual (HCM), and those procedures have been adopted by the Florida Department of Transportation (FDOT) for assessing the level of service (LOS) on state highways.

Although methods of roundabout modeling have been developed in other countries,[22] the *Highway Capacity Manual* does not provide a model for the evaluation of roundabouts. But as the *Florida Roundabout Guide* notes, “The Australian methods are most compatible with the computational structure that has been developed in Florida for comparing other control modes” and “in addition, the Australian method is based on analytical methods while other methods, such as the British method, tend to be more empirical in nature. In general, analytical methods are more transportable internationally because they depend more on mathematical relationships and less on observed driver behavior.

“Therefore, the Australian methodology will be adopted as the basis for roundabout performance analysis and the use of the SIDRA[23] software will be encouraged for the purpose of general evaluation of roundabout performance and comparison with the performance of the alternative control modes.”[24]

aaSIDRA version 2.0.3.217, the current version of SIDRA with the latest upgrades, is the intersection modeling software used for the present study.

3. Peak Hour Level of Service

Level of Service (LOS) and Delay are the two primary measures of traffic flow, as seen from the driver’s perspective. *Level of Service* is a measure of the delay, both stopped delay and geometric delay,[25] experienced by drivers at a controlled intersection.

The table below compares the computed Peak Hour LOS for the three signalized intersections versus the planned replacement roundabouts, as computed by aaSIDRA.

Table 1. Impact on Peak Hour Level of Service (LOS)

Intersection with Cleveland St.	AM Peak Hour			PM Peak Hour		
	Signalized	Roundabout	Impact	Signalized	Roundabout	Impact
Lake Av	A	A	0	B	A	+1
Duncan Av	A	A	0	B	A	+1
Saturn Av	B	A	+1	B	A	+1

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[22] *Roundabouts: An Informational Guide* lists six software packages with the capability to perform operational analysis of roundabouts, p. 97.
[23] aaSIDRA—the current version of SIDRA—is software for modeling intersections and alternate intersection treatments first released in 1984. In use in 75 countries, it is recognized in the USA by the US *Highway Capacity Manual* (HCM), the FHWA roundabout *Guide* and the *Florida Roundabout Guide*. Version 2.0 is fully compatible with the HCM but goes further by providing information on air quality and queue lengths, and is finer-grained and more accurate than HCM because its analyses are performed on a lane-by-lane basis rather than the coarser-grained, less accurate approach-by-approach analyses used by HCM.
[24] *The Florida Roundabout Guide*, pp. 3-1 and 3-2
[25] *Stopped delay* is <definition>. *Geometric delay* is <definition>.

The table above shows the peak hour LOS will be improved by one grade to the highest level, LOS A, for four of the six peak hours, for an overall average improvement of +0.67 grade LOS.

The table shows existing LOS is already quite good at peak hours. This is because of the moderate traffic volume on Cleveland Street, the low volume of turning movements and the low side street volume.

Even at relatively low volumes modern roundabouts are able to improve on the operation of signalized intersections. A major reason for the improvement is the elimination of lost time. Another is the ability of side street vehicles to enter the intersection in gaps in the main street traffic, gaps that are available at roundabouts but are unused at signalized intersections.

Off peak, most vehicles will experience free flow through all six roundabouts. The LOS was not modeled for the three stop-controlled intersections but will be improved for side street traffic making left turning and through movements, particularly at peak hours, for the reasons explained earlier in the section on *Free Flow* (p. 15).

4. Delay

Average vehicle delay is the sum of the overall delay experienced by all drivers averaged over all entering vehicles. [26]

The table below compares the Average Peak Hour Delay for the three signalized intersections versus the planned replacement roundabouts, as computed by aaSIDRA.

Table 2. Impact on Average Peak Hour Delay (seconds)

Intersection with Cleveland St.	AM Peak Hour			PM Peak Hour		
	Signalized	Roundabout	Impact	Signalized	Roundabout	Impact
Lake Av	9.9	6.7	-32%	10.5	7.0	-32%
Duncan Av	9.4	6.6	-30%	10.6	6.7	-30%
Saturn Av	10.2	6.8	-33%	11.3	6.8	-33%

The table above shows that the delay will be reduced by about one-third at all peak hours.

Delay was not modeled for the three stop-controlled intersections, but roundabouts will reduce delay for side street traffic making left turning and through movements, particularly at peak hours, for the reasons explained earlier in the section on *Free Flow* (p. 15).

5. Longest Vehicle Queues

[26] Cite a source for definition

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A *queue* is a line of vehicles waiting to proceed through an intersection. Slowly moving vehicles joining the back of the queue are usually considered part of the queue. The internal queue dynamics can involve starts and stops.[27]

The *Longest Vehicle Queue* is the longest expected vehicle queue of any approach lane, and is another measure of traffic flow as seen from the driver's perspective.

Long queues are all too apparent to the driver near the end of the queue, who can plainly see the distance to the signal ahead, a direct source of driver frustration.

The table below compares the Longest Vehicle Queues for the three signalized intersections versus the planned replacement roundabouts, as computed by aaSIDRA.

Table 3. Impact on Longest Vehicle Queues (feet)

Intersection with Cleveland St.	AM Peak Hour				PM Peak Hour			
	Signal	Roundabout	Impact		Signal	Roundabout	Impact	
Lake Av	138'	30'	-108'	-78%	163'	34'	-129'	-79%
Duncan Av	133'	29'	-104'	-78%	175'	36'	-139	-79%
Saturn Av	169'	33'	-136'	-80%	194'	42'	-152	-78%

The table above shows the Longest Vehicle Queue is shortened more than three-quarters at all peak hours.

In addition, comments from the public about Clearwater's other roundabouts—particularly the Clearwater Beach Entryway Roundabout—have indicated that roundabout queues are less aggravating to some drivers than signal queues. In a signal queue, frustration builds over time as the vehicle sits motionless awaiting the green signal, especially when the cycle is repeated before getting through the intersection. In a roundabout queue, traffic is more or less continuously moving forward in a "dribbling" fashion. The sense of motion and progress seems to take the edge off the frustration of delay, and of course roundabouts never experience *cycle failure*.[28]

The Longest Vehicle Queues were not modeled for the three stop-controlled intersections. Side street traffic volume is low but what queues there are will be shorter with roundabouts for the reasons explained earlier in the section on *Free Flow* (p. 15).

6. Operational impact

Operational impact is expressed in terms of person-hours of delay to the driving public.

The table below compares the predicted annual vehicle-hours of delay for the three existing signalized intersections versus the planned replacement roundabouts, as computed by aaSIDRA.

[27] *Queue* definition from *Glossary of Road Traffic Analysis Terms,* Rahmi Akçelik, August 2002.
[28] *Cycle failure* is <definition>

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Table 4. Annual Vehicle-Hours of Delay			
Intersection with Cleveland Street	Signalized Intersection	Roundabout	Impact
Lake Av	8,215	5,088	- 3,127
Duncan Av	7,761	8,722	967
Saturn Av	8,523	5,467	- 3,056
Totals	24,499	19,277	- 5,222

The table above shows an annual savings of 5,222 vehicle-hours of delay as a result of converting the three signalized intersections to modern roundabouts.

Delay to the driving public was not modeled for the three stop-controlled intersections. Side street traffic volume is low but what delay there is will be shorter with the roundabouts for the reasons explained earlier in the section on *Free Flow* (p. 15).

Since the cost of delay is borne by the public, this impact is examined further under *Costs to Society* in the section on *Cost of Delay* (p. 79).

Separate from operational delay is the impact on travel delay caused by crashes. The cost component of this impact is accounted for later, as discussed under *Cost Impacts* in the section on *Comprehensive Costs* (p.82).

B. Impact on truck traffic

This section examines the impact on truck traffic of converting the six cross intersections to modern roundabouts.

1. AutoTURN

AutoTURN is a software package used for the design and evaluation of vehicle turning movements.[29] AutoTURN was used during the geometric design process to verify vehicle access through the six planned roundabouts.

AutoTURN has a built-in library of standard vehicles, including the SU truck. The standard SU truck was used as the *design vehicle*[30] for the six planned roundabouts.

AutoTURN also has the ability to model custom vehicles as defined through user input of key parameters governing the vehicle's track, including wheel base, width, track, maximum steering angle and front and rear overhang dimensions. AutoTURN was used to model the swept path of certain large vehicles through the six roundabouts.

The figure below shows two of the four design vehicles specified in AutoTURN to design the six roundabouts.

[29] By Transoft Solutions Inc. Version 4.0 was used for this study.

[30] "Design vehicles are selected motor vehicles with the weight, dimensions, and operating characteristics used to establish highway design controls for accommodating vehicles of designated classes. For purposes of geometric design, each design vehicle has larger physical dimensions and larger minimum turning radius than those of almost all vehicles in its class." From the *AASHTO Green Book*, 1994, p. 19

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Figure 3. Design Vehicles	
[Insert AutoTURN image of the Fire Dept design vehicle.]	[Insert AutoTURN image of the SU design vehicle.]
Fire Department 100' Skyarm Design Vehicle by Pierce Manufacturing, Inc.	SU Design Vehicle

The figure above shows the specific parameters specified in AutoTURN for the design vehicles. The other two vehicles inputted into AutoTURN are two vehicles owned by the City of Clearwater Solid Waste Department, examined later in the section on *Solid Waste Trucks* (p. 21).

2. Fire trucks

The largest, least maneuverable vehicle in the Fire Department fleet is the 100' Skyarm apparatus. The parameters for this vehicle were obtained from the manufacturer and inputted into AutoTURN. The resulting swept path plots demonstrated that this vehicle will have no difficulty negotiating all movements through the six planned modern roundabouts without need to mount any of the mountable curbs.[31]

Clearwater's Fire Department has experienced no difficulty or undue delay with the City's current five modern roundabouts, four of which are 1-lane roundabouts similar to the six planned for Cleveland Street. All told, the Clearwater Fire Department has almost eleven "roundabout-years" of experience with modern roundabouts.

The six planned roundabouts may incorporate the FDOT roundabout central island curb to minimize any tire scuffing, as shown in the figure below.

Figure
<Insert FDOT Index 301? Type RA.>

The figure above shows an easily mountable curb which may be suitable for the central island.

[31] See Appendix __.

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3. Solid Waste trucks

   The Solid Waste Department uses six types of trucks. The parameters for the two largest, least maneuverable trucks were obtained by King Engineering by direct measurement at the Solid Waste facility off Hercules Avenue.

   - The *Mack Roll-off* truck is the Department's largest, least maneuverable truck by a substantial margin. This truck will be phased out by the time the six planned roundabouts are constructed and will not be replaced by a similarly unwieldy truck, so by agreement with the Solid Waste Department it was eliminated from consideration as a design vehicle.

   - The *Sterling Roll-Off* truck is the Department's second largest, second least maneuverable truck and will be retained in the fleet. This truck is used to transport dumpsters, mainly to/from commercial sites. Modeling the swept path of this truck with AutoTURN demonstrated that at the intersections with Corona, Meteor and Aurora there was a trade-off between tree preservation and left-turning movements for the vehicle. This trade-off is examined further under *Environmental Impacts* in the section on *Tree Impacts* (p. 64).

   - All other Department vehicles are more maneuverable than the SU design vehicle and therefore will experience no difficulties negotiating the six planned roundabouts.

4. Commercial trucks

   Most commercial trucks will be accommodated because the SU truck is the design vehicle for the roundabouts.[32] Cleveland Street is not a truck route and most vehicles are more maneuverable than an SU vehicle, including SUVs and pick-up trucks

   The FDOT *Green Book* states that "If a significant number or percentage (5 percent of all the total traffic) of vehicles of those classes larger than passenger vehicles are likely to use a particular street or highway, that class should be used as a design control."[33]

   Since SU trucks represent only 1.78% of total traffic on Cleveland Street,[34] using SU as the design vehicle is a conservative approach.

   Trucks larger than an SU represent only 0.18% of total traffic on Cleveland Street.[35] One of the largest of these, the WB-50,[36] is a semi-trailer with a typical wheelbase of 48' and is accommodated by the six roundabouts for through movements using the truck aprons. WB-50 turning movements are not accommodated, but this presents no

[32] *SU* stands for Single Unit truck . "The SU design vehicle characteristics are suitable for all single-unit trucks and small buses; the control dimensions for its minimum turning path suffice for a number of buses and truck combinations no in operation." From the *AASHTO Green Book*, 1994, p. 23

[33] Florida *Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways*, <Edition, date>, Topic #625-000-015, p. 3-.

[34] Traffic study by Adams Traffic, March 25, 2004

[35] Traffic study by Adams Traffic, March 25, 2004

[36] The WB-50 design vehicle is "nearly all-inclusive of the truck tractor-semitrailer combinations in use." From the *AASHTO Green Book*, 1994, p. 20

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problem since there are parallel major arterials (SR 60 and Drew Street) only two blocks on either side of Cleveland Street.

5. Summary of truck impacts

The table below summarizes the impact on truck turning movements:

Table 5. Truck Turning Movement Impacts

Intersection with Cleveland St.	Fire Dept. Skyarm Apparatus	SU	Solid Waste Dept. Sterling Roll-off	Semi-Trailer WB-50
Lake Av	No impact	No impact	No impact	No left turns. No right turns.[37] Through movements track across the truck apron.
Duncan Av	No impact	No impact	No impact	
Saturn Av	No impact	No impact	No impact	
Corona Av	No impact	No impact	No left turns[38] (none are needed)	
Meteor Av	No impact	No impact		
Aurora Av	No impact	No impact		

The table above shows SU trucks and all Fire Department vehicles can make all turning movements at all six planned roundabouts. The Solid Waste Department's Mac Roll-off truck cannot turn left at three intersections but does not do so now and does not need that capability in the future.

C. Impacts Related to Keene Road

When the Skycrest Traffic Calming Plan was created, it took into account the pending widening of Keene Road from two lanes to six, which has now been completed. Left turn lanes on Cleveland Street at Keene Road will not be shortened. With the conversion of the three signalized intersections on Cleveland Street west of Keene Road to roundabouts, east bound traffic will flow freely most hours of the day until it encounters the signal at Keene Road. Eastbound queues will not increase due to the roundabouts. The queues will be longer than they were before the widening of Keene but converting the six intersections to roundabouts should have no impact on the queue lengths because the flow is the same with or without roundabouts.

Depending on the philosophy used to allocate green time at the Keene Road signal, vehicle queues on Cleveland Street will increase or decrease accordingly irrespective of whether roundabouts or signals are used to control traffic on Cleveland Street.

If green time allocation favors Keene Road then eastbound queues at Keene Road may increase and back through the roundabout at Saturn Avenue. If vehicle queues extend to the Saturn roundabout, courteous drivers will not block the roundabout while less courteous drivers may illegally[39] block the eastbound entry into the roundabout. The eastbound entry can be signed with a DO NOT BLOCK INTERSECTION sign to remind drivers of their legal

[37] Some skilled WB-50 drivers may be able to execute a "squared-off" right turn using the truck apron, but AutoTURN does not show this maneuver as possible.
[38] Due to the vehicle's poor turning radius.
[39] Florida Statute ___ .

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responsibility not to block an intersection and help maintain excellent flow for the northbound side street traffic entering the roundabout from the south on Saturn.

Westbound queues on Cleveland Street at Keene Road will be unaffected by the three roundabouts east of Keene Road because it is the allocation of green time at Keene Street that will be the sole determinant of vehicle queues.

D. Impacts on the Street Network

The six planned roundabouts will not have an adverse impact on the street network or vice-versa. Sight distances and the proximity of signals and arterials are examined further under *Traffic Impacts* in the section on *Traffic Impacts Associated with Possible Contraindications* (p. 28).

Sight distances for cross streets are likely to increase slightly because a few trees close to the intersections will be removed for various reasons (see discussion under *Environmental Impacts* in the section on *Tree Impacts*, p. 64). The lower vehicle speeds at roundabouts typically allow shorter sight distances than at cross intersections. Typically, the sight triangle at a roundabout is a 150 foot triangle to the left only.

E. Future Growth

A typical assumed life-cycle period of a intersection project is twenty years, during which time traffic typically grows and that can affect the operation of the project

The *AASHTO Green Book* states that "New highways or improvements of existing highways usually should not be based on current traffic volumes alone, but consideration should be given to the future traffic expected to use the facilities. A highway should be designed to accommodate the traffic that might occur within the life of the facility under reasonable maintenance."[40]

Traffic volume projections in Pinellas County are the responsibility of the Pinellas County Metropolitan Planning Organization (MPO). Using computer modeling software,[41] the MPO projects a traffic volume increase of only 10-12% on Cleveland Street through Skycrest out to the year 2025.

The MPO projects such slight growth for Cleveland Street because: it is a residential collector street that terminates at Belcher, not a through street; the area is built out; there is no vacant land left; there are no re-development plans for this area; and any re-development would most likely duplicate existing land uses.

Because the projected 2025 traffic volume is still less than 50% of the capacity of the six roundabouts, there will be no substantial difference in their operation. Therefore, the *design*

[40] *AASHTO Green Book*, 1994, p. 58
[41] <Get name and version from Ramon Solis>

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life[42] easily extends beyond 2025. A longer design life, such as forty years or longer, would not be unreasonable in the case of this project, given the expected stability of the setting. Design life is discussed further under *Cost Impacts* in the section on *Sensitivity Analysis* (p. 90).

A mile and a half west of Skycrest, Cleveland Street becomes the main street through downtown Clearwater. But Cleveland Street is not the main traffic feeder into downtown; that function is handled by a diagonal section of State Road 60 that intersects Cleveland Street one third mile west of the west end of the Skycrest project.

State Road 60 continues through downtown Clearwater to Clearwater Beach by way of the Memorial Causeway. Currently, the traffic passing *through* downtown to the beach dwarfs the traffic traveling *to* downtown as a destination itself. That distribution of traffic will change radically when the new Memorial Bridge opens in 2006 and all the beach-bound traffic is diverted around downtown via the 1-way pair of Chestnut and Court Streets, which will connect to the new Memorial Bridge.

The City of Clearwater intends to redevelop downtown after the Memorial Bridge. Plans include streetscaping and cul-de-sac'ing Cleveland Street, mixed land uses, 1200 residential dwelling units and a cinema multiplex. A new library on the bluff overlooking Clearwater Harbor opened in 2004. The MPO has not project what, if any, effect re-development of downtown Clearwater may have on traffic volume in the Cleveland Street corridor through Skycrest.

E. Impacts on Non-motorized Traffic Flow

Bicyclists riding in the street will experience the same flow as described above for motorized users. Pedestrians, skaters, wheelchair users, and bicyclists riding on the sidewalks will experience an improved level of service and less delay with the roundabouts. Most of the time non-motorized users will experience less delay at the roundabouts than at the three intersections currently controlled by signals because they will be able to cross as soon as it is safe to do so and they won't have to wait for permission from a signal before crossing even when no vehicles are present.

At Clearwater's four existing 1-lane modern roundabouts, level of service and delay for non-motorized users are essentially LOS A and zero, respectively, almost all the time.

F. Impacts on Traffic at Skycrest Elementary School

The intersection of Cleveland Street and Corona Avenue is located at the SE corner of the Skycrest Elementary School property. Twice a day the streets are congested as buses and parents arrive/depart to drop-off/pick-up students and students on foot arrive/depart.

During these two daily periods, crossing guards at Cleveland and Corona must stop motorized traffic in both directions to prove safe passage across the street for schoolchildren

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[42] *Design life* is the number of years into the future while the intersection operates satisfactorily considering increases in traffic demand volumes). From *Glossary of Road Traffic Analysis Terms,* Rahmi Akçelik, August 2002.

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on foot. Traffic wanting to make left turns and Corona traffic wanting to cross Cleveland must wait for gaps in traffic on Cleveland in both directions to occur simultaneously, as must all traffic wanting to make left turns. Both these problems delay the vehicle wanting to make the movement as well as vehicles behind it, worsening an already congested twice-daily situation. Both problems will be eliminated by the modern roundabout at Corona so traffic flow will be improved.

The figure below compares the two scenarios.

