AUTOMATING TRAFFIC STUDIES AT MODERN ROUNDABOUTS –

A FEASIBILITY STUDY

A Thesis presented to the Faculty of the Graduate School at the

University of Missouri-Columbia

In Partial Fulfillment of the

Requirements for the Degree

Master of Science

by

ROBERT ANDREW RESCOT

Dr. Carlos C. Sun, Thesis Supervisor

August 2007

The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

AUTOMATING TRAFFIC STUDIES AT MODERN ROUNDABOUTS –

A FEASABILITY STUDY

presented by Robert Andrew Rescot, a candidate for the degree of Master's of Science and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Carlos C. Sun, PhD

Professor Mark R. Virkler, PhD

Professor Byron T. Scott, PhD

Professor Bin Wu, PhD

Graduate Faculty Mr. Charles J. Nemmers

Acknowledgements

This thesis would not be possible without the support of the faculty at the University of Missouri – Columbia, including Dr. Carlos Sun, Dr. Mark Virkler, and Mr. Charles Nemmers. The faculty support of transportation research has inspired the author in the pursuit of advanced academic achievements and has provided the necessary funding to make such achievements possible. Invaluable assistance was also provided by the City of Columbia's city traffic engineer, Mr. Richard Stone and his support staff. Additional support was received from undergraduate research assistants, Derek Vap and Patrick Deering.

Table of Contents

List of Tables

List of Figures

Abstract

In the rapidly evolving world of transportation engineering, the modern roundabout is quickly gaining popularity as an alternative to a conventional intersection. While modern roundabouts offer many positive features, one significant shortcoming is the increased difficulty of capturing equivalent turning movement counts after the roundabout has been built. In speaking with several public transportation officials and private consultants, an opportunity for innovation was quickly established, as current methods are often quite laborious, expensive, and prone to errors. The objectives for the research were then crafted to create a cost efficient and easily replicatable system for electronically capturing equivalent turning movement counts at a four leg modern roundabout. Recognizing the temporal variations in traffic, even a 100% perfect count is of similar use as a less than perfect count, the research has sought to strike a balance between accuracy, ease of use, and cost effectiveness for the end user.

This methodology for automated capturing of turning movement counts at a modern roundabout is both hardware and software based. These tools include an aerially mounted video camera, dome mirror, and an off-the-shelf video processing tool. Using a database inside of a scripting language environment, paired with a unique algorithm to detect right turning vehicles, the system created by this research then uses a system of equations to compute volumes for through and left turns movements, resulting in a complete origin-destination matrix. This automated process decreases the analysis time significantly and

reduces labor costs resulting in a cost effective solution in less time than conventional alternatives.

Background and Problem Statement

In the United States of America increasing traffic volumes and congestion are two quickly developing problems facing our modern society. As a consequence, traffic engineers are looking for novel solutions to these problems. More and more, circular traffic control measures are being installed throughout the country, including the state of Missouri, due to their advantageous traffic flow and safety attributes (Transportation Research Board, 2000). Over time such circular traffic control measures have evolved from the traffic circle (or rotary) into today's modern roundabout. Roundabouts have been in widespread use across the European continent for decades; however their presence in America has been limited until recently.

The modern roundabout is a contemporary version of the older traffic circle. The modern roundabout distinguishes its self from its predecessor by having a smaller inscribed circle diameter, deflection of traffic upon entering, yield on entry, and no traffic control on the interior of the circle. These enhancements create a dynamic environment for traffic to freely flow from origin to destination. However, this dynamic flow condition creates a situation where a linear stream of vehicles may consist of various combinations of origins and destinations.

As cities grow and change, so too should the transportation infrastructure. As more vehicles use the road system each day, transportation management agencies have a civic obligation to evaluate and update existing infrastructure to meet the public demands of today and tomorrow. Many such planning studies involve the capturing of various measures of traffic flow including volumes, vehicle classification, and turning movement counts at intersections. It is this last component, turning movement counts, that proves most challenging at a roundabout because of the aforementioned dynamic flow conditions.

In comparing the roundabout to a conventional intersection the complexities of this problem quickly become apparent. At a conventional four way intersection, there are twelve customary turning movements possible (left, right, through for each approach), and each can be counted with relative ease based on traffic signal phase and priority rules. The u-turn is generally permitted unless otherwise indicated; however, the volume of u-turns typically pales in comparison to the other movements. For most locations, the u-turn is a statistical anomaly. If this same intersection is converted to a roundabout, the number of possible movements increases to sixteen as the u-turn is added for each direction. Simply following priority rules (lane assignments) provides no demarcation of traffic patterns. The geometry and operational characteristics provide that multiple vehicles may simultaneously be in the circulating area of the roundabout, all of which may be traveling between unrelated origin and destination legs of the roundabout. At a conventional intersection, movements may be separated by lane configuration, signal phasing, and/or priority rules; all of which make the counting of traffic easier. The interspersial of traffic at a roundabout is at the heart of what makes obtaining turning movement counts at a roundabout a challenge.