Figure 4. Skycrest Elementary School Congestion Scenarios	
[Insert diagram of existing scenario.]	[Insert diagram of planned scenario.]
Current Scenario	Planned Scenario

The figure above illustrates how the planned roundabout will ease congestion at drop-off/pick-up periods.

Also during these two daily periods, Corona Avenue becomes one-way southbound in the section from Cleveland Avenue north to Drew Street. A sign on the NE corner alerts drivers with a flashing light that is activated during the two periods.

With all the vehicle and pedestrian congestion during those periods, it's easy for a driver to not notice the flashing yellow sign before turning north or not at all. Left-turning eastbound drivers on Cleveland Street who are paying attention to judging the gap in oncoming (westbound) traffic and fail to notice the sign until partway through their left turn find themselves awkwardly stopped at a cock-eyed angle in the wrong lane, with nowhere to go. A vehicle in this position cannot proceed forward north on Corona, is in the wrong lane to proceed east on Cleveland, and can't execute a U-turn. Any approaching traffic further blocks the vehicle from moving.

The roundabout at Corona will eliminate this problem, too: the crossing guard will simply "cone off" the north exit with yellow traffic safety cones for the duration of the 1-way period. Drivers noticing the cones at the last minute can simply continue around the roundabout at 11-13 MPH and exit gracefully at any of the other three roundabout exits. Additional flashing signage east and west on Cleveland Street will give drivers better advance warning than they have now.

The figure below illustrates the placement of traffic cones to block circulating vehicles from exiting to the north during student drop-off/pick-up periods.

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Figure 5. Corona Avenue Roundabout "Coned-off"
[Insert diagram showing the vehicle movement past the cones. Also show the 4 crosswalks and which two have crossing guards??] <Show existing awkward situation>
Dots depict cones placed by the crossing guard.

The figure above shows the simple way the roundabout supports the one-way rule in effect during two periods daily on school days.

G. Miscellaneous Traffic Impacts[43]

1. Physical and right-of-way features

   - Impacts associated with physical and right-of-way features are minimal and are examined further under *Environmental Impacts* in the section on *Tree Impacts* (p. 64) and elsewhere in the section on *Cost Impacts* (p. 77).

2. Current and planned site development features such as adjoining businesses, driveways, etc.

   - The planned six roundabouts will not adversely affect existing or planned site development features, or vice-versa, but the low-speed environment, pedestrian/bicyclist/skater-friendliness, enhanced alternate mobility and aesthetic corridor enhancements will contribute to the attractiveness of developments, as will the ease of making U-turns and concomitant improved access.

3. Certain community considerations such as a need for parking, landscaping character, etc.

   - The planned six roundabouts will not adversely impact parking, or vice-versa. The project landscaping will be compatible with and enhance the character of the Cleveland Street corridor, as examined further under *Environmental Impacts* (p.69). Community impacts are also examined under *Environmental Impacts* (p. 70).

4. Traffic management strategies that are (or will be) used in the area

   - Twice annually the City of Clearwater uses Crest Lake Park and the strip of Cleveland Street between Lake Avenue and Highland Avenue, as well as portions of the side streets on Crest, Glenwood and Lake, as an assembly area for major parades. Cleveland Street is closed off the day of the parade and vehicles are positioned in the roadway without regard to normal traffic flow directions. The Parks

[43] The *Florida Roundabout Guide* suggests considering these miscellaneous factors when siting a roundabout, p.__.

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Department has determined that the planned roundabouts need no modification to accommodate the process of parade assembly, because the mountable splitter islands and mountable truck apron at the Lake & Cleveland roundabout will allow the float vehicles sufficient access and mobility.

The only accommodation needed for the floats is to avoid high vegetation on the medians between Highland Avenue and Lake Avenue.

With the coming re-invention of downtown Clearwater, parade frequency will increase to as many as one per month, although most of these will be walking parades without major float vehicles and will be similarly unimpacted by the planned roundabouts.

5. Projected public transit usage

- Experience with Clearwater's four 1-lane roundabouts has demonstrated they present no problems or special considerations for transit vehicles. The Acacia Roundabout on Clearwater beach has bus stop benches at both ends of the south leg crosswalk and these stops are used by both the Pinellas Suncoast Transit Authority (PSTA) buses and the (rubber tired) Jolly Trolley trolleys. The roundabout at Martin Luther King, Jr., Avenue and Palmetto Avenue has a PSTA shelter at the entry for the south leg. The low-speed environment associated with these modern roundabouts facilitates the operation and safety of the bus stops.

  School buses routinely traverse Clearwater's four existing 1-lane roundabouts with no difficulty. A school bus stop is one block west of the roundabout at Martin Luther King., Jr., Avenue and Palmetto Street. Students use the roundabout to get to/from the bus stop daily with no safety or operational problems. Some students in the 14-16 age range have been observed spurning the crosswalks, preferring instead to walk across the truck aprons, but the low-speed environment of this modern roundabout is sufficiently forgiving that this behavior does not appear to present a safety problem.

6. Intersection treatments used at adjacent intersections

- The planned six roundabouts will have no adverse affect on adjacent intersections, or vice-versa. Nearby intersecting arterials are discussed further under *Traffic Impacts* in the section on *Possible Contraindications* (p. 28).

7. History of public complaints that suggest a need for traffic calming

- The planned six roundabouts are part of the larger Skycrest Traffic Calming project, which originated with public requests for traffic calming and complaints of speeding, aggressive driving and children at risk. The roundabouts were proposed by residents of Skycrest and are responsive to Skycrest residents' complaints. The origins of the project are examined further under *Social Impacts* in the section on *Social Origins of the Project* (p.71).

8. Number of other roundabouts in the jurisdiction that would make drivers more familiar with this type of control

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- Experience with Clearwater's 1-lane roundabouts and the experience of other communities has demonstrated that "By their nature, roundabouts are self-educating. The combination of geometry, signs and markings are instructive to drivers."[44] The design features of low-speed modern roundabouts force drivers to slow down and pay attention the first time they encounter the roundabout and every time thereafter, and drivers have demonstrated no problems adapting to the four 1-lane roundabout already built in Clearwater. This holds true for the Acacia Roundabout on north Clearwater Beach, where the population demographics are heavily skewed toward older residents, discussed further under *Safety Impacts* in the section on *Demographics of Older Users* (p. 41).

H. Possible Contraindications[45]

1. Physical or geometric features that could make the construction or operation of a roundabout more difficult

   - There are no physical or geometric features that could make the construction or operation of the six planned roundabouts significantly more difficult.

2. Land use or traffic generators that could interfere with construction or cause operational problems

   - There are no land uses or traffic generators that will cause operational problems for the six planned roundabouts. The impact of the roundabout at Cleveland & Corona on the traffic generated/attracted by Skycrest Elementary School is examined earlier under *Traffic Impacts* in the section on *Impacts on Traffic at Skycrest Elementary School* (p. 24).

     In order to minimize impact on John F. Kennedy Middle School, construction of the 1-lane roundabout at the southwest corner of the school (Palmetto Street & Casler Avenue) was scheduled during the summer session and completed before school re-opened in the fall. This approach worked well and will be repeated for the roundabout at Cleveland and Corona to minimize impact on Skycrest Elementary School.

3. Other traffic control devices along any intersecting roadway which would require preemption

   - The six planned roundabouts will have no adverse affect on preemption of other traffic control devices, or vice-versa.

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[44] *Comparison of Alternate Intersection Control, Blackmarsh Road / Hamilton Avenue / Blackler Avenue, City of St. Johns, NL, Canada*, Mark Lenters, April 26, 2004

[45] The *Florida Roundabout Guide* suggests considering these factors when siting a modern roundabout and states "A contraindicating factor for selecting a roundabout as an intersection control device would be any condition that might reduce the effectiveness of a roundabout" (p. 2-3).

4. Bottlenecks on any of the intersecting roadways that could back up traffic into the roundabout

   - Eastbound Cleveland Street traffic stopped at the traffic signal at Hercules Avenue could queue back as far as the planned roundabout at Cleveland & Aurora, located about 250 feet west of the stop bar at Hercules Avenue. If selfish drivers choose to stop in the roundabout instead of stopping short of it, they will temporarily and illegally block the minor northbound traffic on Aurora Avenue from entering the intersection, the same as can occur with the existing stop-controlled intersection. This problem won't exist outside of the PM peak hour. To alert drivers and encourage considerate behavior, DO NOT BLOCK INTERSECTON signage will be placed on the eastbound approach to the roundabout.

     Similarly, eastbound Cleveland Street traffic stopped at the traffic signal at Keene Road could queue back as far as the planned roundabout at Cleveland & Saturn, located about 450 feet west of the stop bar at Keene Road, and similar signage will be placed to alert drivers and encourage considerate behavior. This topic is discussed further under *Traffic Impacts* in the section on *Impacts Related to Keen Road* (p. 22).

     Although none of them are reached by a traffic signal queue, experience with Clearwater's other 1-lane modern roundabouts have demonstrated that the phenomena of vehicles temporarily blocking a roundabout is not a significant problem because it does not present a safety problem or more than a transient, minor operational problem.

     Clearwater's one 2-lane roundabout, the Clearwater Beach Entryway Roundabout, experiences major operational disruption on Spring Break weekends when a 2-mile long queue forms at the South Beach parking lots and extends several blocks and then through the roundabout all the way back across the Memorial Causeway to the mainland shoreline and beyond, as it has on holiday weekends for decades. Even under these extreme conditions, the roundabout continues to move cars and operate effectively, better than the nine intersections it replaced (three of them signalized).

5. Sight distance observations

   - No sight distances adversely impact the six planned modern roundabouts, or vice-versa.

6. Platooned arterial traffic flow on one or more approaches

   - Platooned arterial flow will not adversely impact the six planned roundabouts, or vice-versa.

     The proximity of other signals is unlikely to have an adverse impact on the roundabouts or vice-versa. Cross traffic should not experience any significant increase in delay when platoons of vehicles from a signalized intersection pass through the roundabouts. The further from signals a roundabout is located, the more dispersed the platoon becomes, the more the headway between vehicles increases and less delay is experienced by side street traffic. The great majority of the time,

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cross street traffic will experience minimal or no delay at the six planned roundabouts.

The table below gives the nearby intersecting arterials along the Cleveland Street Corridor. All of these arterial intersections are signalized.

Table 6. Nearby Arterials Along the Cleveland Street Corridor

Arterial	Distance and Direction to Nearest Roundabout		Nearest Roundabout
Highland Avenue	1,350’	East	Lake Avenue & Cleveland Street
Keene Road	750’	West	Saturn Avenue & Cleveland Street
Hercules Avenue	340’	West	Aurora Avenue & Cleveland Street
Belcher Road	3,050’	West	Aurora Avenue & Cleveland Street

There are also traffic signals along the parallel arterials to the north and south, Drew Street and Gulf-to-Bay Boulevard (SR 60), respectively.

7. Heavy use by persons with special needs that could suggest a requirement for more positive control

   - There is no known heavy use by persons with special needs. Considerations of users who are children, older or impaired are examined further under *Safety Impacts* in the sections on *Older Users* (p. 39) and *Non-Motorized Users* (p.45).

8. Recent safety projects in the area to benefit older drivers

   - There are no projects in Clearwater specifically to benefit older drivers, although Clearwater’s five low-speed modern roundabouts provide a number of benefits to older drivers. Consideration of older drivers is examined further under *Safety Impacts* in the section on *Older Users* (p. 39).

9. Emergency vehicle operations coordination requirements

   - The six planned roundabouts will have no adverse impact on emergency vehicle operations and coordination, or vice-versa. The Police and Fire departments participated in the project at its inception in the Skycrest Traffic Calming Charrette. Consideration of fire vehicles is examined further in the section on *Fire trucks* (p. 20).

10. Emergency evacuation route coordination requirements

    - The planned six roundabouts will have no adverse impact on evacuation route coordination, or vice-versa.

11. Railroad crossings in the vicinity[46]

    - There are no railroad crossings in the vicinity of the six planned roundabouts and therefore no impacts.

[46] This contraindication is suggested by *Guide to Modern Roundabouts*, PENNDOT Publication Number 414, Michael Baker, Pennsylvania Department of Transportation, May 2001, p. 8

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12. Other problems that have been identified

- None.

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III. Safety Impacts

This section examines the safety impacts of converting the six existing cross intersections to low-speed modern roundabouts. Safety impacts on both motorized and non-motorized users are examined.

In the United States, among adults aged 15-44 traffic crashes are the leading cause of death and injury, according to a 2004 *FHWA Brief*.[47]

Intersection safety is a serious and growing problem in the United States. The *FHWA Brief* states that "In 2002 approximately 3.2 million intersection crashes occurred, representing 50 percent of all reported crashes. Twenty-two percent of total fatalities occurred at or within an intersection environment." "The number of fatal motor vehicle crashes at traffic signals is rising faster than any other type of fatal crash nationwide."[48]

The *Brief* also notes that "roundabouts can perform as well as, or even better than, signals in managing both vehicle and pedestrian safety at intersections. This is particularly true where traffic volume is relatively low,"[49] which is the case at the six intersections to be converted to modern roundabouts.

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A. Impact on crashes

This section examines the impact on crashes of converting the six cross intersections to low-speed modern roundabouts.

1. Studies of crash frequency and severity

The FHWA *Informative Guide* to roundabouts notes that "Many studies have found that one of the benefits of roundabout installation is the improvement in overall safety performance. Several studies in the U.S., Europe, and Australia have found that roundabouts perform better in terms of safety than other intersection forms."[50]

Because the six planned modern roundabouts have been designed using the low-speed Australian design philosophy, studies in Australia are perhaps the most relevant of the foreign studies. Australian studies show a mean reduction in all crashes of 41-61% and a reduction in injury crashes of 45-87%.[51]

Roundabouts and roundabout studies are scarce in the United States, but a 1998 study of eight U.S. conventional cross intersections converted to single-lane modern roundabouts, the fatality crash rate dropped 51%, the injury crash rate dropped 73%, and the property-damage only (PDO) crash rate dropped 32%.[52]

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[47] <Verify> *The National Intersection Safety Problem*, FHWA, April 2004
[48] *The National Intersection Safety Problem*, FHWA, April 2004
[49] *The National Intersection Safety Problem*, FHWA, April 2004
[50] *Roundabouts: An Informational Guide*, FHWA, p. 103
[51] *Roundabouts: An Informational Guide*, FHWA, p. 112
[52] *Roundabouts: An Informational Guide*, FHWA, p. 23

A 2001 study of 23 U.S. intersections converted from stop sign or traffic signal control to modern roundabouts found crashes were reduced by 40% and injury crashes by 80%.[53]

A 2000 U.S. study[54] found conversion of three urban, signalized intersections to modern roundabouts resulted in a 32% reduction in all crashes (68% in injury crashes), and conversion of 44 urban, stop-controlled intersections to one-lane modern roundabouts resulted in a 61% reduction in all crashes (77% in injury crashes). Overall, 24 conversions resulted in a 90% reduction in fatal and incapacitating injury crashes.

The State of Maryland has built more than 25 modern roundabouts. A 2001 study of eight one-lane modern roundabouts in Maryland, most of them constructed as alternatives to signalized intersections, showed a 64% reduction in crashes, reduced severity of crashes, and an 83% reduction in injury crashes in the first year after installation.[55]

The City of Golden, Colorado, converted three intersections to roundabouts and added a roundabout at a forth intersection. A comparison of the crash history for the 3 years prior to conversion to the 28 months after found that crashes per million miles declined 60.4% and injuries per million miles declined 94.4%.[56]

A 2003 study of twelve US. urban stop-controlled cross intersections converted to single-lane roundabouts conducted for the New York DOT found an 80% reduction in injuries, a 67% reduction in PDO[57] crashes, and an overall reduction in crashes of 69%.[58]

2. Why modern roundabouts are safer

Some reasons for the increased safety performance of roundabouts are:[59]

- Roundabouts have fewer conflict points in comparison to conventional intersections. A *vehicle/vehicle conflict point* is where the paths of two vehicles cross.[60]

  The figure below compares the vehicle/vehicle for cross intersections versus roundabouts.

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[53] *Safety Effects of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study*, B.N. Persaud, R.A. Retting, P.E. Garder and D. Lord, Transportation Research Record 1751, 2001
[54] *Crash Reductions Following Installation of Roundabout in the United States*, Bhagwant Persaud, et. al., Insurance Institute for Highway Safety, 2000
[55] *Maryland Roundabout Safety Experience*, Office of Traffic and Safety, Maryland State Highway Administration, October 2001
[56] Dan Hartman, Director of Public Works, Golden, Colorado, 2004
[57] Property damage only
[58] *Operational and Safety Performance of Modern Roundabouts and Other Intersections Types*, Eisenman, S., Josselyn, J., List, G., and Persaud, B., Project NYSDOT-C-01-47, October 2003 (unpublished draft reported in a draft chapter of the ITE *Intersection Design Safety Toolbox*, Chapter 2, *Designing and Operating Safer Roundabouts*, Jacquemart, Georges
[59] *Roundabouts: An Informational Guide*, FHWA, p. 103
[60] "Vehicles are finite objects, no two of which can simultaneously occupy the same space without unpleasant results." From *Fundamentals of Traffic Engineering*, 14th Edition, Homburger, et. al., Institute of Transportation Studies, University of California, Berkley, 1996

Figure 6. Vehicle/vehicle Conflict Points[61]	
Conventional Cross Intersection	Roundabout
[Insert diagram of conventional intersection with vehicle/vehicle conflict points.]	[Insert diagram of roundabout with vehicle/vehicle conflict points.]
32 Vehicle/vehicle Conflict Points. The most lethal conflicts are in the center of the intersection	8 Vehicle/vehicle Conflict Points. All the most lethal vehicle/vehicle conflict points are eliminated.

The figure above shows that converting a conventional cross intersection to a modern roundabout reduces the number of vehicle/vehicle conflicts from 32 to 8, a 75% reduction. No other form of intersection re-design reduces vehicle/vehicle conflict points to this degree.

Of the eight vehicle/vehicle conflict points in a modern roundabout, four are rear-end crashes. The remaining four are low-speed, low-angle, low-energy merge crashes between circulating vehicles and entering vehicles, as depicted above in figure above.

- Converting a conventional cross intersection to a modern roundabout eliminates the most lethal conflicts: left-turn, head-on and right-angle crashes, as depicted in. Figure 6 above.

The table below compares the number of vehicle/vehicle conflict points at each existing intersection versus the planned roundabouts.

Table 7. Vehicle/Vehicle Conflict Points

Intersection with Cleveland St.	Existing Intersections	Planned Roundabouts	Impact
Lake Av	32	8	- 16
Duncan Av	32	8	- 16
Saturn Av	32	8	- 16
Corona Av	32	8	- 16
Meteor Av	32	8	- 16
Aurora Av	32	8	- 16
Total	192	48	-144

[61] *Modern Roundabouts,* Wallwork, Michael, PE, 1996

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The table above shows converting to the six planned roundabouts will eliminate 144 vehicle/vehicle conflict points.

- The low vehicle speeds associated with modern roundabouts allow drivers more time to react to potential conflicts. Events play out over a longer time, giving intersection users more time to perceive, think and react to avoid a crash.

- The similar speeds of most vehicles traveling through a roundabout reduces crash severity compared to a conventional intersection.

3. Influence on user behavior

This section examines the influence of intersection type on user behavior, one of the major determinants of safe operation.

Modern low-speed roundabout design forces drivers to slow down and pay attention. In contrast, a signalized intersection allows drivers to pass through the intersection at speed without so much as glancing to either side to check for cross traffic even though there is no physical barrier to prevent cross traffic from impacting in a potentially lethal T-bone crash. Worse, the green-yellow-red ball sequence tempts drivers to speed up to try to beat the red signal, rather than slow down, the exact opposite of safe behavior.

Pedestrians tend to become impatient and not wait for the pedestrian crossing signal. Many pedestrians don't bother to even press the pedestrian button, preferring to attempt crossing multiple lanes of high-speed traffic at the first apparent opportunity. In contrast, a roundabout presents frequent opportunities for pedestrians to cross safely during gaps in slow-moving traffic. The crossing distance is shorter, and safe gaps are easier to judge in slow-moving traffic.