The University of Missouri – Columbia Department of Civil and Environmental Engineering has among its many resources, several custom built Portable Overhead Surveillance Trailer (POST) systems. The POST system has been developed under the auspices of Dr. Carlos Sun as a tool for collecting unsupervised video recordings of traffic. The POST system consists of a portable light trailer, retrofitted with a marine battery, power inverter, a small television, and a video tape recorder. The generator for powering the lights, as well as all the wiring, and the lights themselves have been stripped from the trailer. Video cameras are mounted on a mast arm that can rise approximately thirty feet above the ground. The mast arm can also rotate about the vertical axis, like a periscope on a submarine so that the orientation of the trailer is independent to the orientation of the mast. (Figure 1)

Figure 1:POST trailer and close up of inside.

The POST system has been used in various projects through the years coupled with post processing tools in the laboratory. Such post processing tools include vehicle reidentification and a tool for creating virtual detectors superimposed over video to capture various parameters such as presence, and speed. Together the field equipment and laboratory tools provide the ability to automate many mundane and labor intensive tasks, such as capturing vehicle speeds on a roadway segment or capturing space mean speed. Prior to the commencement of this research, the POST system had never been deployed at a roundabout.

In the fall of 2005, the University of Missouri was approached by the Missouri Department of Transportation (MoDOT) to assist with a traffic study at the Creasy Springs roundabout in Columbia, Missouri. Recognizing the many challenges in conducting a turning movement study at a roundabout, MoDOT engineers wanted to partner with the University to use the unique POST system to record the usage at the roundabout for a twelve hour traffic study. The rewind and fast-forward features of video data underpinned the state's request for the POST system. Upon the completion of the video gathering for MoDOT, the University turned over copies of the video data recorded. MoDOT then processed this data by having several technicians sit in front of a television manually recording turning movements.

In traffic engineering there are many variables at stake in any traffic study. A typical short term traffic study would generally be conducted on a Tuesday, Wednesday, or Thursday so as to best capture "typical" traffic patterns. However, traffic patterns vary hourly, daily, weekly, monthly, seasonally, and annually. Given this temporal variation in traffic, a reasonable margin of error is acceptable for any study as the same exact traffic patterns would likely never exist again in the future. The essence of these studies is to get a gross grasp of user patterns, from which decisions can be made.

Recognizing the significant investment required by MoDOT to complete a turning movement count at a roundabout, led the research team to believe that there had to be a better method for such work. The MoDOT study took a team of individuals several weeks to review the video and summarize the data. Using previous experiences working with video traffic data and computer programming languages led the research team to conceive a proposed methodology to automate this process. The objective was then laid forth to prove the feasibility of an easily reproducible and cost effective solution within acceptable error tolerances.

Literature Review

The current transportation engineering state of the art contains a number of sources of inspiration and lays out a technical foundation for the methodology. The two principal publications are: National Cooperative Highway Research Program (NCHRP) Report 572 (Rodegerdts, 2006),and Federal Highway Administration's (FHWA) Roundabouts: An Informational Guide (Robinson, 2000). The NCHRP report coupled together with the FHWA publication are the basis for much of the recent research on roundabouts. Also factoring in is an omni-directional camera concept of Mr. Gene Waldenmaier, whose research work with Dr. George List of North Carolina State University was showcased in 2006 during a poster session at the annual meeting of the Transportation Research Board. (Figure 2)

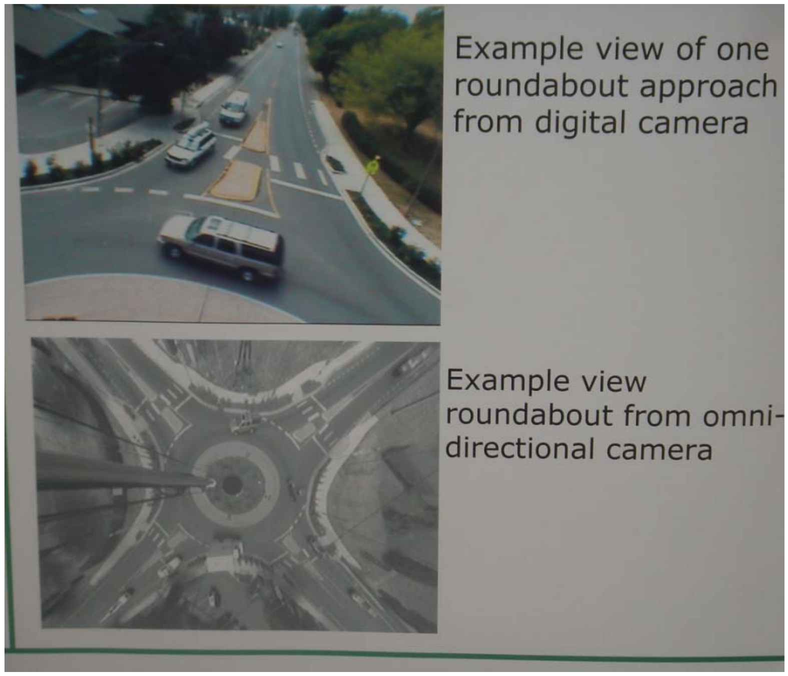


Figure 2:Photo of Dr. George List's poster at 2006 TRB Annual Meeting with image from Waldenmaier's omni-directional camera

Rodegerdts' NCHRP study presents an analysis of traffic flow theory at roundabouts. Measures investigated are geometric design, gap acceptance, delay, capacity, and the interrelationship of these variables. This study focuses on making application of these various fundamental aspects of traffic flow theory and extending them to include roundabouts. The data collected for this study included video data from the same omni-directional camera that appeared on List's TRB poster. In the NCHRP study this video data was analyzed for the aforementioned flow parameters and not for turning movements.