4. Impact on crash frequency

This section applies a methodology for determining the impact the planned roundabout conversions will have on crash rates. The first step is to obtain recent data on the crash history.

The most recent 36 month history of police crash reports for the six intersections was obtained from the Pinellas County Crash Data Center at the Pinellas County Metropolitan Planning Organization (MPO).[62] The Crash Center also provides a summary sheet for each crash which includes a schematic depiction of the crash; those sheets are found in APPENDIX B.

Although crash prediction models have been developed for signalized intersections, no such models exist yet for U.S. roundabouts and driver behavior.[63] There are several alternate methodologies to predict post-conversion crash rates from the pre-conversion crash history. One approach is to apply the empirically researched safety performance prediction model derived in the United Kingdom. However the model is UK-based and not necessarily applicable to drivers, driving conditions, or crash reporting procedures in the United States. In addition, this methodology does not take into account the specific

[62] While not necessarily 100% accurate, this is the best data available.
[63] *Roundabouts: An Informative Guide*, p. 122

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individual characteristics of the crashes that have actually occurred at the intersections in question.

An alternate methodology is to apply crash rates obtained elsewhere, such as from large foreign studies or small domestic studies, to the crash history. These rates are available for both total crashes and injury crashes. This methodology is convenient because it involves simply applying gross crash rates to gross crash totals, but, again, does not take into account the nature of the specific crashes in the crash history nor the crash reduction features of the geometry of modern roundabouts. In addition, crash rates taken from foreign studies may not apply in the United States, and crash rates from domestic studies may be based on sample sizes too small to be reliable or confounded with data from multiple-lane roundabouts.

The methodology employed for the present study involves examining the individual police reports for each of the crashes in the crash history and making a determination as to whether and how each crash would have been affected by the geometry of the planned modern roundabouts. The crashes were classified into seven categories according to how they would have been affected by a low-speed modern roundabout.

The table below gives the past three years of crash history, divided into the seven categories.

Table 8. Crash History (36 months)

Collision Category							
Right-Angle	Left-Turn	Backing Vehicle (driveway)	Rear End	Side-swipe	Out of Control #1	Out of Control #2	Total
18	5	4	7	3	1	1	39

The table above shows a total of 39 *reported* crashes have occurred at the six intersections in the past 3 years, or more than one reported crash a month.

Because of the geometric nature of the roundabouts, it is observed that most of the collisions that are identified in the crash history are preventable for the following reasons:

- Right-angle and left-turn crashes cannot occur in roundabouts because those conflicts don't exist in the design of roundabouts, so those 23 crashes can be prevented.

- In the low-speed environment of a low-speed modern roundabout, the driveway crashes and rear-end crashes are unlikely to occur. A conservative 50% reduction of these crashes is assumed.

- The three sideswipe crashes would likely not have occurred because of the geometry of a 1-lane roundabout. A conservative 50% reduction of these crashes is assumed.

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- The out of control crash #1 is unlikely due to the low-speed corridor created by the series of six planned roundabouts and the planned medians along Cleveland. A conservative 50% reduction of these crashes is assumed.

- The out of control crash #2 was a case in which a DUI driver approaching the intersection passed another vehicle, lost control of his vehicle and crashed into a tree on the left side of the street. A single roundabout ahead would by itself prevent most drivers from attempting a pass but not necessarily an alcohol-impaired driver, but because the planned project creates an entire low-speed corridor with six successive roundabouts and the roundabout splitter islands extend into a series of medians it is not possible to attempt to pass, let alone crash into a tree on the other side of the street, so this crash is considered preventable.

Applying the above determinations to the crash history results in the table below.

Table 9. Crashes That Typically Would be Prevented by a Modern Roundabout (36 mo.)

	Collision Category						
	Right-Angle	Left-Turn	Backing Vehicle (driveway)	Rear End	Side-swipe	Out of Control #1	Out of Control #2
Crash history	18	5	4	7	3	1	1
Reduction	100%	100%	50%	50%	100%	50%	100%
Eliminated crashes	18	5	2	3.5	3	.5	1

The table above shows the likely reduction in crashes had these six intersections been modern roundabouts.

As is the case in almost ever state, the police crash reports were coded with the KABCO injury scale to classify crash victims as:

K – Killed
A – Incapacitating injury
B – Non-incapacitating injury
C – Possible injuries
O – No apparent injuries (property damage only, or PDO)

Note that while the accuracy of KABCO police reporting is not 100% reliable for reporting internal injuries, the reliability for reporting fatalities is virtually perfect.

Summing the injury data from the prevented crashes gives the table below.

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Table 10. Injuries Associated with the Prevented Crashes (36 months)				
K	A	B	C	O
Fatalities	Incapacitating Injuries	Non-incapacitating Injuries	Possible Injuries	No Apparent Injuries (PDO)
2	0	8.5	5.5	19

The table above shows the injuries associated with the crashes that typically would be reduced had the six intersections been modern roundabouts. This table will be referred to later under *Cost Impacts* in the section on *Cost of Crashes* (p.80).

Note that the reduction in injuries enumerated above is due purely to crashes being prevented; this analysis does not factor in any reduction in the severity of the crashes that do occur at low-speed modern roundabouts. However, there are several reasons why severity of the crashes that do occur is also significantly reduced at modern roundabouts, as discussed in the next section below.

5. Impact on crash severity

The two primary factors determining the severity of a crash are the speed and the angle of impact.

a) Speed

Speed is a large determinant of crash severity because the energy of a vehicle increases with the square of the speed. In other words, a vehicle traveling 20 MPH miles per hour has not twice the energy it does at 10 MPH but rather has *four* times as much energy, or two squared ($2^2 = 4$).

The exponential increase produces very large energy levels even at moderate speeds. A vehicle going 40 MPH has *sixteen* (4^2=16) times the energy as it does at 10 MPH.

The more energy to be dissipated, the greater the damage. This same exponential relationship is seen in the graph of *Speed v. Pedestrian Fatality Rate* (p. 46) and the graph of *Impact Speed v. Pedestrian Injury* (p. 47) discussed under *Safety Impacts* in the section on *Non-Motorized Users* (p. 45).

Because energy increases exponentially with speed, the low speeds achievable with low-speed modern roundabout design are critical reason for safety.

The geometric constraints that modern roundabouts impose on entering vehicles forces them to slow down and keeps them slowed.[64] At Clearwater's four 1-lane modern roundabouts, typical circulating speeds are 11-13 MPH and typical speeds at the crosswalks are 14-16 MPH. At these low speeds, vehicles have only a small fraction of the energy they would at higher speeds typical of conventional cross intersections.

[64] Discussed in the section on Why Roundabouts Are Safer (p. 33)

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b) Angle of impact

The angle of impact is also a major determinant of crash severity. Head-on crashes of two vehicles are typically lethal for all occupants because the closing speed is the sum of the two vehicle speeds.

T-bone crashes are typically lethal for occupants of the side-impacted vehicle because vehicles are subject to deformation in the side, the impacting vehicle intrudes into the passenger compartment and strikes occupants, and humans do not tolerate blows to the side of the head well.

Head-on and side-impact (T-bone) crashes cannot occur at modern roundabouts because the geometry of the roundabout does not include paths that cross at those angles, as described earlier in the discussion of conflict points under *Safety Impacts* in the section on *Why Modern Roundabouts are Safer* (p. 33).

Humans do not tolerate blows to the side of the head well, injuries that are common in side-impact crashes. Blows to the side of the head caused by side-impact crashes are considered such a national problem that the National Highway Traffic Safety Administration (NHSTA) has recently announced a Notice of Proposed Rule Making (NPRM) that would substantially upgrade the agency's side impact protection standard.[65]

The lower the angle of impact, the less severe the crash, especially when vehicles are traveling approximately the same speed. Merging crashes are low-angle collisions. When the speed of the merging vehicles is quite low, the energy of the crash is as well.

As described earlier in the section discussing conflict points under *Why Roundabouts are Safer* (p. 33), the two ways vehicle paths cross at a modern roundabout are as low-speed merge collisions, and rear-end collisions. The merge collisions occur at a very low angle of impact, and the rear-end collisions at the lowest possible angle of impact, zero degrees.

Because the geometry of modern roundabouts reduces both the speed and angle of impact and therefore the energy of impact, the collisions that do occur are typically much less severe than at cross intersections and consequently the injuries are typically much less severe.

B. Older Users

This section examines the statistics that reveal the extent to which older users are at risk as drivers, the performance profile of older users, Clearwater's demographics, and the implications for intersection design.

1. Older users at risk

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[65] Docket No. NHTSA-2004-17694

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This section examines the performance profile of older users and the implications for intersection design.

Older users are at heightened risk, partly due to increasing fragility with age. Older adults are in the highest risk category for crashes in terms of crashes per number of miles driven.[66]

Using NHSTA data in the Federal Accident Reporting system (FARS), the figure below shows the rate of involvement in fatal crashes versus the age of the driver.

Figure 7. Fatal Crash Involvement by Age
[Insert FARS bathtub graph of age v. fatality rate per 100 M miles]
Beginning at age 60, involvement in fatal crashes rises sharply.

The bathtub-shaped line in the figure above shows that traffic fatality rates are fairly flat from early adulthood through middle age until a discontinuity at the 55-59 age group, when there is a sharp increase followed by a very steep rise beginning at the 70-74 age group.

And older roadway users are at increasing risk. Between 1991 and 2001 the number of Americans aged 70 and older killed in traffic crashes increased by 27 percent and crashes involving at least one older driver increased 20 percent. [67]

2. Older users at intersections

Older users are especially at risk at intersections. A 2001 FHWA report states that “The single greatest concern in accommodating older road users, both drivers and pedestrians, is the ability of these persons to negotiate intersections safely.”

Thirty-eight percent of pedestrian deaths among people aged 65 and older in 1998 occurred at intersections. For drivers 80 years of age and older, about half of fatal crashes occur at intersections, compared with 23% or less for drivers up to 50 years of age. In other words, older drivers are about twice as likely to be killed while driving through an intersection than younger drivers.[68]

A current FHWA Brief states that “Elderly drivers do not deal with complex traffic situations as well as younger drivers do, which is particularly evident in multiple-vehicle

[66] *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA publication FHWA-RD-01-051

[67] *Designing Roadways to Safely Accommodate the Increasingly Mobile Older Driver*, The Road Information Program, July 2003

[68] *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA Report No. FHWA-RD-01-051

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crashes at intersections. People 56 years and older have a higher probability of causing a fatal crash at an intersection, and about one-half of these fatal crashes involved drivers who were 80 years and older."[69]

A current FHWA Brief states that "Drivers 85 years of age and older are more than 10 times as likely as drivers in the 40-49 age group to have multi-vehicle intersection crashes."[70]

3. Demographics of older users

The increase in older drivers killed in traffic crashes is occurring as older Americans form a greater portion of the overall population. The segment of the population aged 65 and older grew nearly twice as fast as the total population between 1990 and 2000, and by 2020 one in five people will be aged 65 or older. [71]

In addition, older Americans are more mobile than ever, with the number of licensed drivers aged 70 and older increasing 32 percent from 1991 to 2001. Since 1995 their level of driving as measured in minutes per day increased 28 percent and the number of miles driven per day increased 20 percent.[72]

The size of the older generation is projected to double over the next 30 years, and Americans aged 85 and older are the fastest growing part of the population. Florida leads the nation in the proportion of its population aged 65 and over.[73] And in 2001, Florida led the nation in the number of older drivers killed in traffic crashes.[74]

Local demographics make the user profiles presented above especially relevant to intersection design in Clearwater. As shown in the table below, Florida has a higher proportion of population aged 65 and older than does the nation and Clearwater's proportion is higher yet.

Table 11. Age Demographics[75]

Jurisdiction	Aged 65+	Compared to Nation
United States	12.4 %	1.0x
St. Petersburg	17.4 %	1.4x
Florida	17.6 %	1.4x
Clearwater	**21.5 %**	**1.7x**

69 *The National Intersection Safety Problem*, FHWA, April 2004
70 The National Intersection Safety Problem, FHWA Brief, April 2004
71 *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA publication FHWA-RD-01-051
72 *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA publication FHWA-RD-01-051
73 *Designing Roadways to Safely Accommodate the Increasingly Mobile Older Driver*, The Road Information Program, July 2003
74 *Designing Roadways to Safely Accommodate the Increasingly Mobile Older Driver*, The Road Information Program, July 2003
75 *2000 Census*, U.S. Bureau of the Census

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Pinellas County	22.5 %	1.8x
Dunedin	29.9 %	2.4x
Clearwater Beach	31.9 %	2.6 x

The table above shows that 21.5% of Clearwater citizens are aged 65 and older, a figure 1.7 times greater than the nation generally. Florida and Pinellas County also have a higher proportion of older citizens than the nation as a whole, and nearby Dunedin has almost two and a half times as many 65+ citizens proportionally.

In addition to the population over sixty-five, sixteen percent of Clearwater's population is too young to drive (<16),[76] for a combined fraction of 37.5%—more than a third of the population that is not in the prime of driving life.

Some areas of Clearwater have much higher proportions of older persons. The population of Clearwater Beach is 31.9% aged 65 and older[77], or 2.6 times the national figure. Interestingly, the residents and business owners of Clearwater Beach became the first citizen group in Clearwater to ask for a modern roundabout when the Beach Association made a formal request to the Clearwater City Commission on—and backed it up with a donation of $3,000 to encourage the City to follow through.

Beach residents even threw a street party to celebrate the day their new roundabout opened, a rarity for any intersection project. That roundabout, the Acacia Roundabout on North Clearwater Beach, has been in operation since December of 2000 with no problems. The photographs below show the Acacia Roundabout and some of the street partiers celebrating the opening.

<table>
<tr><th colspan="3">Figure 8. Acacia Roundabout on North Clearwater Beach</th></tr>
<tr><td>[Insert aerial photo]</td><td>[Insert photo showing older partiers and wheelchair]</td><td>[Insert photo of partiers group on splitter island]</td></tr>
<tr><td>Looking South</td><td colspan="2">Beach Residents Celebrating Opening Day by Throwing a Street Party</td></tr>
</table>

As described later in the section on *Public Acceptance* (p. 72), the Clearwater Beach citizen's request has subsequently been followed by requests from seven other Clearwater citizen groups for roundabouts in their neighborhoods, including Skycrest residents.

4. Performance profile of older users

This section examines the performance profile or "operating characteristics" of older users.

[76] *2000 Census*, U.S. Bureau of the Census
[77] *2000 Census*, U.S. Bureau of the Census

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The *AASHTO Green Book* states that "An appreciation of driver performance is essential to proper highway design and operation."[78] The same could be said of all transportation corridor users, including users of local streets such as Cleveland Street.

Older persons differ from their younger selves in many ways that bear on roadway design for both driver and pedestrian usability, including:[79]

- *Diminished acuity*, the ability to discriminate high-contrast features
- *Yellowing of the eyes' lenses* and *increased density*, which makes seeing in low light conditions more difficult
- *Diminished contrast sensitivity*, which makes it harder to distinguish an object from its background. Additionally, persons over 60 have an increasing risk for developing cataracts and other conditions that reduce contrast sensitivity.
- *Increased sensitivity to glare*, which diminishes the ability to see in the presence of oncoming headlights, at night, or in the presence of sun glare in the daytime. Glare introduces stray light into the yes; it reduces the contrast of important safety targets.
- *Slower dark adaptation*, which diminished the ability to see targets when moving from areas of light to dark
- *Loss of limb strength, flexibility, sensitivity and range of motion,* needed for tasks such as rapidly shifting the right foot from the accelerator pedal to the brake pedal or arm movements to steer around obstacles

Of particular relevance to safely negotiating intersections are these changes that come with age:[80]

- *Narrowing of the visual field*, which diminishes the ability to see objects in the periphery, such as signs, signals, vehicles, pedestrians and cyclists
- *Restricting of the area of visual attention*, which diminishes the ability to see potential conflicts in the periphery and to discriminate relevant from irrelevant information. Both abilities are necessary for responding quickly and appropriately to a changing traffic scene. Restrictions in the area of visual attention can lead to "looked but didn't see" crashes, where a stimuli can be detected, but cannot be recognized and understood sufficiently to permit a timely response.
- *Decreased motion sensitivity*, which diminishes the ability to accurately estimate closing speeds and distances and is needed for judging gaps to safely perform left

[78] *A Policy on Geometric Design of Highways and Streets*, p.42, American Association of State Highway and Transportation Officials, 1994

[79] *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA publication FHWA-RD-01-051

[80] *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians,* L. Staplin, et. al., October 2001, FHWA publication FHWA-RD-01-051

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turns at conventional cross intersections with oncoming traffic or to cross an intersecting traffic stream

- *Decline in selective attention*, the ability to filter out less critical information and continuously re-focus on the most critical information, such as detecting a lane-use restricted message on an approach to a busy intersection or detecting a pedestrian crossing while watching oncoming traffic to locate a safe gap

- *Decline in divided attention*, the ability to perform multiple tasks simultaneously and process information from multiple sources

- *Decline in perception-reaction time (PRT)*, the time required to perceive a situation, evaluate it, decide what response is appropriate and make a vehicle control action such as steering or braking. PRT increases disproportionately for older motorists with increase in complexity of the driving situation.

- *Decline in working memory*, the ability to store, manipulate and retrieve information for later use while driving

- *Loss of head, neck and trunk flexibility,* needed to rapidly glance in each direction from which a vehicle conflict might be expected when approaching an intersection

According to the *AASHTO Green Book*, all "Drivers often commit errors when they have to perform several highly complex tasks at the same time under extreme time pressure." "Speed reduces the visual field, restricts the peripheral vision, and limits the time available to receive and process information."[81] Older drivers are even less able to perform flawlessly under these circumstances.

In short, older persons need reduced demands to accurately judge gaps in fast oncoming traffic. They need less complicated situations to interpret than when they were younger. They need more time to perceive and evaluate situations, more time to make decisions, and more time to take action. They need less demands on their ability to quickly perform wide visual scans of rapidly changing situations. All of these needs are helped by lower traffic speed and less complexity, two design features of modern roundabouts. Reduced demands, reduced complexity and more time to react benefit all intersection users.

5. Impact on older users

The *AASHTO Green Book* states that "There is agreement that elderly road users require mobility, and that they should be accommodated by the highway's design and operational characteristics to the greatest extent practicable. Thus, designers and engineers should be aware of the problems and requirements of the elderly, and consider applying applicable measures to aid their performance."[82]

[81] *AASHTO Green Book*, 1994, pp. 46-47.
[82] *A Policy on Geometric Design of Highways and Streets*, p.42, American Association of State Highway and Transportation Officials, 1994

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These findings reinforce a long-standing recognition that driving situations involving complex speed-distance judgments under time constraints—the typical scenario for intersection operations—are more problematic for older drivers than for their younger counterparts. Other studies within the large body of evidence showing dramatic increases in intersection crash involvements as driver age increases have associated specific crash types and vehicle movements with particular age groups.

By 2020 the 65 and older age group will grow to roughly one-fifth of the population of driving age in the United States. In effect, if design is controlled by even 85th percentile performance requirements, the "design driver" of the early 21st century will be an individual over the age of 65.[83] This demographic fact has profound implications for intersection design.

The FHWA roundabout *Informational Guide* states that "Roundabouts designed for low, consistent speeds cater to the preferences of older drivers: slower speeds; time to make decisions, act, and react; uncomplicated situations to interpret; simple decision-making; a reduced need to look over one's shoulder; a reduced need to judge closing speeds of fast traffic accurately; and a reduced need to judge gaps in fast traffic accurately."[84]

C. Non-motorized Users

This section examines the performance profiles, or "operating characteristics," of several categories of non-motorized intersection users and the implications for intersection design.