The FHWA guide focuses on policy and implementation of roundabouts into an existing transportation network. The guide covers such principal topics as policy, planning, operation, safety, and design. In the operational chapter, the guide proposes a formulation for extracting turning movements.

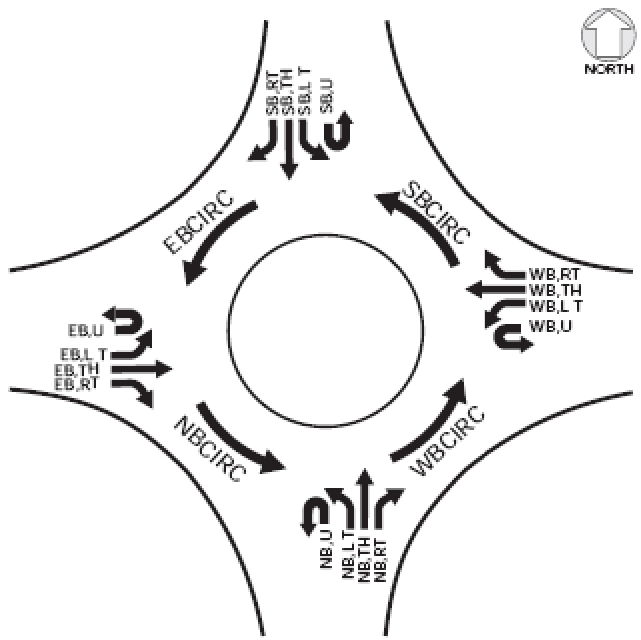


Figure 3: Roundabout Diagram with Traffic Flow Labels (Robinson, 2000)

Given this diagram, the FHWA suggests that if u-turns are considered negligible and ignored, each specific turning movement may be obtained by adding and subtracting various volumes such as the following equation to obtain the east bound through volume:

$$V_{EB,TH} = V_{EB,Entry} + V_{WB,Exit} - V_{EB,RT} - V_{NB,RT} - V_{NB,Circ.}$$

Equation 1: Estimating east bound through volume at a roundabout as a function of east bound entry, east bound right turn, north bound right turn, and northbound circulating volumes. (Robinson, 2000)

This equation (Equation 1) can be further extended into a total of eight equations; four through movement equations and four left turn equations. These equations are underpinned by several quantities which must be known in order to satisfy the system of equations, most notably, the right turn volume. Thus given right turn volumes and point volumes at entry, exit and circulating locations, the rest of the turning movements can subsequently be extrapolated, creating a unique solution.

In looking for an automated solution to the problem, several additional sources were tapped into. A principal source of inspiration was the creator of the omni-directional camera for the NCHRP study, Mr. Gene Waldenmaier. Gene had developed his camera system while working as an optical engineer at the US National Aeronautical and Space Administration (NASA). Noteworthy among Gene’s many projects is his work designing the optical system for the Hubble Space Telescope. During his time at NASA, he devised an optically correcting camera that could capture a 360° view of the ground below by using fisheye like optics to create a circular, curvilinear image. Waldenmaier also designed a series of optics to then convert the curvilinear image on the surface of the mirror into a rectilinear image for the camera to record. His work on this camera was done in conjunction with the current chair of the civil engineering department at North Carolina State University, Dr. George List while he was a professor at Rensellaer Polytechnic Institute. Through a phone conservation with Waldenmaier it became quickly apparent that the ability to reproduce his system would be extremely costly as one would need the precision optical manufacturing instruments available to NASA to create his system of curvilinear to rectilinear transformation. (Waldenmaier, 2006) As the NCHRP report 572 (Rodegerdts, 2006) focused on traffic flow theory, it was important that the study was able to work with data where linear movements anywhere on screen are of equal size.

In 2005 Stacy Eisenman and Dr. List published a paper documenting how vehicular time stamps could be used for turning movement counts at roundabouts. Eisenman asserts that if at the entrance to the roundabout a timestamp is recorded and labeled to mark the entrance, and time stamps also recorded at circulating locations and the exits and labeled accordingly, turning movement volumes can then be estimated. (Figure 4) Based on an assumption of first-in-first-out, sequences of timestamps can be stitched together to recreate turning movements. Eisenman states that the timestamps can be collected manually in the field or by watching video and recording the various timestamps. The author goes on to note that various heuristics need to be accounted for to recreate turning movements, such as accounting for slow vehicles, fast vehicles, and erratic vehicles. This data was then recorded in a spreadsheet and analyzed with custom macros.

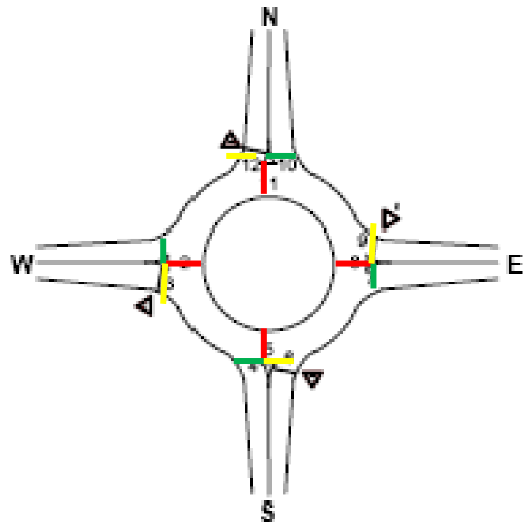


Figure 4:Timestamp locations at a roundabout in Eisenman's Study (2005). Colored lines added for clarity to indicate locations of timestamps; red lines indicate circulating volume, green lines indicated exit volume, and yellow lines indicate entrance volume.

In reading Eisenman and List's paper, it was felt that their work could be significantly extended and automated following their idea of using timestamps. A shortcoming of Eisenman's work is that it does not account for simultaneous movements occurring with overlapping vehicle trajectories (e.g. four simultaneous left turns), and the methodology employed suggests a tremendous amount of manual labor to record the timestamps. The research team felt that using advanced heuristics, and video processing equipment this methodology could be refined and automated.

Looking more in depth at the topic of time series traffic modeling, nothing specifically written for roundabouts was specifically uncovered. This led the research team to several indirectly related papers as to ascertain further proof that the concept might be possible. A number of papers cite the usage of detectors for speed measurements. A notable paper from Dr. Bo Xu, and Dr. Ouri Wolfson of the University of Illinois at Chicago department of Computer Science, asserts that using speeds combined with presence detection can be chained together to predict future locations for a moving object (e.g. a vehicle). The challenge here is that if enough detectors are set up, the path of a vehicle can be accurately predicted using multivariate models. (Xu, 2003) The implication for a roundabout being that a variation of this may be possible to ascertain origin-destination information.

In February 2007, long after this study had begun, a related study was published by the American Society of Civil Engineers written by a team of engineers at the University of Idaho. The study was led by Assistant Professor Michael Dixon. Dixon evaluated various current methodologies used for conducting turning movement equivalent counts at roundabouts. In Dixon's study reference is also made to the 2005 paper from Eisenman and List, referring to their camera system as a form of "inductive vehicle tracking." Dixon remarks that the system proposed in 2005 by Eisenman, "…the accuracy of these data tends to degrade as traffic conditions approach stopped, or queued, conditions." (Dixon 2007) Dixon then asserts later that his team of researchers attempted to manually reconstruct the data gathered but does not indicate how successful that was, but rather concludes, "It appears that this manual method, as opposed to more automated methods, must be used until detection technologies have improved to the point where they support this procedure’s input data accuracy requirements.” (Dixon 2007)

Development of Methodology

After reviewing the problem, and becoming familiar with available literature and personal skills, it was felt that an automated solution may indeed be possible. The development of the methodology has evolved through several generations. The first generation used a standard POST trailer at the edge of a roundabout combined with a first generation algorithm of heuristics for post processing in the lab. The second generation used a modified POST trailer system set further back from the roundabout, and manual post processing. The third generation uses a custom built camera configuration, combined with advanced post processing heuristics. The advanced heuristics were developed through understandings gained in previous generations combined with literary consultation.

Throughout all generations of development the research has been mindful of considering errors. In this specific scenario of conducting turning movement counts at modern roundabouts, two types of errors have been identified. Type I errors represent a movement that was counted by the heuristic algorithm, but does not exist in reality. Type II errors represent a movement that was not counted by the heuristic algorithm, yet actually exists.

In generation one, the POST system was deployed to the Creasy Springs roundabout in Columbia, Missouri in direct request from the Missouri

Department of Transportation (MoDOT). MoDOT wanted the raw video footage to manually count the turning movements. MoDOT employed a team of individuals to watch the video tape and tally the turning movements.

In reviewing the Creasy Springs video tapes separate from MoDOT, it was thought that perhaps such a laborious process could be automated. This belief was based on previous experience working with off-the-shelf video image processing tools such as Autoscope. Utilizing a series of virtual presence detectors placed in a successive series from start to finish along a specific origin-destination path, it was theorized that using techniques of time-series modeling, traffic volumes moving along a specific path could be captured.

The first challenge to this research is that the video image processing tool lacks the ability to analyze specific, complex patterns. At a roundabout this situation, the sixteen origin –destination pairs, all overlap thus creating a complex situation beyond the scope of the native logic of the video processing tool. Recognizing the limitations of the video processing hardware, a software solution would need to be developed. Thus, the output data would then need to be analyzed with a database and scripting language. Based on previous experience of the researcher in extracting data patterns from a MySQL database using the PHP scripting language, this platform was selected.