1. Pedestrians

The *AASHTO Green Book* states that "A pedestrian is any person afoot, and involvement of pedestrians in traffic is a major consideration in highway planning and design. Pedestrians are a part of every roadway environment, and attention must be paid to their presence in rural as well as urban areas."[85]

A 2002 study noted that in the United States definitive statistics are lacking for pedestrian safety at roundabouts, although the study also noted an Australian study and a Scandinavian study found that roundabouts are safe for pedestrians. The research applied three alternative approaches[86] to assess pedestrian safety at roundabouts and found "the results suggest roundabouts are safe with respect to pedestrians."[87]

Since the arrival of modern roundabouts in the United States in the mid-nineties, some pedestrian data has accrued. The Montpelier, Vermont 1-lane modern roundabout has been in operation for 8.5 years with one non-injury pedestrian crash and several

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[83] *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, L. Staplin, et. al., October 2001, FHWA Report No. FHWA-RD-01-051
[84] *Roundabouts: An Informational Guide*, p. 32.
[85] *AASHTO Green Book*, 1994, p. 110
[86] Case study analysis, statistical analysis, and simulation analysis
[87] *The Effects of Roundabouts on Pedestrian Safety*, John Stone, et. al., The Southeastern Transportation Center, University of Tennessee – Knoxville, August, 2002

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property damage. The four 1-lane modern roundabouts in Clearwater have experienced no reported pedestrian crashes.

The 2-lane Clearwater Beach Entryway Roundabout, with 2,000-8,000[88] non-motorized users per day, has experienced no reported pedestrian injuries.[89] When the area was under signal control[90] there was an average of four bike/pedestrian crashes per year and an average of 35 crashes per year with about half of them involving injuries, making mid-beach the most dangerous section of Clearwater Beach for pedestrians and bicyclists.[91]

In the absence of long-term U.S. data, an indirect surrogate for pedestrian risk is speed of motorized vehicles, since motorized vehicles are what kill pedestrians at intersections.

Non-motorized intersection users are at risk of severe injury or death from being struck by a motorized vehicle. The findings for pedestrians cited in the three studies below may apply equally to bicyclists, skaters and wheelchair users.

A 1999 NHSTA study[92] confirmed the strong relationship between vehicle speed and pedestrian crash severity. A 1994 study found a nearly identical relationship.[93] The figure below depicts the findings of the two studies.

Figure 9. Pedestrian Fatality Rate v. Vehicle Speed	
[Insert graph from NHSTA study.]	[Insert graph from Limpert study.]
1999 NHSTA Study	1994 Limpert Study

The two graphs in the figure above show that even moderate vehicle speeds of 30-40 MPH are very dangerous to pedestrians.

Another way to appreciate the NHSTA findings is to consider the pedestrian fatality rates as multiples of the fatality rate at 20 MPH. The NHSTA graph above shows that a

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[88] Pedestrian volume varies seasonally at this vacation destination. Non-motorized users were counted manually twelve hours a day for eleven straight days from a nearby 11th-story overlooking rooftop during Spring Break 2000.

[89] <verify>

[90] The *Clearwater Beach Entryway Roundabout* project replaced nine cross intersections, three of them signalized.

[91] *Clearwater Beach Gateway Roundabout Feasibility Study*, Alternate Street Design, PA, 1998 <look up>

[92] *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*, Leaf, W.A. and D.F. Preusser, NHSTA Report DOT HS 809 021, October 1999

[93] *Motor Vehicle Accident Reconstruction and Cause Analysis*, Limpert, Rudolph, Fourth Edition, Michie Company, Charlottesville, 1994, p. 663

pedestrian struck at 30 MPH is *eight times* more likely to die than at 20 MPH, and *sixteen* times more likely if struck at 40 MPH.

A 1998 study (not included in the NHSTA study) examined the relationship between pedestrian injuries and vehicle speed.[94] The figure below depicts the study findings.

Figure 10. Impact Speed v. Pedestrian Injury

[Insert graph of Impact Speed v. Pedestrian Injury]

1998 Transportation Research Board study (TRB 1636)

The shape of the graph in the figure above is very similar to the two graphs in the preceding figure, again demonstrating that even moderate vehicle speeds of 20-30 MPH are very dangerous for pedestrians.

Because the six roundabouts are designed for vehicle speeds well below 20 MPH, the fatality and injury rate should be low for pedestrians struck by vehicles.

The speed limit on Cleveland Street is 35 MPH. A recent traffic study[95] on Cleveland at Skycrest Elementary School found that 150 vehicles per day exceed 44 MPH.

The table below compares typical motor vehicle speeds at the existing intersections versus the replacement modern roundabouts.

Table 12. Typical Vehicle Speeds (MPH)

Intersection with Cleveland Street	Existing Conventional Cross Intersections (through movements)	Modern Roundabouts[96]	
		Circulating	At Crosswalks
Lake Av	30-45+	11-13	14-20
Duncan Av	30-45+	11-13	14-20
Saturn Av	30-45+	11-13	14-20
Corona Av	30-45+	11-13	14-20
Meteor Av	30-45+	11-13	14-20
Aurora Av	30-45+	11-13	14-20

[94] *Method for Estimating Effect of Traffic Volume and Speed on Pedestrian Safety for Residential Streets*, Davis, Gary, Transportation Research Record 1636, 1998, pp. 110-115.
[95] Traffic study by Adams Traffic, March 25, 2004
[96] Roundabout speeds given in this table are *typical*, not the highest speeds attainable, and are based on typical speeds observed at Clearwater's four existing 1-lane modern roundabouts and similar low-speed modern roundabouts elsewhere. Even in a modern sports car, it's difficult to exceed 20 MPH at the crosswalks at Clearwater's existing four 1-lane roundabouts.

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The table above shows the existing motor vehicle speeds are well into the high-injury/fatality rate zone, whereas the planned roundabouts will produce vehicle typical speeds at or below 20 MPH, where pedestrians stand a 95+% probability of survival.

The low vehicle speeds at low-speed modern roundabouts also give drivers much more time to react and compensate for non-motorized users in their path. Experience with Clearwater's four one-lane roundabouts has demonstrated that the low-speed design does produce actual low vehicle speeds.

A current FHWA publication states that "Although intersections represent a very small percentage of U.S. surface road mileage, more than one in five pedestrian deaths is the result of a collision with a vehicle at an intersection."[97]

The publication also states that "Intersections are disproportionately responsible for pedestrian deaths and injuries. Almost 50% of combined fatal and near-fatal injuries to pedestrians occur at or near intersections."[98]

The publication further states that "The design and improvement of roadways often fail to meet the needs of pedestrians of all ages and capabilities for safely crossing intersections, including older persons, young children and those with impaired vision or difficulty in walking.[99]

Signalized intersections may seem safe for pedestrians crossing during the red light because vehicles come to a stop. But in fact, vehicles continue to make right- and left-turning movements and travel across the crosswalks even when the light is red. The diagram in the figure below shows three situations that can lead to a vehicle striking a pedestrian.

Figure 11. Pedestrian Crossing Hazards
[Insert Ken's diagram]
Some Pedestrian Hazards at a Conventional Cross Intersection

The figure above shows three situations where the driver is looking out for threats and looking away from the crossing pedestrian.

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[97] *The National Intersection Safety Problem*, FHWA, April 2004
[98] *The National Intersection Safety Problem*, FHWA, April 2004
[99] *The National Intersection Safety Problem*, FHWA, April 2004

Roundabouts have fewer *pedestrian*/vehicle conflict points in comparison to conventional cross intersections. The figure below compares the pedestrian/vehicle conflicts in the two intersection configurations.

Figure 12. Pedestrian/vehicle Conflict Points[100]

Conventional Cross Intersection	Roundabout
[Insert diagram of conventional intersection with *pedestrian*/vehicle conflict points.]	[Insert diagram of roundabout with *pedestrian* /vehicle conflict points.]
24 Pedestrian/vehicle conflict points. Drivers are looking left.	8 Pedestrian/vehicle conflict points. The conflicts where drivers are looking left while turning right don't exist.

The figure above shows that converting a conventional cross intersection to a modern roundabout reduces the number of pedestrian/vehicle conflicts from 24 to 8, a 2/3 or 67% reduction.

The table below compares the number of pedestrian/vehicle conflict points for the existing intersections versus the planned replacement roundabouts.

Table 13. Pedestrian/Vehicle Conflict Points

Intersection with Cleveland St.	Existing Intersections	Planned Roundabouts	Impact
Lake Av	24	8	- 16
Duncan Av	24	8	- 16
Saturn Av	24	8	- 16
Corona Av	24	8	- 16
Meteor Av	24	8	- 16
Aurora Av	24	8	- 16
Totals	144	48	- 96

The table above shows the six planned roundabouts will eliminate 96 pedestrian/vehicle conflict points.

The shape of the roundabout is significant, too, because pedestrians cross in front of vehicles while the driver is still looking forward. Because of the splitter islands, pedestrians have much less exposure at a roundabout, where they must cross only one direction of traffic at a time, and their distance and time exposure to cross only one lane is shorter than crossing two lanes of opposite flow as they must at a conventional cross intersection.

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[100] <*Name of Paper*>, Wallwork, Michael, PE, <date>

The table below compares two measures of pedestrian exposure at the existing intersections versus the planned replacement roundabouts.

Table 14. Pedestrian Exposure

Inter-section Approach	Number of Contiguous Lanes Pedestrians Must Cross			Number of Directions of traffic Pedestrians Must Cross at Once		
	Exist-Ing	Round-About	Impact	Exist-Ing	Round-About	Impact
E	3	1	- 2/3	2	1	– ½
W	3	1	- 2/3	2	1	– ½
N	2	1	– ½	2	1	– ½
S	2	1	– ½	2	1	– ½

The table above shows a significant reduction in the number of contiguous lanes pedestrians must cross to get across the street at each approach to the intersections. Even more significant is that the splitter islands eliminate having to cross opposing directions of traffic at once.

2. Older pedestrians

The performance profile or "operating characteristics" of older users has already been examined earlier in the section *Performance Profile of Older Users* (p. 42). This section examines specifically older users who are pedestrians.

Crossing distance is especially important for older pedestrians, who walk more slowly and thus are exposed to traffic for longer periods of time.

The table below compares the existing intersections versus the planned roundabouts for two measures of pedestrian exposure.

Table 15. Pedestrian Exposure

Inter-section Approach	Pedestrian Crossing Distance (typical)			Older Pedestrian Crossing Time (sec.) @ 2.8 ft/sec* (typical)		
	Exist-Ing	Round-About	Impact	Exist-Ing	Round-About	Impact
E	40’	14’	-26	112	39	-73
W	40’	14’	-26	112	39	-73
N	28’	14’	-14	78	39	-39
S	28’	14’	-14	78	39	-39

* Older Driver Highway Design Handbook, FHWA

The table above shows that the pedestrian exposure distance and exposure time are reduced about two-thirds at the east and west legs and reduced by half at the north and south legs.

Older pedestrians are exposed for 73 fewer seconds at the east and west legs and 39 fewer seconds at the north and south legs. Clearwater has 1.7 times the national

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proportion of population aged 65 and older, as discussed earlier in the section on *Demographics of Older Users* (p. 41).

3. Children

This section examines the performance profile or "operating characteristics" of pedestrians who are children.

A current FHWA report states that "Almost one-forth (23 percent) of children between the ages of five and nine years who were killed in traffic crashes were pedestrians."[101]

Compared to adults, children have a narrower visual field, less ability to isolate sounds and determine the direction of approaching traffic by auditory cues, and less ability to judge closure speed. Children cannot understand complex situations or focus on multiple thoughts at once. They have a drive for constant motion and once in motion, have a compulsion to complete the motion. They are more prone to fearlessness and less able to perceive risk. Children assume adults will assure their safety; they live in a self-centered world where fantasy is mixed with reality.[102]

In Clearwater, 16% of the population is younger than 16, as mentioned earlier in the section on *Demographics of Older Users* (p. 41).

Because of their low-speed, uncomplicated design, one-lane modern roundabouts can be significantly easier for children to use safely and significantly more amenable to the drivers who must see and avoid them, than cross intersections.

Of particular interest are the safety impacts for schoolchildren walking to school, because the roundabout planned for the corner of Corona & Cleveland is on the southeast corner of the Skycrest Elementary School property, as discussed earlier under Traffic Impacts in the section on Skycrest Elementary School (p. 24).

A 2003 study for the New York DOT reported on a project in Howard, Wisconsin, where installation of two roundabouts near an elementary school and a middle school calmed traffic sufficiently that students were allowed to resume walking and biking to school.[103] Letters from the principal and sheriff's office for this school are found in **APPENDIX L**.

The one-lane modern roundabout in Clearwater in front of John F. Kennedy Middle School has been in operation for one full school year with no reported safety problems.

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[101] *The National Intersection Safety Problem*, FHWA, April 2004

[102] *Trail Intersection Guidelines*, Wayne E. Pein, University of North Carolina Safety Research Center, Chapel Hill, North Carolina. Prepared for the State Safety Office, Florida Department of Transportation

[103] *Operational and Safety Performance of Modern Roundabouts and Other Intersections Types*, Eisenman, S., Josselyn, J., List, G., and Persaud, B., Project NYSDOT-C-01-47, October 2003 (unpublished draft reported in a draft chapter of the ITE *Intersection Design Safety Toolbox*, Chapter 2, *Designing and Operating Safer Roundabouts*, Jacquemart, Georges

4. Bicyclists and skaters

Bicyclists and skaters (especially novice skaters) have yet other user profiles[104] and present further challenges to intersection design. Both have a strong motivation to keep moving to conserve their kinetic energy. Novice skaters are on the edge of control, including adults just learning to skate on roller-blade skates. Like pedestrians, bicyclists, skaters and especially wheelchair users are much less noticeable to drivers.

Because of their low-speed, uncomplicated design, one-lane modern roundabouts can be significantly easier for bicyclists and skaters to use safely and significantly more amenable to the drivers who must see and avoid them, than cross intersections.

5. Mobility impaired users

This section examines the challenges mobility impaired users must face at intersections and the impacts for them of converting the six existing cross intersections to low-speed modern roundabouts.

The *AASHTO Green Book*s states: “For the designer to adequately provide for the handicapped pedestrian, he must be aware of the range of impairments to expect so that the design can provide for them. In this way the mobility of this sector of our society may be greatly enhanced.”[105]

The *AASHTO Green Book* states that “For the designer to adequately provide for the handicapped pedestrian, he must be aware of the range of impairments to expect so that the design can provide for them. In this way the mobility of this sector of our society may be greatly enhanced.”[106]

The *AASHTO Green Book* states that “Ambulation difficulties range from persons who walk unassisted but with difficulty, to persons who require aid from braces, canes, or crutches, to persons confined to a wheelchair.”[107]

Because of their low-speed, uncomplicated design, one-lane modern roundabouts can be significantly easier for wheelchair and cane users to use safely and significantly more amenable to the drivers who must see and avoid them, than cross intersections.

6. Visually impaired users

This section examines the challenges visually impair users at intersections and the impacts for them of converting the six existing cross intersections to low-speed modern roundabouts.

The *AASHTO Green Book* states that “Pedestrians with very limited vision require special consideration. Intersections are the major threat to their safety.”[108]

[104] *Trail Intersection Guidelines*, Wayne E. Pein, University of North Carolina Safety Research Center, Chapel Hill, North Carolina. Prepared for the State Safety Office, Florida Department of Transportation
[105] *AASHTO Green Book*, 1994, p.__
[106] *AASHTO Green Book*, 1994, p. 121
[107] *AASHTO Green Book*, 1994, p. 121
[108] *AASHTO Green Book*, 1994, p. 121

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Signalized intersections are problematic for pedestrians who cannot see or who cannot see well. A 2000 survey queried orientation and mobility specialists regarding the problems students with visual impairments *were* experiencing at signalized intersections. 98% of respondents indicated that their students sometimes had difficulty knowing when to cross; 97% indicated students sometimes had difficultly aligning to cross the street; and 94% indicated students sometimes experienced difficulty using pushbuttons.

Much of the difficulties students experienced arose from confusing, masked or missing aural cues that students needed in order to assess the intersection, to orient themselves and for wayfinding. As vehicles become *quieter*, the challenge is greater. The report concluded that "Increasing complexity of intersection design and signalization are unquestionably decreasing the safety and independence of pedestrians who are visually impaired."[109]

Most of the safety, mobility and access advantages low-speed modern roundabouts offer to non-motorized users generally and pedestrians in particular, would seem benefit intersection users who cannot see well or at all. However, pedestrians with visual impairment are a special case. The primary issue identified so far seems to stem from lack of aural cues—or at least lack of the same cues available some of the time at conventional cross intersections—coupled with the need to identify gaps in traffic.

At roundabouts as at all intersections, drivers are required to stop for pedestrians in the crosswalks when present, just as they are required to stop for stop signs and red lights when present. At all five of Clearwater's modern roundabouts drivers can be observed stopping for pedestrians who are in or at the crosswalks and exchanging friendly waves with pedestrians. Drivers are often observed stopping even *before* pedestrians have arrived at the crosswalk. This civil driver behavior is attributed to the low vehicle speeds and other factors and is generally not observed elsewhere in Clearwater, except on Gulfview Avenue, where vehicle speeds are also low.

As with signalized intersections, the fact that quieter vehicles are gaining market share increases the challenge. "The sound of the continuous flow of traffic in the roundabout and on the roundabout approaches masks the audible cues used in orientation and wayfinding so that gap identification cannot be accurate at all locations at all times."[110]

Designed and built back in 1999, Clearwater's two-lane roundabout incorporated many features known at the time to be helpful to all non-motorized users, including persons with impaired vision. The intersection handles as many as 58,000 motorized vehicles per day, but is also used by as many as 8,000 non-motorized users per day of all sorts, including pedestrians, bicyclists, skaters, older persons, children, handicapped persons, tourists, families and infants in strollers, and it was an important design goal to make it as friendly and comfortable as possible for non-motorized users.[111]

[109] *Addressing Barriers to Blind Pedestrians at Signalized Intersections*, Billie Bentzen, Janet Barlow and Lukas Franck, ITE Journal, September 2000

[110] *Roundabout Accessibility Summit*, Draft Proceedings Version 2.0, Institute of Transportation Engineers, October 29, 2002

[111] *Assessing the Clearwater Beach Roundabout*, Ken Sides, PE, 70th Annual International Conference of the Institute of Transportation Engineers, 2000, Nashville, Tennessee

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The figure below gives quotations from independent blind-access researchers commenting on the Clearwater Beach Entryway Roundabout.

Figure 13. Independent Researchers Comment on Clearwater's First Modern Roundabout

"We appreciate the commitment of the City of Clearwater to provide an exemplary roundabout including features that make it accessible to and usable by persons with disabilities. The design includes a number of excellent features, including separation of the pedestrian and vehicular way and landscaping which prevents persons who are blind from inadvertently crossing the streets entering the roundabout at locations other than the crosswalks."	*"The greatest roundabout ever built in the United States is on Clearwater Beach, Florida."*
Letter to the principal author from Lukas Franck, Chair, Janet Barlow and Billie Louise Bentzen, Environmental Access Committee, Association for the Education and Rehabilitation of the Blind and Visually Impaired, Division Nine – Orientation and Mobility, July, 1999	*Roundabouts and Pedestrians with Visual Disabilities: How Can We Make Them Safer?*, Lal C. Wadwa, Ph.D., Head, Civil and Environmental Engineering, James Cook University, Australia, Transportation Research Baord,82nd Annual Meeting, January 2003, Washington, D.C.

Since designing and building the 2-lane roundabout commented upon above, the City of Clearwater has designed and built four 1-lane roundabouts.

Persons with impaired vision must execute four tasks at modern roundabouts:[112]

- Locate the crosswalk
- Detect a safe gap in traffic
- Locate the splitter island refuge area
- Locate the correct walkway to either continue their path or locate the adjacent crosswalk to cross the next leg of the roundabout

All of Clearwater's 1-lane roundabouts were designed to include several features helpful to pedestrians who cannot see, as will the six planned roundabouts: curb-return ramps are included because "curb-return ramps with returned edges aligned with crosswalk direction offer useful cues for establishing a line of travel",[113] and the at crosswalk cut through the splitter islands will continues this guidance mid-way across the street, leaving only about 14' of unguided crossing on either side. Consistency in the location of

[112] *Guide to Modern Roundabouts*, PENNDOT Publication Number 414, Michael Baker, Pennsylvania Department of Transportation, May 2001, p. 16

[113] *Pedestrian Access to Modern Roundabouts: Design and Operational Issues for Pedestrians who are Blind, Bulletin*, Federal Access Board

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crosswalks and shape of splitter islands can make it easier to find the crosswalks. Each crosswalk will be illuminated by a dedicated street light.