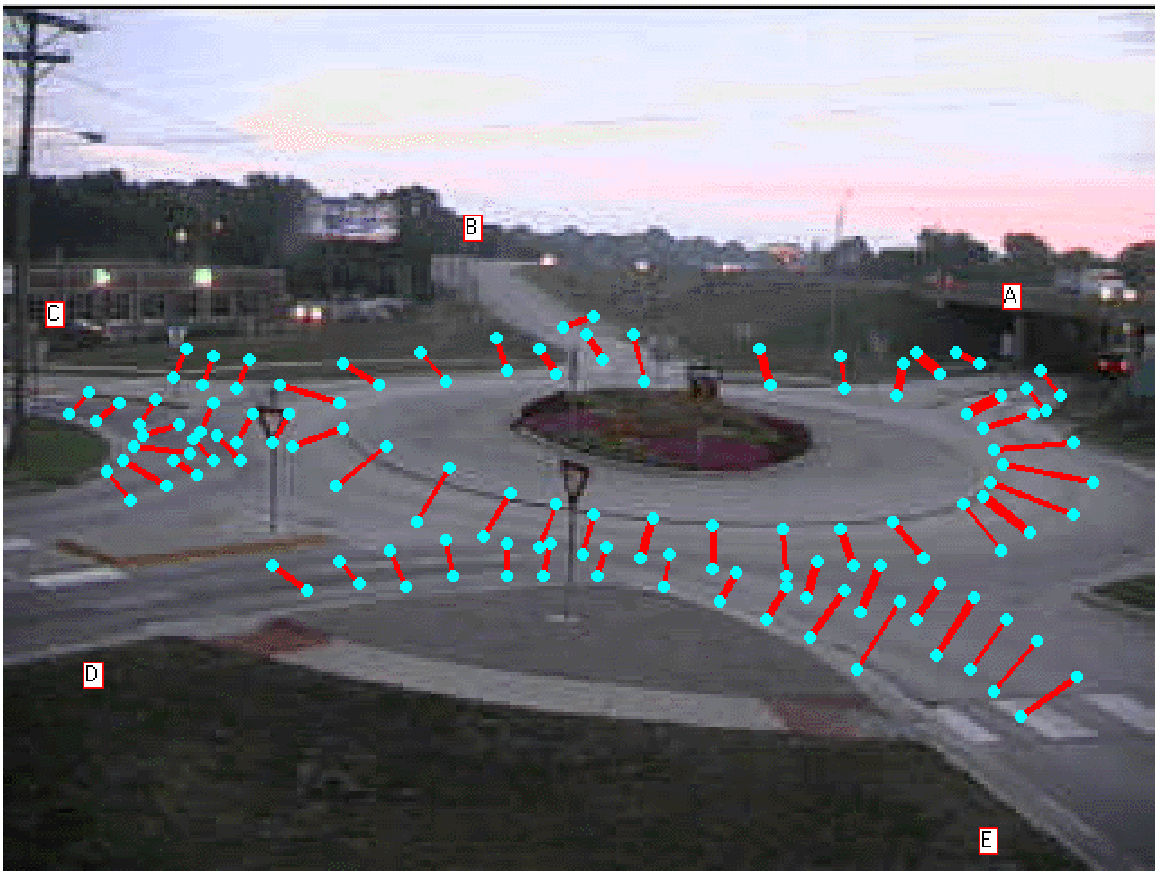


Figure 5: Creasy Springs roundabout with virtual presence detectors

During the development of the first generation system, multiple iterations were executed. The premise of this was to place a sufficient number of presence detectors around the roundabout that would record a timestamp into a log file when a vehicle crossed the detector. The virtual detector works by recording an actuation whenever a change in color across the detector occurs. Then by defining series of detectors from each origin to destination, turning movements could be extracted vis-à-vis a signature pattern of detector actuations. In various development stages modifications were made to improve the accuracy of the heuristic algorithm used for search for detector signature patterns. Such modifications include adjusting the placement of the virtual presence detectors, and adjusting the conditions specified in the heuristic algorithm that define a movement. (Figure 5) In order to check for both type I and type II errors, a ground truth of the data set was created by watching and manually recording several five minute segments, noting the entrance and exit times of each vehicle.

Vehicle occlusion is the condition where, due to camera perspective and the nature of a camera converting a three dimensional reality into a two dimensional image, that two vehicles occupy a substantial amount of the same two dimensional location. To a human watching the screen, one can tell that a vehicle is hidden simply because of cognitive object persistence. However to an electronic eye, the simultaneous existence of two objects, with one in front of the other, creates a contradiction of expected realities.

After numerous modifications in the first generation several limitations were reached. Due to the placement of the POST system adjacent to the roundabout, the resulting video data had many instances of vehicles occluding other vehicles. After much manipulation it was felt that this was a significant barrier for increasing the accuracy of the system. (Figure 6)

Figure 6: Truck about to occulde entering vehicle at CreasySprings roundabout. (cropped and enlarged for emphasis)

Recognizing both the limitations and possibilities, work commenced in December 2006 on a second generation system. The second generation system was developed in cooperation with the consulting firm Crawford Bunte & Baumeister (CBB) of St. Louis, Missouri. CBB contacted the University for assistance in counting traffic at the Halls Ferry Circle in St. Louis. The Halls Ferry Circle is not technically a roundabout, but rather a traffic circle as it lacks deflection of vehicle paths at the entrances and exits. This traffic circle has the capacity for two circulating lanes, though it is not striped. (Figure 7)

The size of roundabout or other circulatory roadway can be measured by the inscribed circle diameter. According to the FHWA guide, “The inscribed circle diameter is the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway." (Rodgerdts, 2006) The Halls Ferry Circle is quite large in comparison to modern roundabouts, with an inscribed circle diameter of 330 feet (Light, 2006), while the FHWA recommends that the inscribed circle diameter for a modern double lane roundabout should be between 150-180 feet (Robinson, 2000).