The technique of stamping concrete to create the required ADA-compliant truncated domes detectable surface at the bottom of the pedestrian ramps has been found to be highly problematic in terms of getting an acceptable consistency of surface, dome height and concrete hardness,[114] and there is no color contrast with the surrounding concrete. A number of recent installations by others in the Tampa Bay area show inconsistent and mostly poor results, and even when the domes are well formed they have shown a tendency to chip off soon after installation.

Seeking a superior solution, the City of Clearwater arranged for a vendor demonstration of a prefabricated tile accepted exclusively by the City of San Francisco. The demonstration showed that use of the tile product gives a consistent high quality installation without demanding high skill on the part of the installer or inspector.

In addition, the tile product is a bright yellow color, easily seen and providing a strong contrast with the surrounding concrete. Of the ten million visually impaired people in the United States, only 1.3 million are legally blind and only an estimated 260,000 are totally blind.[115] Studies have show this tile product to provide superior aid[116] for persons with impaired vision. Research indicates that safety yellow is especially visible and is strongly preferred by many people having low vision.[117] These findings were confirmed by Florida DOT research.[118]

The prefabricated tile product has another feature specially designed for persons who cannot see: it produces a “hollow” sound detectable by a blind person using a long cane, and was rated significantly higher than other tested products in this respect.[119] All in all, “By far the largest number of participants chose Armor Tile as particularly easy to detect” based on both objective and subjective measures of detectability based on surface texture, sound-on-cane-contact and visual contrast.[120]

The figure below shows the prefabricated truncated dome tile demonstration installation and the use of curb return ramps at the 1-lane modern roundabout at John F. Kennedy Middle school in Clearwater.

[114] *Detectable Warnings: Synthesis of U.S. and International Practice*, Billie Louise Bentzen, Ph.D., Janet Barlow and Lee S. Tarbor, Accessible Design for the Blind, U.S. Access Board, 12 May 2000, p.78
[115] E-mail communication from Janet M. Barlow, Certified Orientation and Mobility Specialist, May 19, 2004
[116] *XXXX* – cite study
[117] *Detectable Warning Surfaces: Color, Contrast, and Reflectance*, Billie Louise Bentzen, Ph.D., Tina L. Nolin, Ph.D., Randolph D. Easten, Ph.D., Accessible Design for the Blind, U.S. Department of Transportation, September 1994
[118] *A Florida DOT Field Evaluation of Tactile Warnings in Curb Ramps: Mobility Considerations for the Blind and Visually Impaired*, R.G. Hughes, Highway Research Center, University of North Carolina at Chapel Hill, 1995
[119] *Detectable Warnings Evaluation Services*, Appendix C, Billie Louise Bentzen, Ph.D., and L.A. Myers, Crain & Associates, Sacramento Regional Transit District, p. 11
[120] *Detectable Warnings Evaluation Services*, Appendix C, Billie Louise Bentzen, Ph.D., and L.A. Myers, Crain & Associates, Sacramento Regional Transit District, pp. 11, C-2

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Figure 14. Some Blind Access Features in Clearwater	
[Insert photo of curb return ramp at JFK Rbt]	[Insert photo of Armor-tile demo installation]
Curb return ramp at roundabout in front of John F. Kennedy Middle School	Vendor demonstration of the Armor-tile prefabricated truncated dome product. 26 City staff and personnel from other agencies observed the installation, arranged by City staff.

The January 1998 organizing meeting of the ITE Committee on Accessible Intersections for People who are Blind or Visually impaired identified the need for "more than anecdotal information about difficulties that visually impaired persons experience at signalized intersections." Research efforts are under way for roundabouts,[121] too, and

[121] The City of Clearwater has been present at the forefront of research into making roundabouts friendlier for persons who cannot see. City staff, including the principal author, received the three authors of the 2000 ITE paper on June 24,1999, for an evening until midnight of discussing the design of the Clearwater Beach Entryway Roundabout, including dinner at a restaurant with an overlooking view of the project under construction. A follow up letter from the guests is quoted in Figure __.

In 2000, the principal author proposed a daylong technical conference devoted solely to a case study presentation of the Clearwater Beach Entryway Roundabout and that the conference be held at the Clearwater Beach Hilton, where attendees could observe the operation of the roundabout from their hotel room balconies. The Transportation Industrial Alliance (TIA) agreed to present the conference and the University of Florida T^2/LTAP Center agreed to host it (Technology Transfer / Local Technology Assistance Program, an FHWA program). The TIA is a public service program created to advance the exchange of new, useful transportation technologies and end-user applications among America's local agencies.

The T^2 Center advertised the conference nationally. The conference was held September 20, 2000, and drew attendees from as far away as California and Alaska, including several blind attendees and blind access experts. City informally discussed with them ways roundabouts might be made friendlier for persons who cannot see.

On November 20, 2000, the principal author of this impact study responded to a request e-mail from Dr. Richard Long at the Department of Blind Rehabilitation at Western Michigan University (WMU) with an e-mail identifying nine circular intersections in the Tampa Bay area and providing an evaluation of their potential suitability for research Dr. Long's team was organizing under a grant from the National Institute of Health (see Appendix __). The note included this strong recommendation, "Of the nine candidates above, I think by far the best for research purposes is the Acacia Roundabout …". At that time, the Acacia Roundabout was a month from completion.

The WMU team did come to the Tampa Bay area and this impact study principal author spent a Saturday assisting with the research trials in the field. [Insert B&W photo of researchers in rain] By then it was already evident the Acacia Roundabout is very pedestrian friendly for sighted pedestrians. Clearwater's only one-lane modern roundabout at the time, the Acacia Roundabout, offered the researchers a rare opportunity to study a pedestrian-friendly, low-speed one-lane roundabout with typical circulating speeds

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may ultimately yield additional design guidance to enhance the accessibility of low-speed modern roundabouts for person who cannot see.

The 2000 study notes that many of the tasks required of a visually impaired person to cross safely and independently at signalized intersections are easier at familiar intersections; the same may prove true of low-speed modern roundabouts.

A roundabout in Montpelier Vermont has been used for more than eight years by a visually impaired lady. Crossing Cleveland Avenue at the existing stop controlled intersections presents a significant challenge for visually impaired persons because they must select a gap in traffic that is coming from two directions and then cross three lanes where drivers are known to be traveling at more than 45 mph. When the intersection have been converted to modern low-speed roundabouts, pedestrians will not have to cross two lanes of high speed traffic but a instead single lane of traffic that is moving slowly through a roundabout. The conversions to roundabouts should therefore provide a considerable improvement in mobility for visually impaired pedestrians who want to cross Cleveland Avenue.

7. Cognitively impaired users

This section examines the challenges cognitively impaired users must face at intersections and the impacts for them of converting the six existing cross intersections to low-speed modern roundabouts

The *AASHTO Green* Book states that "People with mental impairment are unable to drive and are therefore often captive pedestrians. To help ensure the correct response from these pedestrians, including young children, the pedestrian signals or other pedestrian-related facilities must be simple, straightforward, and consistent in their meaning."[122]

There is little or no research on the challenges cognitively impaired users face at intersections in general and modern roundabouts in particular. Clearwater's roundabouts all have visually and texturally emphasized crosswalks which make it more apparent where to cross safely.

The typical 11-13 MPH circulating speeds and 14-16 MPH speeds at the crosswalks are much less lethal in event of a crash than even moderate vehicle speeds. The low speeds give drivers more time to detect and compensate for pedestrian errors, and drivers are not pre-occupied with judging gaps in high-speed traffic.

A recent FHWA publication states that "An intersection is, at its core, a planned point of conflict in the roadway system. With differing crossing and entering movements by both drivers and pedestrians, an intersection is one of the most complex traffic situations that motorists encounter. Add the element of speeding motorists who disregard traffic

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of 11-15 MPH and typical speeds of 14-16 MPH at the crosswalks. The team chose not to study the Acacia Roundabout, however, opting instead to study and publish research performed at higher-speed roundabouts in Tampa and 2-lane roundabouts.

[122] *AASHTO Green Book*, 1994, p. 122

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controls and the dangers are compounded." "Driving near and through intersections is one of the most complex conditions drivers will encounter.""[123]

As discussed earlier in regard to users who are older, children or visually impaired, cognitively impaired users may also benefit from the less complex operating environment of a 1-lane modern roundabout. The next section discuses impact on complexity of the intersection environment.

8. Complexity

Complexity of an intersection is a factor that affects all users but disproportionately so users who are older, children, or who are mobility, visually or cognitively impaired. This section examines measures of complexity as applied to the existing cross intersections and the planned replacement roundabouts.

The table below compares four measures of complexity for the existing three signalized intersections versus the planned replacement roundabouts.

Table 16. Measures of Complexity

Intersection with Cleveland Street	Signalized Intersections, Number of				Roundabouts, Number of			
	Phases	Color Codes	Signal Heads	Signal Bulbs	Phases	Color Codes	Signal Heads	Signal Bulbs
Lake Av			8	24			0	0
Duncan Av	2	3	8	24	0	0	0	0
Saturn Av			8	24			0	0
Totals	2	3	24	72	0	0	0	0

The table above shows a significant reduction in the complexity of the intersections when converted to modern roundabouts. The roundabouts have no colors to decode, no phases to track, no signal heads to observe, and no bulbs to monitor for change.

A fifth measure of complexity is the number of conflict points. As shown earlier, converting the cross intersections to roundabouts will reduce pedestrian/vehicle conflicts by two-thirds.

A sixth measure of complexity is the number of rules that must be known and understood to use an intersection safely. The table in APPENDIX D compares the rules for signalized intersections and roundabouts. As shown in the table, there are approximately two dozen rules governing the operation of signalized intersections, compared to one rule for 1-lane modern roundabouts. And which rules apply at any given instant change at signalized intersections every few seconds, whereas the one roundabout rule never changes.

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[123] *The National Intersection Safety Problem*, FHWA, April 2004

IV. Environmental Impacts

This section examines the environmental impacts of converting the six existing conventional cross intersections to modern roundabouts. Impacts on fuel consumption, pollutant emissions, trees, landscaping, aesthetics, the character of Cleveland Street, noise, Skycrest and the city are considered.

The National Environmental Policy Act (NEPA) of 1969 declared it national policy "to use all practicable means and measures…to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[124]

The 1994 *AASHTO Green Book* states that "The effects of the various environmental impacts can (and should) be mitigated by thoughtful design processes. This principle, coupled with that of esthetic consistency with the surrounding terrain or urban setting, is intended to produce highways that are safe and efficient for users and acceptable to nonusers and the environment.

"A highway necessarily has wide-ranging effects beyond that of providing traffic services to users. It is essential that the highway be considered an element of the total environment. Environment as used herein refers to the totality of man's surroundings: social, physical, natural, and manmade. It includes human, plant, and animal communities and the forces that act on all three. The highway can and should be located and designed to complement its environment and serve as a catalyst to environmental improvement.

"The area surrounding a proposed highway is an interrelated system of natural, manmade, and sociologic variables. Changes in one variable within this system cannot be made without some effect on other variables. Some of these consequences may be negligible, but others may have strong and lasting effect on the environment, including the sustenance and quality of human life. Because highway and design decisions have an effect on adjacent area developments, it is important that environmental variables be given full consideration."[125]

A. Impact on Fuel Consumption

This section examines the impact on fuel consumption of converting the six cross intersections to modern roundabouts.

Internal combustion engines waste fuel while idling at red lights and consume fuel voraciously while accelerating from green lights. Having neither red nor green lights, and providing mostly free flow off peak hours, modern roundabouts extract less fuel from motorized vehicles than do signalized intersections.

Fuel consumption was modeled using aaSIDRA software. aaSIDRA uses a four-mode elemental[126] drive-cycle model for estimating fuel consumption, operating cost and pollutant

[124] *Public Law 91-190*, January 1, 1970
[125] *AASHTO Green Book*, 1994, Foreword p. xlviii and p. 131
[126] See Appendix ___ for an overview of the four-mode elemental model used in aaSIDRA

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emissions for all types of traffic facilities, including roundabouts and signalized intersections. The four drive-cycle modes are acceleration, deceleration, idling, cruise, as depicted in the graph below.

Figure 15. Drive cycle during a stop at traffic signals[127]

[Insert Figure 3.1 from *Operating cost, fuel consumption, and emission models in aa SIDRA and aaMOTION*]

This graph depicts the motion of a vehicle stopping at a red light, as modeled in aaSIDRA

For each lane of traffic, aaSIDRA constructs vehicle movements through the intersection as a series of cruise, acceleration, deceleration and idling elements as shown above, distinguishing between stopped and unstopped vehicles as well as light and heavy vehicle characteristics. Fuel consumption, cost and pollutant emissions are calculated for each of the four modes of driving, and the results are added together for the entire driving maneuver.

Converting a signalized roundabout to a modern roundabout can substantially reduce fuel consumption because of the elimination of the red light and along with it most of the time spent idling the engine and most of the accelerating from a dead stop, the two engine states that deliver the worst fuel economy in terms of miles per gallon. During most hours of the day most traffic flows freely through a roundabout, and even vehicles that come to a dead stop seldom wait long before being able to enter the roundabout.

The table below compares the fuel consumption of the three signalized intersections versus the planned replacement roundabouts, as computed by aaSIDRA.

Table 17. Annual Fuel Impact

Intersection with Cleveland Street	Fuel Consumption (gals)		Fuel Impact (gals)
	Signalized Intersection	Roundabout	
Lake Av	131,400	127,896	- 3,504
Duncan Av	135,780	129,429	- 6,351
Saturn Av	149,796	11,388	- 7,884
Totals	416,937	399,237	- 17,739

The table above shows a total annual savings of 17,739 gallons of fuel achieved by converting the three signalized intersections to roundabouts.

[127] *Operating cost, fuel consumption, and emission models in aa SIDRA and aaMOTION*, Rahmi Akcelik and Mark Besley, December 3, 2003, 25th Conference of Australian Institutes of Transport Research, University of South Australia, Adelaide, Australia

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The fuel impact for the three unsignalized intersections converted to roundabouts was not modeled but should be a slight savings.

The impact on fuel consumption will be examined again later under *Cost Impacts* in the section on *Fuel Costs* (p. 79).

B. Pollutant Emissions

The air in Pinellas County is so polluted from motorized vehicle, power plant and other sources that the Environmental Protection Agency has classified the Tampa Bay air basin as "Maintenance" status since 19__, although with gradual air quality improvement it is expected it will achieve reclassification as "attainment" status next year.

A 2002 Pinellas County report notes that "In most cases, air pollution frequently affects those who are least prepared to protect themselves, namely children and the elderly." Most of the air pollution generated within Pinellas County comes from transportation-related sources. Automobiles contribute approximately 50% of the total emissions of oxides of nitrogen [NO_x] in Pinellas County.[128]

NO_x and CO are precursors to the creation of ozone. In Pinellas County, "Stagnant high pressure systems, coastal recirculation patterns, high surface temperatures, relatively low surface wind speeds and abundant sunlight, which provides the solar radiation necessary for the photochemical process, are key factors in the formation of tropospheric ozone."

"Stationary high pressure systems create inversion conditions where the air becomes stagnant and allows ozone precursors to accumulate. Our proximity to the coast and the various effects caused by the migration of convergence zones and thermal contrasts in and around Tampa Bay and the Gulf of Mexico, results in recirculating wind patters promoting the accumulation and regional transport of ozone precursors."[129]

1. Effects on humans

Air pollution has substantial deleterious effects on humans:

- "The respiratory system is particularly susceptible to effects ranging from short term coughs to the possibility of lung cancer or pulmonary emphysema. Complications with chronic diseases, such as bronchial asthma and chronic bronchitis, arise as a consequence of air pollution. Persons suffering from heart disease are adversely affected by the increased effort required to get oxygen into the blood. Sulfur oxides and misted sulfuric acid have particularly severe effects. The health effects of all photochemical smog products have not been completely determined. They are known to irritate exposed mucous membranes, such as the eyes.

[128] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 1
[129] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 2

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- "Smog can cause irritation of mucous membranes and headaches and, in the case of long-term exposure, lung lesions. Smog effects may be exacerbated by the presence of SO_2 and/or particulates, and are aggravated by exercise.

- "The effect of carbon monoxide (CO) on health and performance of humans is of special concern. Under adverse weather conditions, CO will remain in the vicinity of where it was emitted for some time." [130]

Transportation-related sources account for over 98% of all CO pollution in Pinellas County.[131]

2. Effects on plants and animals

Air pollution is likewise deleterious to plants and animals:

- "The types and severity of effects on vegetation varies with different plants and the concentration of contaminants. Leaf vegetables, grapes, and citrus trees suffer loss in production and reduced growth in the presence of ozone, PAN's, SO_2, and NO_2.

- "The effects on animals are similar to human effects; however, small animals are bothered more. A major concern is the cumulative effect of toxic substances, such as arsenic and lead. Ingestion of deposits on plants by foraging animals can lead to loss in productivity from illness, and even death.[132]

3. Effects on other living and non-living things

Air pollution has adverse effects on other living and non-living things:

- "Acid rain has a wide-ranging adverse impact on soil and water quality, the latter especially in lakes. The pH level of water can drop sufficiently after rainfalls containing even small amounts of sulfuric acid to injure or kill aquatic life.

- "The accelerated corrosion of metal is a primary effect. Building stone, in particular marble, deteriorates more rapidly due to the attack of SO_2, NO_2 and related acids. Paper and leather are embrittled by SO_2. Rubber is severely damaged by ozone. Fabrics, both natural and synthetic, ad are adversely affected. Paints and similar coatings are damaged."[133]

4. Scale of effects

The effects of pollutant emissions range from local to global:

- "CO effects are frequently confined to within .4km of the source; the others accumulate on an air basin scale."[134]

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[130] *Fundamentals of Traffic Engineering*, Chapter 30

[131] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 2

[132] *Fundamentals of Traffic Engineering*, Chapter 30

[133] *Fundamentals of Traffic Engineering*, Chapter 30

[134] *Fundamentals of Traffic Engineering*, Chapter 30

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- On a global scale, CO_2 and NO_x are *global heating ("greenhouse") gases*, or primary contributor to global warming and climate change.[135]

Being a coastal community, Clearwater benefits from "prevailing coastal winds that assure thorough transport of air parcels above the county and our relatively flat and coarse topography provides ample mixing and dilution of CO. Thus, elevated and sustained ambient CO concentrations in Pinellas County are uncommon."[136]

5. Economic effects

The 2001 Pinellas County report states that "Sustained exposure to air pollution can result in high morbidity rates and premature death" and "Although the major economic impact from air pollution includes the costs associated with medical treatments, morbidity, and reduced productivity, air pollutants are capable of causing significant economic impacts in other ways" such as removal and disposal costs for remediation of air toxics.[137]

6. Aesthetic effects

The 2002 Pinellas County reports notes that "Aesthetic effects may include intangible factors that can not be easily quantified. Air pollution can result in impaired visibility, excessive amounts of dirt and soot[138] and nauseous orders that decrease personal comfort and enjoyment of the environment."[139]

7. Impact on emissions

Although motorized vehicles are classified as a "mobile source" of pollutant emissions, intersections act as a point location or "source" of pollutant emissions because internal combustion engines operate less cleanly when decelerating, idling or accelerating than at steady speeds. Signalized intersections force motorized vehicles to do more decelerating, idling and accelerating than do roundabouts.

The table below shows the emissions impact resulting from converting the three signalized intersections to modern roundabouts, as computed by aaSIDRA.