Figure 7: Ariel photgraph of the Halls Ferry Circle (Google, 2007)

While the challenge of counting traffic at the Halls Ferry Circle is different from that of a roundabout, it was seen as unique learning opportunity. Based on the first generation system at Creasy Springs Road in Columbia, Missouri, several adjustments were made. For the Halls Ferry Circle, the camera was set further back and elevated above the circulating roadway. The purpose for this change was to minimize vehicular occlusion. However for the Halls Ferry Circle, this had to be balanced against visibility through the trees in the central island of traffic on the opposite side of the circle. After carefully surveying the area, a suitable location was found at an abandoned gas station. The POST system was set up with one camera positioned on top of the metal cabinet and the other on the vertical mast arm. (Figure 8)

Figure 8: Camera positioning on the POST trailer for the Halls Ferry Circle

After the Halls Ferry field data collection was complete, it was analyzed to extract turning movements. It was anticipated that similar methods from the first generation using virtual presence could be applied to this scenario; however, the automation processed failed. It quickly became apparent that due to the trees in the central island severely restricting view of traffic on the opposite side, and the sheer size of the traffic circle, that the data would need to be extracted manually. (*Figure 9*) The research team then resorted to watching video segments and tallying the turning movements. (*Figure 10*)

Figure 9: Camera view at Halls Ferry Circle.

Figure 10: Television with flags taped to screen to note the location of entrances and exits for manual data extraction.

After the Halls Ferry Circle data was complete some reflection and more research were undoubtedly needed if the concept were to succeed. The most fundamental problem was finding a suitable camera vantage point so that all vehicles could be seen without blocking the view of the rest of the vehicles. The first two generations suffered problems with vehicular occlusion and any subsequent solutions must correct for this shortcoming. Thus the quest began for an omni-directional camera that would be able to visualize the entire roundabout, likely to be positioned in the center.

The concept of an omni-directional camera has several variations. One variation is of a camera that can be rotated to see any direction, while a second variation is of a camera that sees in all directions at all times. It is the latter of the two variations that would be needed for a roundabout. Keeping in mind that one limitation is to use off-the-shelf parts, the first consideration was to simply invert the camcorder used in the POST system to look directly downward. However, at a height of thirty feet, based on a horizontal field of view of 47° the resulting diameter of the field of view is approximately 22.2 feet, while the FHWA recommends that the inscribed circle diameter for urban roundabouts range between 100-150 feet (Rodegerdts, 2006), thus making this idea too small for further consideration. If a wide angle adaptor is added to the camera, the horizontal field of view can be increased to approximately 77°, resulting in a field of view diameter of 47.7 feet, still too small. (Helix *.55x WA Adapter*, 2007) A fisheye lens was also considered, which would increase the horizontal field of view to 125°, thus resulting in a field of view diameter of 115.3 feet. (Helix *.3x Fisheye Adapter*, 2007) While this result is close, it still is not sufficiently large enough, additionally; the availability of fisheye lenses for most off-the-shelf camcorders is very limited, and expensive.

Coming up short with simple camera optical attachments, the research team looked for commercially available omni-directional cameras. Several examples were found, most for military or high risk security applications. The most interesting camera system was from the firm Remote Reality, that claims “Unlike rotating pan-tilt-zoom (PTZ) cameras, the OmniAlert360S Camera captures 360-degrees of activity in every video frame.” (Remote Reality, 2007) This camera uses a camera pointed upwards towards a dome mirror. (Figure 11) A quote from Remote Reality for this camera is $15,000, with an additional $1,500 in software recommended. Clearly the cost is quite prohibitive. Little more technical detail could be ascertained about this proprietary system, however the camera and mirror concept seemed noteworthy for further study.

Figure 11: Remote Reality OmniAlert360 camera

With the Remote Reality camera as a design inspiration, the research team sought to see if the upwards facing camera and domed mirror concept could be extended for this application. Several vendors supplying domed mirrors were quickly located. The context for these mirrors is for overhead mounting in a warehouse so vehicles such as a forklift are able to see around a corner. Available sizes range between twelve and forty-eight inches in diameter. The larger the mirror diameter, the larger the resulting field of view becomes, however this must be balanced against increased weight, size, and wind resistance when elevated thirty feet. Using an eighteen inch diameter full dome mirror and based on camcorder's horizontal viewing angle ranging between 36°-42° a field of view diameter was expected to range between 110-193 feet. This was within scope based on the FHWA guidelines, and would permit visibility upstream of entry locations. The cost for such a mirror ranged between $100 -$150 depending on vendor.

After receiving a dome mirror from a local vendor, construction commenced on building an attachment for the POST system to accommodate it and an upwards facing camera. Using materials available from a local hardware store, a support structure was constructed. After several tests and modifications, the research team settled on a design. Critical in the design was the use of "L" shaped aluminum struts. The "L" shape was chosen because the lower portion provided a flat surface to mount the mirror against, while the vertical portion of the strut provided the structural support through its greater moment of inertia. Additional "L" shaped struts were attached for the camera mount. These had to be placed such that the center of the camera lens would be in alignment with the center of the mirror, and fit around the camera body. The "L" shape of the camera support struts also provided a channel in which the various wires for the camera could be placed. The wires were secured into the channel with tape to permit easy removal later. (Figure 12)

Figure 12: Close up of dome mirror and camera mounting bracket on the POST trailer

The image captured by the camera is a mirrored curvilinear image projected into a rectilinear image on the camera tape. The distance between any two points on the mirror is similar if measured along the curved surface, but once translated into a flat image this induces distortion. This induced distortion is similar to measuring the distance between two cities on a flat map and on a spherical globe. The distortion induced into the video footage from the curvilinear mirror causes negligible impacts, and if anything improves the image as the circular roadway becomes straighter. The other impact of the mirror is the reversal of traffic flow, such that traffic appears to be flowing clockwise around the roundabout instead of counter-clockwise.

Figure 13: Still image from video camera of roundabout as seen looking at the dome mirror.

After construction of the new camera and mirror hardware, several tests were performed to assess the system. First, the system was tested for field of view with a one hundred foot tape measure. With the tape anchored under the center of the camera and mirror, an orange traffic cone was moved outward to test the visibility limits. With the traffic cone the radius of view was approximately eighty-five feet, providing for a one hundred and seventy foot viewing diameter. As a vehicle rises vertically from the ground higher than a cone and the vehicle has a greater length, it was surmised that a greater field of view would be possible. The vertical rise is significant such that as mirror increases in curvature, the curvilinear to rectilinear distortion warps the height of an object radially outward, thus making it appear larger based on height in addition to length. The further from the center of the dome, the greater this distortion appears. The system was also tested for rigidity through repeated raising and lowering of the mast arm on the POST trailer and while the mast was raised the impact on wind blowing the camera out of place was observed. After several trials no problems were noted and the testing moved to full scale. To test conditions similar to a roundabout, a pickup truck was driven concentrically around the POST trailer and recorded. This recording showed that indeed the system worked as it was expected to.

After having developed the hardware, a suitable test location was needed. In consultation with the City of Columbia, the roundabout located at the intersection of Bearfield and Old US 63 was chosen. This roundabout has an accessible center island inside which the POST trailer could be positioned, and had been built several years earlier, so drivers were familiar with its operation. A shortcoming of this location is that while the roundabout technically has four approaches and exits, the southernmost approach and exit are for an empty field. Significant traffic flow is from between the two collector roads Old US 63 and Bearfield, Chinaberry is a local road with much less traffic. (Figure 14)

Figure 14: Bearfield at Old US 63 roundabout, Columbia, Missouri (Google, 2007). Annotations added for clarity.

After the data source was improved for the third generation model, the processing heuristic algorithm also needed to be modified to account for previous sources of error. The modifications included detector skipping, elimination of detectors at entry yield lines, and backwards or forwards time comparisons. Based on the formulas published by the FHWA, the data requirements needed to compute an origin-destination matrix for a four approach / four exit roundabout are the four approach volumes, the four exit volumes, the four circulating volumes, and the four right turns.

In various stages of development it was noticed that infrequently, the video processing unit might not immediately detect a change in the state of the virtual presence detector and subsequently would not write the actuation into the log, or it would be written out of sequence. This seemed to happen more frequently with darker vehicles, without a distinctive colored bumper on the leading edge of the vehicle. The actuation then appeared to coincide with a windshield or sunroof passing through the virtual presence detector, at which time the leading edge of the vehicle (front bumper) had already triggered the next virtual presence detector, thus causing the actuations to occur out of sequence. The solution derived for this problem, was to build into the heuristic algorithm a logic pattern to permit a detector to be skipped if it cannot be found under the specified threshold. This adaptation permitted two, non-successive detectors to be skipped.

To skip the first detector in the series requires two iterations. The first iteration of the algorithm checks the entire series starting from the first detector, which is required, permitting up to two non-successive detectors to be skipped. The second iteration, assumes the first detector in sequence is skipped, drops it from the series, then loops through the rest of the detectors, permitting a single additional skipped detector so that no more than two are skipped. The algorithm then compares the results, and any results that are unique to the second iteration are appended to the results of the first iteration.

The circulating volume is a straight forward application of the heuristic algorithm. A series of detectors is passed to the algorithm, and then the algorithm searches for occurrences of that series in the log files from the video processor. A time threshold is given to limit the time gap between detectors for a successful series. A series of detectors is used for circulating volumes so as to minimize false actuations due to the camera shifting in the wind. While a single detector would actuate falsely more frequently in the wind, the individual detector actuations must be in sequence, rather than simultaneously as a wind event would cause, thus causing such events to be discarded. As seen in Figure 15, these sequences are marked with a blue line.