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[135] *Fundamentals of Traffic Engineering*, Chapter 30
[136] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 2
[137] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 2
[138] Dirt and soot were not modeled for this study.
[139] 2001 *Air Quality Annual Report*, Air Quality Division, Department of Environmental Management, Pinellas County, Florida, December 2002, p. 1

Table 18. Emissions Impact (Kg/yr)					
Intersection with Cleveland Street	Pollutant				Total
	HC	CO	NO_x	CO_2	
Lake Av	-123	-1,314	-26	-42,048	-43,511
Duncan Av	-149	-2,716	-61	-54,312	-57,238
Saturn Av	-184	-4,818	-105	-73,584	-78,691
Totals	-456	-8,848	-193	-169,444	-179,440

The table above shows a total annual emissions reduction of 179,440Kg of pollutant resulting from converting the three signalized intersections to modern roundabouts.[140] The three stop-controlled intersections were not modeled.

C. Tree Impacts

The round shape and size of the roundabouts and associated sidewalks will encroach on the root systems of several nearby trees. Good design practice allows some flexibility in locating the pedestrian crosswalks, particularly with Cleveland Street's moderate traffic volume and consequently less frequent, shorter queues.

A multi-disciplinary team[141] was formed and went on a "tree walk" to visit every site in the project that might have tree impacts. Each impacted tree was evaluated for: health, vitality, structure, remaining life, value to the neighborhood, status in City policy, and susceptibility to trauma imposed by the project.

By judiciously relocating some of the crosswalks it was possible to minimize the impact on ___ trees, as illustrated in the figure below.

Figure 16. Crosswalks Were Relocated to Minimize Tree Impacts	
[Insert portion of CAD drawing showing crosswalk into tree]	[Insert photo of saved 48" oak]
The original design required removal of a significant tree.	This valuable 48" diameter oak was saved by relocating the pedestrian crosswalk.

[140] Traffic volume on Cleveland Street is moderate and side street volume is low; heavier volumes would have produced even greater emissions reductions.

[141] The team consisted of Certified Arborist, the City's Landscape Architect, two consulting Landscape Architects, two consulting Professional Engineers, and the Project Manager. The Certified Arborist is a long-term resident of Skycrest and was selected by the Neighborhood Traffic Calming Tech Team to represent the neighborhood on tree matters.

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The figure above demonstrates how attention to tree impacts coupled with flexibility in design significantly reduced the negative impact of the project. The Tech Memo resulting from the Tree Walk is in APPENDIX E.

Designing the roundabouts at Corona Avenue, Meteor Avenue and Aurora Avenue to fully accommodate the Solid Waste Department's Sterling Roll-off truck[142] would have meant removing eight valuable trees. But the Solid Waste Department determined that they ordinarily never make left turns at these intersections and if they ever *do* need to take the truck into this residential area—for instance, to retrieve a dumpster at a house demolition—they can easily take alternative routes on Drew St. or Gulf-to-Bay Blvd., or even use the roundabouts by running over the mountable truck aprons and splitter islands.

Accordingly, alternative roundabout designs were developed to spare the eight valuable trees, as shown in the table below.

Table 19. Alternate Roundabout Geometries

Intersection with Cleveland St	Corner	Alternate A Impacts 8 Valuable Trees	Alternate B Impacts the Sterling Roll-off Vehicle
Corona Av	NW	Remove a 16" oak Remove a 12" oak	No left turns without driving over mountable curbs. All other turns OK.
	SW	Remove a 24" oak	
	NE	Remove a 48" oak	
	SE	Remove a 24" oak	
Meteor Av	NW	Remove a 10" oak	
	SE	Remove a 24" oak	
Aurora Av	NE	Remove a 16" laurel oak	

The table above shows 8 valuable trees were saved by the alternate roundabout geometries.

But several other trees *will* unavoidably be lost to construction of the roundabouts, as shown on the table below.

Table 20. Tree Impacts
[Insert tree impact table.]
[Caption]

[142] The Sterling Roll-off truck is discussed in the section on *Solid Waste Trucks* (p. 21)

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The table above shows a total loss of 19[143] trees, some of them valuable. To put this number in perspective, the table below compares it to rough estimates of the number of trees in the right-of-way in the Cleveland Street corridor through Skycrest, and to ROW trees within the project boundaries.

Table 21. Trees Lost to Roundabouts		
Number	As %age of Trees in ROW in Cleveland Corridor	As %age of Trees in ROW within Project Boundaries
19	__%	__%
[Caption]		

The table above shows the proportion of trees lost to the roundabouts is a very small proportion of the trees within the right-of-way along the Cleveland Corridor or within the project boundaries.

Loss of these trees will be mitigated by the addition of more trees in the six roundabout central islands and in the medians to be constructed along Cleveland Street as part of the project. How many trees will be added will be determined later in the design process, but the planting area in the medians is 10’ wide and the total length is 1200 linear feet, enough for as many as possibly 40 trees to be added to the corridor, spaced at 30’ intervals. The six roundabout central islands can accept one large tree each.[144]

Cleveland is a canopy street, but there are stretches where the canopy trees are missing on one or both sides. In those areas, canopy trees will be planted in the median and in 20 years will produce gracious shade. In the stretches of Cleveland Street where the canopy is intact, smaller, complementary trees will be planted in the median.

D. Landscaping Impacts

The *AASHTO Green Book* states that “Landscaping should be provided for esthetic … purposes in keeping with the character of the street and its environment.[145]

The *Florida Roundabout Guide* states that “Landscaping should be an integral part of the design of roundabouts on both the state highway system and local road roundabouts. Both the central islands and the approach roadways present an opportunity for landscaping. This landscaping should be designed to increase the efficiency of the roundabout while improving safety and enhancing the aesthetics of the area.

“The central island of a roundabout provides an opportunity for landscaping enhancements which other intersection treatments would not provide … Landscaping for the roundabout should be a feature in the design and not simply an enhancement undertaken after the

[143] Figure not final
[144] There may be other opportunities in the project to plant trees elsewhere besides in the Cleveland Street corridor, such as in the 3 oval medians, in the medians along South Lake Drive, possibly in one in the medians on North Jupiter Avenue, since the existing roadway is 30' wide leaving a 10’ wide median with 9' of green space width (part of a tree well/median combination).
[145] *AASHTO Green Book*, 1994, p. 486

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construction of the roundabout. It should adhere to all safety requirements while, at the same time, it is increasing the efficiency of the intersection treatment.

”Carefully planned landscaping can enhance the safety of the intersection my making the intersection a focal point and by lowering speeds … The lateral restriction and funneling provided by the splitter island encourages the driver to reduce speeds. Landscaping along the approaches can be designed to enhance this effect.”[146]

The central islands for the six planned roundabouts create 3,932 square feet of new planting area where currently there is asphalt. The planned medians on Cleveland Street create another 19,920 SF for a total of 17,853 square feet of new planting area in the Cleveland Corridor. In addition, the existing right-of-way around the planned roundabouts is available for possible plantings. In all, the project creates 26,705 SF of new planting area in the Skycrest neighborhood in place of asphalt.

E. Aesthetic Impacts

This part of Cleveland Street passes through a residential area known as Skycrest. The street is graced with oaks and other large trees along both sides which form a canopy over the street for much of its length through Skycrest. Cleveland Street is Clearwater’s only “canopy street” and is considered one of its most beautiful streets.

The project will have aesthetic impact beyond the significant landscape impact.

The roundabout central islands will be mounded and landscaped, the truck aprons and splitter islands will be paver bricked and ornamental lighting will be installed, as has been done with the existing 1-lane roundabouts, where the aesthetic impact has been received as positive.

Instead of paver bricks for the pedestrian crossings, the City is investigating the use of a new product, DuraTherm, which may provide an equally good or superior crosswalk for lower installation and maintenance costs. In areas of high water velocity, the sand bed under paver bricks in crosswalks may be subject to flushing.

The figure below compares the two crosswalk treatments.

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[146] *Florida Roundabout Guide*, pp. 5-4 and 5-5

Figure 17. Crosswalk Treatments	
[Insert photo of paver crosswalk]	[Insert vender photo of DuraTherm crosswalk. Swap in Ken's photo when the vendor does a demo installation in the Tampa Bay area.]
Photo of a crosswalk using paver bricks at the ______ roundabout in Clearwater	Vendor photo of a crosswalk using the DuraTherm treatment

The figure above shows both treatments add visual and textural contrast to the crosswalk.

In addition to the impact of the roundabouts themselves, the significant new planting area on the Cleveland Street medians will have a major aesthetic impact on the corridor.

On the North Greenwood Corridor enhancement project, paver bricks were used to create an at-grade "visual median" to fill the access gaps in the raised median, as shown in the figure below. A similar treatment along Cleveland Street in the project area would reinforce the traffic calming effect generated by "visual narrowing", as it has on Martin Luther King, Jr., Avenue in North Greenwood. In addition, visually continuing the median through the median gaps supports the use of generously-wide median driveway cuts to minimize impact homeowners along Cleveland Street. Providing for the wider, low-impact driveway cuts results in some long stretches with no raised median at all, making the visual median that much more important.

The City is investigating the use of an imprinted asphalt product shown in the figure below to create the same effect as on Martin Luther King Avenue, but at potentially lower cost for installation and maintenance. In fact, the money saved by cutting back the raised medians for the generous driveway gaps will cover most of the cost of the imprinted asphalt at-grade median.[147]

The photos below show how contrasting color and texture create an at-grade "visual median" in the gap between raised medians.

[147] Cutting back the medians to provide generous driveway cuts saves an estimated $97,559 in demolition, concrete and landscaping costs, or 73% of the cost of imprinted asphalt across the entire width of the median cuts.

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Figure 18. Median Treatments	
Photo of the at-grade paver treatment between raised medians on Martin Luther King Avenue in Clearwater	Vendor photo showing at-grade imprinted asphalt median in Agusta, GA

The figure above shows both treatments for creating at-grade “visual medians” are effective in demarcating the “lane” area between raised medians and thereby visually narrowing the travel lanes on each side of the median. Visually narrowing travel lanes to calm traffic is the purpose of the at-grade visual medians, and will help keep down approach speeds to the six planned roundabouts.

F. Impact on Character of Street

The portion of Cleveland Street in Skycrest is a shady, tree-lane mostly residential street with tree canopy for much of it. The planned roundabouts and median were designed to be both compatible with the character of the street and enhance it. Generous median cuts will afford easy accessibility to all the existing driveways along the street. With lower traffic speeds, shorter or non-existent intersection queues, much more greenery and markedly fewer instances of excessive speeding, it will be an even more pleasant street to live along.

G. Impact on Noise

The *AASHTO Green Book* states that “Pollution from vehicles in the form of noise must also be recognized by the highway designer. Noise is unwanted sound, a subjective result of sounds that intrude on or interfere with activities such as conversation, thinking, reading, or sleeping. Sound can exist without people—noise cannot.” [148]

“Modern automobiles are relatively quiet, particularly at the lower cruising speeds, but exist in such numbers as to make their total noise contribution significant.” Because the amplitude of the noise varies with highway design features, the designer must “therefore be concerned with how highway locations and design influence the vehicle noise perceived by persons residing or working nearby.”[149]

[148] *AASHTO Green Book*, 1994, pp. 37-38.
[149] *AASHTO Green Book*, 1994, pp. 37-38.

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The *AASHTO Green Book* further notes that "Noise produced by automobiles increases dramatically with speed." [150] Because the project will reduce the number of vehicles traveling at excessive speeds along the Cleveland Street corridor, particularly at the six intersections with roundabouts, there will be less noise generated by speeding vehicles.

In addition, vehicles generate more noise when accelerating from a stop than at idle or steady speed. Because the three roundabouts replacing signalized intersections will reduce the number of vehicles accelerating from a stop, these intersections will generate less noise from that source. At the three stop-controlled intersections replaced by roundabouts, the number of side-street vehicles accelerating from a stop will be reduced, but there will be offsetting noise from vehicles accelerating mildly as they leave the roundabout.

Noise is examined further under *Cost Impacts* in the section on *Noise Impacts* (p. 83).

H. Impact on Neighborhood and City

The *Florida Roundabout Guide* states that "Not only can roundabouts prove to be an efficient and safe treatment for intersection control by they provide a unique opportunity for aesthetic community enhancement. An emphasis on the importance of community enhancement in conjunction with our transportation system is clearly illustrated by the support contained in the recent Intermodal Surface Transportation Efficiency Act (ISTEA)."[151]

The portion of Cleveland Street in Skycrest is much beloved by Skycrest residents and considered a major neighborhood asset, much like Crest Lake Park, a park bordering the street. As Clearwater's only canopy street and one of the city's loveliest, the street is a favorite of many outside Skycrest. The planned roundabouts and medians were designed to preserve and enhance the character of the street for all who use it to enjoy. Motorists level of service at the three signalized intersections will be improved while mobility and safety for most users will be improved at all six intersections.

Cleveland Street continues west past Skycrest to become the main street for downtown Clearwater. When the new Memorial Bridge to the beach opens, Cleveland Street downtown will be reinvented with streetscaping and landscaping as a low-volume, pedestrian-friendly environment comfortable for visitors to downtown. New hotels, restaurants, a cinemaplex and 1200 dwelling units are planned to reinvent downtown itself to a vital business and after-hours district. The gap between the part of Cleveland Street enhanced by the planned roundabouts and the downtown part of Cleveland Street, starting at Missouri Avenue, is 0.8 mile, so any synergistic effect between the two projects may be weak or nonexistent, but it shouldn't be negative.

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[150] *AASHTO Green Book*, 1994, pp. 37-38.
[151] *Florida Roundabout Guide*, p. 5-6

V. Social Impacts

This section examines the social impacts of converting the six existing intersections to modern roundabouts. Considered here are the social origins of the project, public acceptance, equity impacts, travel Impacts, Impacts on neighborhood health, Impacts on residents health, and Long-range impacts.

A. Social Origins of the Project

The project enjoys strong buy-in, ownership and consensus among stakeholders. These social impacts were achieved through use of a *design charrette*[152] at the beginning. The design charrette is a highly inclusive, participatory, compressed and visual public meeting format. Participants in the Skycrest Traffic Calming Design Charrette attended a 3-4 hour training class at the first session on a Saturday morning, where they became qualified *citizen-designers*. Applying what they had learned, they worked together to create the Skycrest Traffic Calming Plan at the second session. The engineers validated the plan in the field the next morning.

At the third and final session, charrette participants came to agreement on the final form of their design, based on field observations from the engineers. The police and fire departments participated in all three charrette sessions and were available to answer questions, but only residents performed the actual design work. Buy-in was automatic because it was their own work product.

The six roundabouts, medians and all other elements of the project were proposed by the residents themselves; none by City staff or its consultants.

Management of this project differs from the typical public works project, which usually follows a “top-down” path in which the need and design of a project is conceived by government staff, then presented to the public stakeholders, and followed by construction if opposition is not too strong.[153]

This project followed a “bottom-up”, path in which stakeholder residents did the work of preliminary design and consensus-building themselves, followed with continued involvement of them and other stakeholders during the engineering design phase.

Resident participants in the charrette formed two teams at the conclusion of the charrette. The Consensus Team launched a multi-month effort to explain their plan to the rest of the neighborhood and generate consensus. City staff played no role in this effort, other than generating the petition[154] form for their use. When they had collected signatures of support from at least 65% of the property owners in the project boundaries, the project became

[152] The traffic calming design charrette process is described in detail in a paper, *Surviving Traffic Calming with Charrettes*, given at the ITE 70th <verify> International Conference in Irvine, California, and is found in Appendix _.
[153] The ultimate top-down approach to public works projects as practiced by Robert Moses in New York City is described in *The Power Broker* by Robert Caro
[154] A sample page from the traffic calming petition is in Appendix _ .

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eligible for the City's Work Program. City Commission approval for the design Work Order was unanimous.

The Traffic Calming Tech Team represents the neighborhood during the design and construction phases. They review the engineering plans for faithfulness to the charrette vision and keep their neighbors informed of progress and any design changes that arise by necessity.[155] After reviewing the 30% plans and briefing the Skycrest Homeowners Association, the association issued a strong statement of support for the project.[156]

Evaluating tree impacts was important to the neighborhood but requires specialized expertise. To represent the neighborhood's interest, the Tech Team enlisted a Skycrest resident who is a Certified Arborist and intimately familiar with the area and issues, having just retired from a 30-year career with the City.

The Fire Department is also kept in the loop by way of the standard plans review process. A total of __ AutoTURN plots[157] were generated to demonstrate to the Fire Department that their apparatus would be able to negotiate the six roundabouts without difficult. Credibility with the Fire Department has already been established with the four 1-lane roundabouts the City has previously constructed.

Similarly, the Solid Waste Department is kept in the loop through the plans review process, including __ Auto-Turn plots[158] of their vehicles.

Skycrest Elementary School staff was informed of the plan to build a modern roundabout at their SE corner last year and reviewed the 30% Plans when they became available recently. A member of the Tech Team and the Project Manager jointly gave a presentation on the roundabout at a regular meeting of the School Advisory Committee (SAC), a group representing parents.

Many roundabout projects have had an immediate social impact the moment they are proposed in the form of controversy and some never gain enough social or political support to overcome opposition. The bottom-up approach and continuing involvement of stakeholders in the project appear to have engendered social acceptance of a project whose nature has generated divisive controversy in other U.S. communities. This level of social acceptance has been achieved at a cost of zero City staff time spent "selling" the project to the public.

When the project is constructed it will have additional social impacts. The Cleveland Street corridor through Skycrest will feel calmer, safer and more comfortable to residents and users, especially non-motorized. Mobility of all users will be enhanced, especially non-motorized users. These are measures of quality of life for "livable communities".[159]

B. Public Acceptance

[155] The guide explaining the role of the Traffic Calming Tech Team is in Appendix _.
[156] The Skycrest Neighbors statement is in Appendix _ .
[157] The fire apparatus AutoTURN plots are in Appendix _.
[158] The Solid Waste Department vehicle AutoTURN plots are in Appendix _.
[159] <citation>.

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A 2002 study found that "The large reduction in the proportion of drivers strongly opposed to roundabouts suggest that opinions of even those with strongly held opinions can be influenced by exposure to modern roundabouts."[160]

This phenomenon has occurred in Clearwater, where highly publicized and prolonged public disapproval of Clearwater's first roundabout was followed only six months after opening fo the roundabout by the first citizen group requesting a second roundabout be built, also on the beach. That request was subsequently followed by nine more citizen groups requesting low-speed modern roundabouts be built in their neighborhoods. Seven of these groups obtained signatures of support from 65% or more of property owners in the area (one of the groups obtained signatures of 98% supporting their two modern roundabouts).

Besides the requisite 65% approval of Skycrest property owners, the six planned roundabouts have also received a strong endorsement from Skycrest Neighbors, the Skycrest homeowners association (see APPENDIX F). Only one complaint has been received (

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[160] *Public Opinion and Traffic Flow Impacts of Newly Installed Modern Roundabouts in the United States, Richard Retting*, Greg Luttrell and Eugene Russell, ITE Journal, September 2002

APPENDIX A).

Communities near Clearwater are moving to embrace modern roundabouts, too. Across the Bay to the east, Tampa has four and across the Bay to the South, the Sarasota MPO Board has passed a resolution recommending that roundabouts be considered whenever a n intersection is a candidate for signalization (see APPENDIX H). This resolution is similar to one passed by the Vermont legislature in <year> (APPENDIX I).

C. Equity Impacts

As described earlier, the planned six modern roundabouts are part of the Skycrest Traffic Calming Project. A 1999 study by the Victoria Transport Policy Institute (VTPI) found that "Traffic calming tends to provide the greatest benefits to pedestrians, bicyclists and local residents, while imposing the greatest costs on motorists who drive intensively (i.e., as fast as possible). Traffic calming tends to increase horizontal equity[161] by reducing the external costs imposed by motor vehicles and improving the balance between different uses of public streets. Traffic calming tends to increase vertical equity[162] because it benefits people who are physically, economically and socially disadvantaged, while imposing the greatest benefits on relatively wealthy, higher mileage drivers."[163]

D. Travel Impacts

The 1999 VTPI study also notes that "There is considerable latent demand for non-motorized travel. That is, people would walk and bicycle more if they had suitable conditions" and that "Traffic calming can be an important part of Transportation Demand Management (TDM) by creating streets that are more suitable for walking, bicycling and public transit.

"Residents in neighborhoods with suitable street environments tend to walk and bicycle more, ride transit more, and drive less than comparable households in other areas.

"Another study found that walking is three times more common in a community with pedestrian friendly streets than in otherwise comparable communities that are less conducive to foot travel.

"Better walking and cycling conditions are particularly important for people with disabilities, the elderly, and children, who are more dependent on non-motorized travel and often have difficulty crossing busy traffic. As the population ages, a greater portion of the urban residents are likely to walk and cycle for transportation and recreation.

[161] *Horizontal equity* refers to the distribution of impacts among people or groups considered to equal in wealth and ability. From *Traffic Calming Benefits, Costs and Equity Impacts*, Todd Alexander Litman, Victoria Transport Policy Institute, 7 December 1999, p. 22
[162] *Vertical equity* refers to the distribution of impacts between people or groups that differ in wealth and ability, with the assumption that people who are disadvantaged may require greater public resources. From *Traffic Calming Benefits, Costs and Equity Impacts*, Todd Alexander Litman, Victoria Transport Policy Institute, 7 December 1999, p. 22
[163] *Traffic Calming Benefits, Costs and Equity Impacts*, Todd Alexander Litman, Victoria Transport Policy Institute, 7 December 1999, p. 22

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"A reasonable assumption is that traffic calming which significantly improves walking and cycling conditions can increase non-motorized trips in an areas by 10-20% from what would otherwise occur, and that half of these trips substitute for motor vehicles trips." [164]

Whether change of that magnitude is likely to occur in Skycrest is not evaluated in the present study, but somewhat similar reasoning has justified federal CMAQ[165] grant funding for four upcoming Clearwater projects: a pedestrian bridge over Mandalay Channel to the beach, a pedestrian walkway over McMullen Booth Road for the East-West Trail, and a trail along Druid Road to connect the Pinellas Trial with the future Progress Energy Trail. Together, these grants are expected to funnel about $10 million in federal funding to Clearwater, predicated on the assumption that a significant portion of nearby parallel motorized trips will leave the motorized vehicle behind and take the trail instead.[166]

Similarly, construction of the six planned roundabouts may contribute to more trips to Crest Lake Park, for instance, by foot or bicycle and fewer by motor vehicle.

E. Impacts on neighborhood health

The increased comfort and mobility of non-motorized travel in a traffic-calmed neighborhood can lead to increased neighborhood interaction because more hospitable streets encourage street activities and community interaction. The 1999 VTPI study notes that "Public streets are an important component of the "public realm" where people can meet in a neutral space. Street environment conditions affects how people interact in a community. Traffic calming helps make public streets lively and friendly, encourages community interaction, and attracts customers to commercial areas." The Improved urban environment may also encourage urban infill that reduces sprawl. [167]

F. Impacts on residents' health

A sedentary lifestyle has a significant deleterious effect on health. The improved pedestrian mobility and access provided by the six planned roundabouts can encourage more walking. [168]

G. Long-range impacts

The *Charles A. McIntosh, Jr. Award of Distinction for Outstanding Achievement in the Community* was recently awarded[169] to the City of Clearwater for the *North Greenwood*

[164] *Traffic Calming Benefits, Costs and Equity Impacts*, Todd Alexander Litman, Victoria Transport Policy Institute, 7 December 1999
[165] *CMAQ* refers to the federal Congestion Mitigation and Air Quality program.
[166] The CMAQ program provides $1 billion annually in funding for transportation projects, many of them trail projects justified using the same assumption.
[167] *Traffic Calming Benefits, Costs and Equity Impacts*, Todd Alexander Litman, Victoria Transport Policy Institute, 7 December 1999
[168] *Transportation Cost and Benefit Analysis—Safety and Health Costs*, Todd Litman, Victoria Transport Policy Institute

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Transformation, a collection of four projects in the North Greenwood community: a new recreation and aquatics center, a new branch library, rehabilitation of 25 diverse-income apartment buildings, and the North Greenwood Corridor Enhancement Project. The corridor enhancement project includes a low-speed modern roundabout at the corner of Palmetto Street and Martin Luther King, Jr., Avenue and is central to the transformation, as the three other projects occupy three of the roundabout's four corners. The roundabout is also the hub of medians extending up and down Marten Luther King, Jr., Avenue.

The six planned roundabouts on Cleveland Street will transform that corridor, too, with six times as many roundabouts and __ times greater length of median as the North Greenwood project.

The transformed Cleveland Street corridor could become a showcase urban project which may attract regional and possibly national attention, and could conceivably influence the conception and execution of similar projects elsewhere.

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[169] by the Tampa Bay Regional Planning Council

VI. Cost Impacts

This section examines the cost impacts of converting the six existing intersections to modern roundabouts. Costs to the City and to society are considered, concluding with a benefit-cost analysis (BCA).

The preface to the FHWA *Economic Analysis Primer* states that "Although the idea of comparing the benefits and costs of transportation projects on a dollar-to-dollar basis has long appealed to decision makers, the application of economic analysis to such projects is often neglected in practice. Agencies may believe that transportation benefits and costs are too hard to quantify and value, or too subject to uncertainty to provide meaningful guidance. Fortunately, an expanding research base on economic methods and values, improved modeling of traffic and uncertainty, and more powerful desktop computers have made the widespread use of economic analysis for highway projects an attainable goal."[170]

A benefit of performing a benefit cost-analysis is that "The discipline of quantifying and valuing the benefits and costs of highway projects also provides excellent documentation to explain the decision process to legislatures and the public," but "most agencies do not consider the full range of costs and benefits when conducting their analysis."[171]

The foreword to the 1984 *AASHTO Green Book* states that "Cost-effective design is also emphasized. The traditional procedure of comparing highway-user benefits with costs has been expanded to reflect the needs of nonusers and the environment."[172]

The scope of the 1994 *AASHTO Green Book* "is wider than that of previously published AASHTO guides." Among other things, "The traditional procedure of comparing highway-user benefits with costs has been expanded to reflect the needs of nonusers and the environment."[173]

Similarly, the present study conducts a more comprehensive examination of cost impacts than was traditional before1984.

A. Costs to the City of Clearwater

1. Capital costs

Capital costs are non-recurring and include the cost of design, right-of-way (ROW) acquisition and construction. The design costs are already established but the costs for right-of-way acquisition and construction have to be estimated.

[170] *Economic Analysis Primer*, FHWA, Eric Gabler August 2003, p. 5
[171] *FHWA Encourages Economic Analysis of Transportation Projects*, The Urban Transportation Monitor, October 17, 2003
[172] *AASHTO Green Book*, 1984, Foreword, pp. xlvii
[173] *AASHTO Green Book*, 1994, Foreword, pp. xlvii-lxviii.

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Very little right-of-way was needed for Clearwater's existing five roundabouts. No right-of-way acquisition at all was needed for the two roundabouts on the Beach and the one at Baker & Drew. The Florida Department of Transportation transferred title to the City at no charge for all the right-of-way needed for the Clearwater Beach Entryway Roundabout. The owner of Greenwood Apartments donated 3200 SF of right-of-way for the roundabout at Martin Luther King, Jr., Avenue & Palmetto Street and the Pinellas School System donated ___ SF for the roundabout in front of John F. Kennedy Middle School. Of the remaining needed right-of-way, most was acquired in return for minor concessions rather than cash.

A total of only 91 square feet of right-of-way need be acquired for the six planned roundabouts. A nominal $5,000 is assumed for right-of-way acquisition for the six planned roundabouts. This figure is conservative; actual ROW acquisition costs at the four previous 1-lane roundabouts was much lower.

The City of Clearwater has recent experience constructing four similar 1-lane modern roundabouts, and the cost of the one most similar[174] to the planned six roundabouts is the basis for the construction cost estimate below.

Table 22. Roundabout Capital Costs

Design[175]	ROW Acquisition	Construction (each)[176]
$55,398	$5,000	$173,726

The table above gives the non-recurring costs for the six roundabouts. These figures are used in the benefit-cost analysis, discussed later in the section on *Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

2. Operations and Maintenance (O&M) costs

Operations & maintenance costs for signalized intersections include the cost of power for illumination, signal bulbs and control equipment, the cost of bulb replacement and maintenance of the detection loops and control equipment.

Nationally, costs typically range from $3,000[177] to $5,000 annually, depending on the climate, cost of electricity and the complexity of the intersection (number of signal heads, detection loops and controllers). The Florida DOT suggests an annual average maintenance cost of $2,150 per intersection, not counting the cost of power.[178] On an annual basis the typical costs are loop replacement, electricity, globe replacement and signal controller quarterly inspections. Replacing signal heads every ten years and the controller every ten years or so are additional costs, as is a rebuild every 20 years, typically on the order of $80,000. Since the Florida climate is mild, power is relatively inexpensive and the existing signalization at these intersections is simple, a conservative

[174] The roundabout at Palmetto Avenue and Casler Street
[175] Part of a July 18, 2003, Work Order agreement between the City of Clearwater and King Engineering, Inc.
[176] Year 2002 cost, adjusted to current year in the section on *Benefit Cost Analysis* (p. 84).
[177] *Roundabouts: An Informational Guide*, FHWA Publication No. FHWA-RD-00-067, June, 2000, p.76
[178] *2002 Transportation Costs*, Office of Policy Planning, Florida Department of Transportation, March 2003, p. 17

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figure of $2,000 annually is a reasonable estimate, or $6,000/year for all three signalized intersections. Operations and maintenance costs for the three unsignalized intersections is conservatively considered zero for the cost-benefit analysis.

Operations and maintenance costs that are additional for roundabouts are mainly the cost of landscaping. The similar but slightly larger Acacia Roundabout is under private contract for landscape maintenance for $740/year so that figure is used here as a conservative estimate, or $2,200/year for the six roundabouts.

Both cross intersections and roundabouts have costs for roadway illumination, signage and pavement marking. These costs can be considered part of roadway costs rather than intersection costs and anyway are roughly comparable for the two configurations, so they are ignored in the benefit-cost analysis.

The table below compares the annual maintenance cost for the existing signalized intersections versus the planned replacement roundabouts.

Table 23. Annual Operations & Maintenance Costs	
Existing six cross intersections	$ 6,000/year
Six planned roundabouts	$ 2,220/year

The figures above are used in the benefit-cost analysis, discussed later in the section on *Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

B. Costs to Society

1. Fuel costs

Table 17 in the earlier section on *Impact on Fuel Consumption* (p. 60) gives the fuel consumption impact of converting the three signalized intersections to modern roundabouts.

Assuming a nominal fuel cost of $1.50/gallon, the fuel savings from converting to roundabouts translates to an annual fuel cost savings of $26,609 for the three signalized intersections. This figure is used in the benefit-cost analysis, discussed later in the section on *Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

Fuel costs for the three unsignalized intersections was not considered because fuel consumption was not modeled for these intersections, but should be slightly improved by converting to the three planned roundabouts.

2. Cost of Delay

The FHWA roundabout *Guide* notes that "The operational benefits of a project may be quantified in terms of the overall reduction in person-hours of delay to the public. Delay has a cost to the public in terms of lost productivity, and thus a value of time can typically

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be assigned to changes in estimated delay to quantify benefits associated with delay reduction."[179]

Table 4 (p.19) shows an annual savings of 5,222 vehicle-hours of delay as a result of converting the three signalized intersections to modern roundabouts. At a nominal cost of $11.20 [180] per vehicle-hour, this translates to an annual savings of $58,486.40.[181] This figure is used in the benefit-cost analysis, discussed later in the section on *Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

The cost impact on delay to the public due to converting the three unsignalized intersections was not examined because the three unsignalized intersections were not modeled, as discussed earlier under *Traffic Impacts* in the section on *Operational Impacts* (p. 18). There should be a slight cost savings from reduced delay at these three intersections.

Separate from operational delay is the impact on travel delay caused by crashes. The cost component of this impact is accounted for later, as discussed later under *Cost Impacts* in the section on *Comprehensive Costs* (p. 82).

3. Costs of crashes

The economic consequences of crashes are substantial and long-lasting. This section examines the components of the economic impacts of crashes and estimates the impact of converting the six intersections to modern roundabouts.

a) Human capital costs

In the year 2000, 41,821 persons were killed, 5.3 million persons were injured and 27.6 million vehicles were damaged in motor vehicle crashes in the United States. The economic costs of these crashes totaled $230.6 billion. Included in the losses are lost productivity, property damage costs, medical costs, rehabilitation costs, travel delay (caused by crashes[182]), legal and court costs, emergency service costs, insurance administration costs, premature funeral costs and costs to employers.[183]

Individual crash victims pay only about 26 percent of these costs. The remaining $170 billion, borne by society, is paid from public revenues, by private insurers and by third parties such as charities and health care providers. Costs paid out of public revenues are funded by taxes from the general public. Costs paid by private insurance companies are funded by insurance premiums paid by policy holders, most of whom are not involved in crashes. Even unpaid charges are ultimately paid

[179] *Roundabouts: An Informational Guide*, FHWA Publication No. FHWA-RD-00-067, June, 2000, pp.74-75.
[180] *Revised Departmental Guidance Memorandum*, Emil H. Frankel, Assistant Secretary for Departmental Policy, U.S. Department of Transportation, ___ <date?>
[181] in ___ <year> dollars
[182] Travel delay caused by operational impacts is examined under *Traffic Impacts* in the section on *Operational Impacts* (p. 18), and its cost is accounted for under *Cost Impacts* in the section on *Cost of Delay* (p. 79).
[183] *The Economic Impact of Motor Crashes 2000*, Lawrence Blincoe, et. al., NHSTA, May 2002

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by users of health care facilities. In short, society at large pays nearly three-fourths of all crash costs that are incurred by individual motor vehicle crash victims.[184]

Almost 9,000 persons are killed annually in intersection-related crashes, which cost society more than $90 billion annually.[185]

b) Non-recompensable costs to society[186]

The human capital costs detailed above are the economic costs that result from goods and services that must be purchased or productivity that is lost as a result of motor vehicle crashes and do not represent the intangible consequences of these events to individuals and families, such as pain, suffering and loss of life.

"Economic costs represent only one aspect of the consequences of motor vehicle crashes. Persons injured in these crashes often suffer physical pain and emotional anguish that is beyond any economic recompense." "For an individual, these non-monetary outcomes can be the most devastating aspect of a motor vehicle crash." "The family and friends of the victim feel the psychic repercussions of the victim's injury acutely as well."

"A significant number of people experience mental disorders as a result of being involved in a motor vehicle crash … and there is an additional number of people not injured or not involved in the crash who also experience some of the same disorders."

"In addition to the possibility of physical injury as the result of a motor vehicle crash behavior or emotional changes can occur when a person experiences a motor vehicle crash. These emotional experiences can be feelings of terror, helplessness or fear of dying. These feelings can result on a psychological reaction that can have a major impact on a person's life, independent and separate from the physical outcome of injury."

"A preliminary estimate of the incidence of these disorders, believed to be a conservative lower bound, is that at least 31,000 people have post traumatic stress symptoms at one year post injury and at least 62,000 people have major depressive symptoms at one year post injury, with some overlap of these two populations. There is evidence that the actual incidence is likely to be much higher."

i) Post Traumatic Stress Disorder

Post Traumatic Stress Disorder is the experience of psychological stress after being exposed to a traumatic situation and includes four clusters of symptoms:

- *Re-experiencing*, where the person recalls the traumatic situation

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[184] Ibid
[185] *Championing Innovation*, Gene Fong, et. al., Public Roads magazine, Jan/Feb 2004
[186] This section draws on *The Economic Impact of Motor Crashes 2000*, Lawrence Blincoe, et. al., NHSTA, May 2002

- *Avoidance*, where the person attempts to minimize exposure to the stimuli that evoke the re-experiencing

- *Numbing*, where the person exhibits inability to care for others

- *Hyperarousal*, where the person experiences sleep disturbance, irritability or outbursts of anger, difficulty concentrating, hypervigilance and an exaggerated startle response

Post traumatic stress disorder is a very persistent condition and the prognosis is not favorable.

The data suggest that between 10 and 30 percent of the people treated in an emergency room as the result of a motor vehicle injury experience post traumatic stress disorder at one year post injury, and for those treated at trauma centers the range appears to be between about 20 to 40 percent.

ii) Major Depressive Episode

Major Depressive Episode is a type of mood disorder with symptoms of depressed mood, loss of interest, or diminished ability to derive pleasure from everyday activities, plus some mix of other symptoms such as change in weight or sleeplessness.

For persons treated in a trauma center, the percentage with major depressive episode at one year post injury appears to be in the 40-50 percent range.

c) Comprehensive costs

The *comprehensive cost* is “a method of measuring motor vehicle accident costs that include the effects of injury on peoples lives. **This is the most useful measure of accident cost**[187] since includes all cost components and places a dollar value on each one. Comprehensive quality of life cost values are estimated by examining risk reduction costs from which the market value of safety is inferred. The 11 components of comprehensive cost are: property damage, lost earnings, lost household production, medical costs, emergency services, travel delay,[188] vocational rehabilitation, workplace costs, administrative, legal, and pain and lost quality of life.”[189]

Note that lost quality of life costs do not represent real income not received nor expenses incurred, as explained earlier in the section on *Non-recompensable Costs to Society* (p. 81).

[187] Emphasis added
[188] Note that travel delay caused by crashes is separate from travel delay caused by operational delay. The travel time component of operational impacts are examined earlier under *Traffic Impacts* in the section on *Operational Impacts*. (p. 18) The cost component of operational impacts are examined earlier under *Cost Impacts* in the section on *Cost of Delay* (p. 79)
[189] *Motor Vehicle Accident Costs, Technical Advisory T7570.2*, FHWA , October 31, 1994

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The National Safety Council recommends that estimates prepared using the willingness-to-pay methodology should be used for benefit-cost analysis when feasible. A misnomer, *willingness-to-pay* is derived from market data and refers to the costs people *actually* pay to reduce safety risks, not necessarily what they are *willing* to pay.[190] If they had to, people might pay more in order to obtain the safety benefits; therefore using market-based data is a conservative approach.

The National Safety Council (NSC) classifies crashes into five categories for the purpose of assigning comprehensive costs. The most recent NSC comprehensive crash costs are given in the table below.

Table 24. Average Comprehensive Crash Cost per Injured Person[191]

Death	Incapacitating Injury	Non-incapacitating Injury	Possible Injury	No Injury (PDO)
$3,470,000	$172,000	$44,200	$21,000	$2,000

The table above gives the comprehensive costs according to the severity of the injuries as classified by the KABCO system described earlier under *Safety Impacts* in the section on *Impact of Crash Severity* (p. 38).

The NSC crash cost data above and the injury reduction impacts presented earlier in Table 10 (p. 38) are used to estimate the major economic impact to society of converting the six intersections to modern roundabouts, as discussed later under *Cost Impacts* in the section on *Monetary Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

4. Noise impacts

The combined effect of the six planned roundabouts and the planned medians will lower traffic speeds in the Cleveland Street corridor from Glenwood to Aurora. The roundabouts will lower speeds through a combination of geometry, negative superelevation and landscaping, as explained earlier under *Safety Impacts* in the section on *Why Roundabouts Are Safer* (p. 33). The medians will lower traffic speeds through a combination of visual narrowing, vertical curbs on the left, and landscaping.

A 1984 EPA study found that reduced noise from reduced traffic speeds increases adjacent residential property values, with a 5-10 MPH reduction increasing property values by about 2%.[192]

Conservatively assuming only a 5-10 MPH speed reduction and applying it to only the homes on the four corners of the six planned roundabouts, and assuming a nominal

[190] *Motor Vehicle Accident Costs, Technical Advisory T7570.2*, FHWA , October 31, 1994
[191] *Estimating the Costs of Unintentional Injuries*, 2002, National Safety Council. NSC figures are adjusted to 2004 dollars later, as discussed under *Cost Impacts* in the section on *Benefit-Cost Analysis* (p. 84).
[192] *Cost-Benefit Analysis of the Application of Traffic Noise Insulation Measures to Existing Houses,* M. Modra, Environmental Protection Agency (EPA), 1984

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average property value of $150,000, gives a total property value improvement of $72,000.

If the above assumptions were applied to all the approximately 110 properties in the corridor, the increased property value due to noise reduction alone would total $330,000, not counting any impact on property value of the median landscaping and imprinted asphalt.

Because, the increased property value mainly impacts just the property owners and not society as a whole[193] or even the neighborhood as a whole, this impact is excluded from the benefit-cost calculations in the section on *Monetary Benefit-Cost Analysis,* sub-section *Impacts Evaluated in Monetary Terms* (p. 88).

C. Benefit-Cost Analysis (BCA)

Previous sections have identified and examined a number of impacts that are expected to result from converting six conventional cross intersections to low-speed modern roundabouts. In this section, those impacts that are favorable are classified as "benefits" and unfavorable impacts are considered "costs."

The Benefit/Cost Ratio is simply a way of expressing the relationship between the benefits of a project and the costs. The FHWA *Economic Analysis Primer* states that "Benefit-cost analysis (BCA) considers the changes in benefits and costs that would be caused by a potential improvement to the status quo facility.

"BCA attempts to capture all benefits and costs accruing to society from a project or course of action, regardless of which particular party realizes the benefits or costs, or the form these benefits and costs take."[194]

Whenever practical, impacts have been expressed in quantitative terms. When possible, the impacts expressed quantitatively are also expressed in monetary terms. Fuel impacts, for instance, are expressed in both gallons and dollars.

1. Impacts evaluated in non-monetary terms

Of the 69 impacts examined in this study, 64 have been expressed in non-monetary terms. These impacts are listed in the following four tables.

The table below lists the thirty-three traffic impacts that have been evaluated in non-monetary terms.

[193] Aside from the increase in the tax base.
[194] *Economic Analysis Primer*, FHWA, August 2003, p. 17

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Table 25. Traffic Impacts Expressed in Non-Monetary Terms

Area of Impact	Impact		Cost = C Benefit = B
Free flow	1	All intersections users prefer to stay in motion; prefer not to have to come to a stop; and prefer not to be stopped and waiting	B
Level of Service (LOS) (p.16)	2	Improved +0.67 grade	B
Delay (p. 8)	3	Reduced by 1/3	B
Queue length (p. 17)	4	Reduced by ¾	B
Delay to the driving public (p. 18)	5	Reduced by 5,222 person-hours	B
Truck traffic (p. 19)	6	No significant adverse affect	-
Keene Road (p. 22)	7	No impact	-
Street network (p. 23)	8	No impact	-
Future growth (p. 23)	9	No impact	-
Non-motorized traffic (p. 24)	10	Reduced delay	B
	11	Improved mobility	B
	12	Improved Level Of Service (LOS)	B
Skycrest Elementary School (p. 24)	13	Improved congestion management	B
	14	Improved 1-way operation on Corona Avenue	B
Physical and right-of-way features (p. 26)	15	No adverse impact	-
Current and planned site development features (p. 26)	16	Enhanced attractiveness of the corridor will benefit developments.	B
Certain community considerations (p. 26)	17	No adverse impact	-
Traffic management strategies (p. 26)	18	No adverse impact	-
Public transit (p. 27)	19	The low-speed environment facilitates public transit safety and environment.	B
Adjacent intersection treatments (p. 27)	20	No adverse impact	-
Public complaints (p. 27)	21	The project is responsive to the complaints.	B
Other roundabouts in the jurisdiction (p. 27)	22	No adverse impact	-
Physical or geometric features (p. 28)	23	No adverse impact	-
Land use or traffic generators (p. 28)	24	No adverse impact	-
Other traffic control devices requiring pre-emption (p. 28)	25	No adverse impact	-
Bottlenecks on intersecting roadways (p. 29)	26	No adverse impact	-
Sight distances (p. 29)	27	No adverse impact	-
Platooned arterial traffic flow (p. 29)	28	No adverse impact	-
Heavy use by persons with special needs (p. 30)	29	No adverse impact	-
Safety projects to benefit older drivers (p. 30)	30	No adverse impact	-
Emergency vehicle operations coordination requirements (p. 30)	31	No adverse impact	-
Emergency evacuation (p. 30)	32	No adverse impact	-

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Table 25. Traffic Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
Railroad crossings (p. 30)	33	No adverse impact	-

The next table lists the sixteen safety impacts that have been evaluated in non-monetary terms. Some impacts are listed more than once because they impact more than one group; those impacts are marked with an asterisk (*) when have already been numbered earlier in the table.

Table 26. Safety Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
Motorists (p. 32)	34	Fewer crashes	B
	35	Less severe crashes	B
	36	Most lethal crash types eliminated	B
	37	Vehicle/vehicle conflicts reduced by ¾	B
	38	Increased non-motorized travel options	B
Pedestrians (p. 45)	*	Increased comfort and mobility	B
	39	Much lower, safer vehicle speeds	B
	40	Shorter crossing exposure distance/time	B
	41	Pedestrian/vehicle conflicts reduced by 2/3	B
Older drivers (p. 39)	42	Less complexity	B
	43	No left turns in front of oncoming traffic	B
	44	Less demanding time-constrained decisions	B
	45	Lower demands on vision, flexibility and reaction time	B
	46	More time for other drivers to compensate for older drivers' errors	B
Older pedestrians (p. 50)	*	Increased comfort and mobility	B
	*	Shorter crossing exposure distance/time	B
Child pedestrians (p. 51)	*	Less complexity	B
	*	Much lower, safer vehicle speeds	B
	*	Shorter crossing exposure distance/time	B
	*	More time for drivers' to compensate for children's errors	B
Bicyclists & skaters (p. 52) Mobility impaired users (p. 52)	*	Increased comfort and mobility	B
	*	Much lower, safer vehicle speeds	B
	*	Shorter crossing exposure distance/time	B
	*	More time for drivers' to compensate for non-motorized users' errors	B
Pedestrians with impaired vision (p. 52)	*	Less complexity	B
	*	Much lower, safer vehicle speeds	B
	47	Missing aural cues sometimes available at signals	C
	*	More time for drivers to compensate for visually impaired users' errors	B

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Table 26. Safety Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
	48	Curb return pedestrian ramps, splitter island crosswalk curbs and superior installed truncated domes surfaces help wayfinding	B
Cognitively impaired pedestrians (p. 57)	*	Less complexity	B
	*	Much lower, safer vehicle speeds	B
	*	More time for drivers to compensate for cognitively impaired users' errors	B
	49	visually and texturally emphasized crosswalks make it more apparent where to cross safely	B

The next table lists the six environmental impacts that have been evaluated in non-monetary terms.

Table 27. Environmental Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
Fuel Consumption (p.)	50	Save 17,739 gallons over 20 years	B
Emissions (p.61)	51	Reduced by 3,746,444 Kg over 20 years. Reduction of global warming gases	B
Trees and plants (p.64)	52	Lose 19, gain 6 (plus 1,390 LF of 10' median for more trees)[195]	B
	53	Increased shade and habitat	B
Stormwater (p.)	54	3,932 SF of impermeable surface replaced with planting area in central islands (plus another 13,920 SF in medians)	B
Noise (p.)	55	Reduced noise	B

The next table lists the ten social impacts that have been evaluated in non-monetary terms.

Table 28. Social Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
Aesthetics	56	Gain six attractive roundabouts	B
	57	Enhance character of Cleveland street	B
	58	Compatible with character of Cleveland Street	B
Landscaping	59	3,932 SF of asphalt replaced with planting area in central islands (plus another 13,920 SF in medians)	B

[195] The medians are referenced here because both the roundabouts and the medians are part of the same project and both are integral to the planned corridor treatment. Although the medians are joined seamlessly with the roundabout splitter islands, their cost is not considered here.

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Table 28. Social Impacts Expressed in Non-Monetary Terms			
Area of Impact	Impact		Cost = C Benefit = B
Community	60	Improved mobility for all users	B
	61	Increased neighborhood interaction	B
	62	Improved urban environment encourages urban infill that reduces sprawl	B
	63	More hospitable streets encourage street activities and community interaction	B
Crashes	64	Reduction in injuries, trauma, suffering, pain, emotional anguish, and emotional and mental disorders	B

The preceding four tables list 64 impacts expressed in non-monetary terms: 44 providing a net benefit, 19 having no adverse impact, and one being a cost.

Perhaps the most straightforward way to compare the non-monetary benefits and costs is to construct a kind of net present value (NPV), as follows

$$\begin{aligned}\text{Non-monetary NPV} &= \text{(number of benefits)} - \text{(number of costs)}\\ &= 44\text{-}18\\ &= 26\end{aligned}$$

Another way is to construct a kind of benefit/cost ratio, as follows

$$\text{Non-monetary Benefit/Cost Ratio} = \frac{\text{Number of Benefits}}{\text{Number of Costs}}$$

$$= \frac{44}{1} = 44$$

Both methods above implicitly assign equal weight to all non-monetary impacts.

These 64 non-monetary impacts are ignored in the Monetary Benefit/Cost Ratio evaluation in the next section.

Four of these non-monetary impacts also have a monetary consequence which *is* factored into the Monetary Benefit/Cost Ratio discussed below. Fuel savings, for instance, has both an environmental impact due to a reduction of fuel consumption and an economic impact due to the money saved not purchasing fuel. The three other non-monetary impacts with secondary monetary impacts are operational impacts, crash impacts and reduced noise.

2. Impacts evaluated in monetary terms

The FHWA roundabout *Informational Guide* states that "Economic evaluation is an important part of any public works planning process. For roundabout applications, economic evaluation becomes important when comparing roundabouts against other forms of intersection and traffic control, such as comparing a roundabout with a

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signalized intersection. The most appropriate method for evaluating public works projects of this type is usually the benefit-cost analysis method."[196]

The methodology used to calculate the monetary benefit/cost ratio is standard engineering analysis for intersection projects. This is the same methodology used by Hillsborough County to evaluate 400 signalized intersections to prioritize safety countermeasures and is an updated version of the procedures adopted by the Florida Department of Transportation for calculating benefit-cost.

Of the 69 impacts examined in this study, 5 have been evaluated in monetary terms. These impacts have been amortized over the 20 year life of the project and the future impacts were converted into present worth. A spreadsheet with the calculations is found in APPENDIX J.

The nominal 20-year life-cycle is a conservative assumption, since at the projected rate of growth the six planned modern roundabouts should function quite well into the foreseeable future.

The five impacts expressed and evaluated in monetary terms are listed in the table below.

Table 29. Impacts Expressed in Monetary Terms

Area of Impact	Impact (2004 dollars)			Cost = C Benefit = B
Costs to the City of Clearwater	65	Capital costs (design + ROW + construction)	$ 1,740,398	C
	66	Annual Operations and Maintenance (O & M) Costs	$ 3,780	C
Reduced Costs to Society	67	Annual fuel costs	$ 26,609	B
	68	Annual cost of delay	$ 58,486	B
	69	Annual comprehensive costs of crashes	$ 2,656,989	B

The table above lists five impacts expressed in monetary terms. Construction costs are historical and have been adjusted to base year 2004 dollars using the formulas below.

Current year cost = (historical year cost) x $(1 + k)^{\text{(current year)-(historic year)}}$

Where k = 3.5%[197] annual adjustment factor for construction costs

The same formula was used to adjust the other historical cost data, using j as the adjustment factor,

where i = 3% annual adjustment factor for consumer costs

Future benefits are inflated, discounted and summed to arrive at a present value.

[196] *Roundabouts: An Informational Guide*, p. 70
[197] *2002 Transportation Costs*, Office of Policy Planning, Florida Department of Transportation, March 2003, p. 17

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Future benefits are inflated for each year of the project life cycle according to the standard geometric cash flow series formula below.

$$A_k = A_{k-1}(1+r)^{k-1} \qquad k=1,\ldots,n$$

Where $r = r_i + r_{TG}$
r_i = 3% = inflation rate
r_{TG} = 0.45% = rate of traffic growth

The standard formula for discounting was used to discount the series of life-cycle costs and benefits to present value,[198]

$$PV = \sum_{t=1}^{N} A_t\,[1/(1+j)^t]$$

Where PV = Present Value
t = year of life-cycle analysis period
A = amount of benefit or cost in year t
N = 20 = length of life cycle (years)
j = 7%[199] = discount rate

Perhaps the most straightforward way to compare monetary benefits and costs over the life cycle is with the Net Present Value[200] (NPV), as follows

Monetary NPV= (benefits) – (costs) = $ 39,492,884

The other most widely used measure to compare benefits and costs is the Benefit/Cost Ratio,[201] as follows

$$\text{Monetary Benefit/Cost Ratio} = \frac{\text{Present Value of benefits}}{\text{Present Value of costs}} = 34.5$$

The monetary Benefit/Cost Ratio shown above is substantially greater than unity, or one.

Although the project was proposed by and is supported by Skycrest residents for its traffic calming benefits, rather than its economic benefits, a project with a monetary Benefit/Cost Ratio greater than 1.0 is generally considered worth doing on the basis of economics alone.

3. Sensitivity analysis

Sensitivity analysis is an accepted procedure for exercising models—including engineering and economic models—to see how they behave when the inputs are varied

[198] *Economic Analysis Primer*, Eric Gabler, Office of Asset Management, FHWA, August 2003, p.12
[199] *Economic Analysis Primer*, FHWA, August 2003, p. 13
[200] *Economic Analysis Primer*, Eric Gabler, Office of Asset Management, FHWA, August 2003, p.23
[201] *Economic Analysis Primer*, Eric Gabler, Office of Asset Management, FHWA, August 2003, p.23

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within normal ranges and to identify any inputs that alter the outcome significantly more than others.

Because the benefit-cost analysis involves factoring in assumptions—however reasonable—about the future, it may seem somewhat speculative to some. The FHWA Economic Analysis Primer states that "In some cases, agency personnel are skeptical about the accuracy of the BCA due to perceived uncertainties in measuring or valuing costs and benefits. In reality, there is much more substance to economic analysis techniques and values than is generally understood. Where uncertainty does exist, it can usually be measured and managed. It is helpful to remember that sound economic analysis reduces uncertainty. Not doing the analysis only serves to hide uncertainty from decision makers."[202]

There is an accepted way to manage the risk, and "The traditional means by which analysts have evaluated risk is through sensitivity analysis."[203] What sensitivity analysis does is allow "the analyst to get a feel for the impact of the variability of individual inputs on overall economic results."[204]

A sensitivity analysis was performed on the BCA model and established the following:

- The BCA model is insensitive to normal variations in most of the input factors.

- Assuming a reasonable 30-year life-cycle would produce a significantly higher Benefit/Cost Ratio.

- All economic projection models are sensitive to the assumed inflation and discount rates. The inflation rate adjusts for the effects of inflation of the value of the dollar over time and the discount rate adjusts for the time value of money. The benefit-cost analysis uses a nominal discount rate of 7%, because "The U.S. Office of Management and Budget (OMB) currently requires U.S. Federal agencies to use a 7 percent real discount rate to evaluate public investments and regulations.[205] The 3.5% adjustment factor for historical construction costs is taken from a 2004 FDOT guide.[206] Varying these factors within normal ranges does not substantially alter the outcome, however.

The factors with the most influence on the cost/benefit ratio are the comprehensive costs of crashes. Fortunately, many economic models make use of cost of injury data and much extended effort has been expended developing reliable data. The U.S. Government has been sponsoring research to develop reliable comprehensive cost of crashes data since 1982[207] and the NSC data used in the cost/benefit ratio calculations is among the latest and most authoritative data available. Comprehensive costs data is discussed earlier under *Cost Impacts* in the section on *Comprehensive Costs* (p.82).

[202] *Economic Analysis Primer*, FHWA, August 2003, p. 17
[203] *Economic Analysis Primer*, FHWA, August 2003, p. 30
[204] *Economic Analysis Primer*, FHWA, August 2003, p. 30
[205] *Economic Analysis Primer*, FHWA, August 2003, p. 13
[206] *2002 Transportation Costs*, Office of Policy Planning, Florida Department of Transportation, March2003, p. 17
[207] *Motor Vehicle Accident Costs, Technical Advisory T7570.2*, FHWA , October 31, 1994

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Economic models of this type are highly sensitive to severity of injuries. For that reason, it may be tempting to invent crashes or injuries that never happened in order to alter the Benefit/Cost Ratio, but introducing fake data to affect the outcome is obviously wrong.

Likewise, deleting crashes in order to alter the Benefit/Cost Ratio would be improper because the fact is the crashes and associated injuries that occurred *did* occur and wishful thinking will not change that reality. The likelihood of crashes and injuries is unchanged under the status quo so in the absence of improvements to the intersections there is no basis for arbitrarily assuming a particular crash type or crash outcome will not reoccur.

4. Robustness

A project with a monetary Benefit/Cost Ratio greater than 1.0 is generally considered economically viable. The B/C Ratio here is more than thirty times greater and in addition there are 44 non-monetary benefits.

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APPENDICES

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APPENDIX A AutoTurn plots

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APPENDIX B Crash schematic diagrams

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APPENDIX C Table of USA school roundabout locations

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APPENDIX D Intersection rules

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APPENDIX E Tree walk tech memo

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APPENDIX F Endorsement from Skycrest Neighbors

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APPENDIX G Complaint letter to Mayor Aungst and reply; Letter to City Manager Horne & reply

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APPENDIX H Sarasota MPO resolution

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APPENDIX I Vermont resolution

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APPENDIX J Benefit-Cost Analysis Calculations

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APPENDIX K Overview of the Four-Mode Elemental Model used in aaSIDRA

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APPENDIX L Lineville Road roundabout letters from principal and sheriff

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APPENDIX M Overview of the Four-Mode Elemental Model used in aaSIDRA[208]

The four-mode elemental model is applied in aaSIDRA as follows:

- Traffic performance is different in each lane of traffic at intersections. aaSIDRA calculates the fuel consumption, operating cost and pollutant emission estimates for each lane of traffic separately.

- In each lane, the model is applied to queued and unqueued vehicles separately according to the proportion queued estimated by aaSIDRA. For unqueued vehicles, only the cruise and geometric stop components apply. For queued vehicles, aaSIDRA determines the "drive cycles", distinguishing between major stops, queue move-ups (stops in queue) and geometric stops (slow-down or full stop in the absence of any other vehicle). These drive cycles are very different for different intersection types (signalized, sign-controlled, roundabout), for different signal phasings (one or two green periods in the cycle), for yield and stop control, and for different congestion levels.

- If the approach and exit section cruise speeds are different for unqueued through vehicles at traffic signals and priority movements at unsignalized intersections, they are considered to be subject to an acceleration or deceleration during their travel.

- Drive cycles are defined by the initial and final speeds in each element of the driving maneuver. Approach and exit cruise speeds, intersection negotiation speeds and queue move-up speeds are used for this purpose. Some of these speeds are specified as input by the user, some are calculated by the program according to the intersection geometry and traffic congestion levels, and some default parameters are used where applicable.

- The drive cycle information is used to calculate acceleration and deceleration times and distances for each element of the drive cycle individually. Effective cruise distance, cruise time and idling time are calculated using this information as well as traffic performance estimates (delay, number of stops). The drive cycle information is also used to calculate different delays (stopped delay, queuing delay, geometric delay, control delay, etc), which are reported to the user along with the proportion stopped (proportion queued for a more precise term), effective stop rate, queue move-up rate, etc.

- The fuel consumption, emission rates and operating cost values are calculated for each element of the drive cycle individually using the statistics derived as explained above. The results are added together for the entire queued vehicle maneuver, and then the results for queued and unqueued vehicles are aggregated.

- Fuel consumption and emission rates are calculated from a set of equations which use such vehicle parameters as mass and fuel/emission efficiency rates, as well as road grade and relevant speeds (cruise, initial, final).

- In the above process, light and heavy vehicles are treated separately with different parameters (e.g. different mass, different acceleration and deceleration characteristics).

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[208] Overview information provided by Akcelik & Associates, publishers of aaSIDRA software