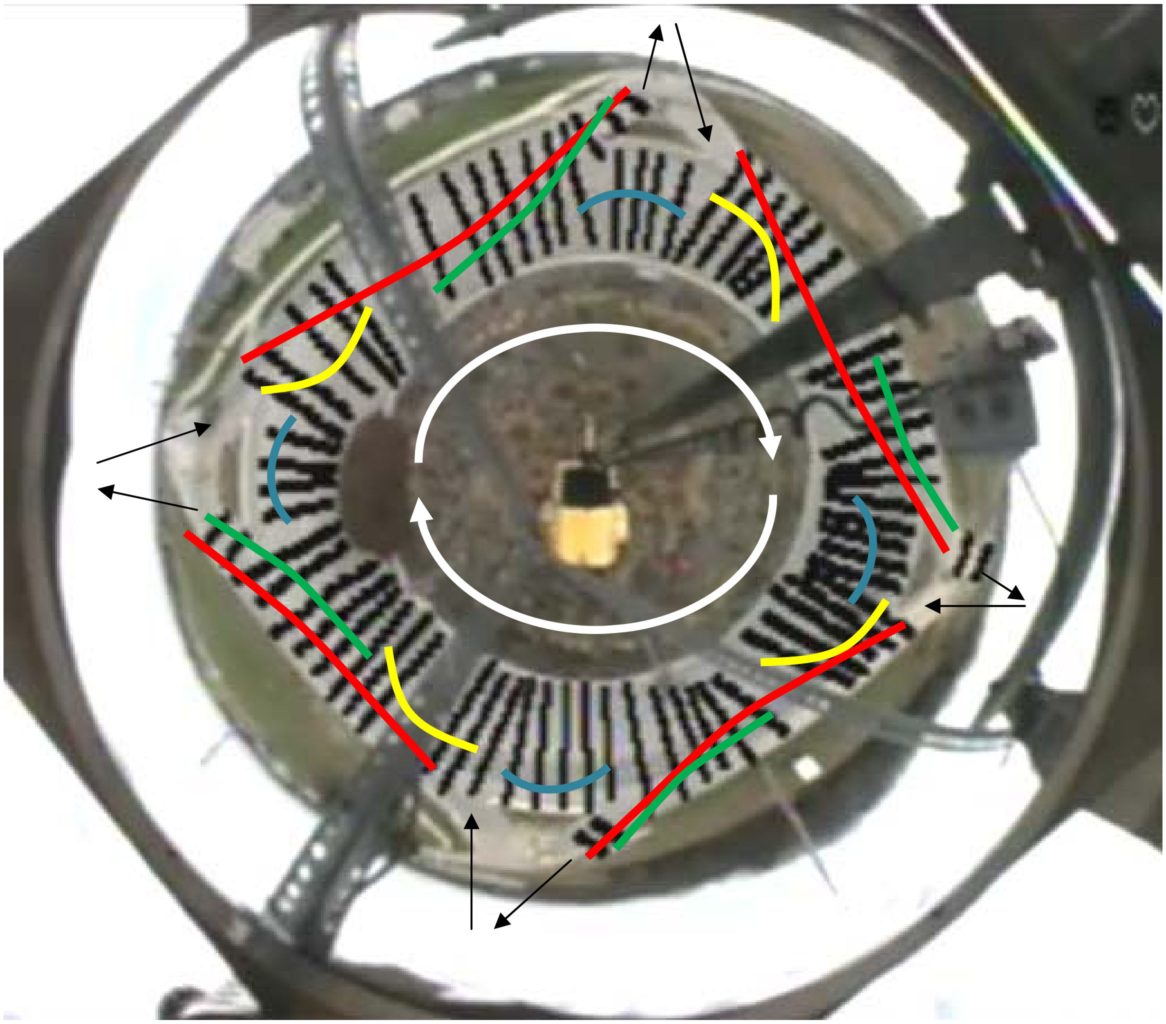


Figure 15: Bearfield Roundabout shown with various detector sequences, and direction of travel arrows.

The variation of the size of the gap in conflicting traffic accepted at the entry location (yield line), combined with queues of traffic, caused large gaps between successive detector actuations near the origin and multiple actuations of the same detector by the same vehicle resulting in additional errors. This problem was reduced by eliminating the need for detectors to be placed at entry locations.

Instead a combination of detectors was used to capture the same movement. A driver can only safely enter the roundabout if there is an acceptable gap between circulating vehicles. This implies that if a set of detectors is placed upstream of an entry location (the blue detectors in Figure 15), they should not be actuated in series, when a vehicle enters just downstream. To compute entrance volumes, the heuristic algorithm uses a string of detectors along the circulating roadway from just past the entrance to midway between the entrance and the next exit (downstream detectors, marked in yellow in Figure 15) and a string of detectors upstream from the entrance (marked in blue in Figure 15). The upstream detector sequence is augmented with the first 15% of the downstream detectors or a minimum of two whichever is greater to ensure overlap between the two detector series. If the algorithm reports that a downstream detector sequence (marked in yellow in Figure 15) succeeded, then it will check the upstream sequence (marked in blue in Figure 15), working backwards in both time and direction starting from the actuation at the end of the last overlap detector. If this upstream check fails, yet the downstream check succeeded, this is counted as a successful movement. However, if the downstream check succeeds, and the upstream check succeeds, no movement is counted as this would be a circulating vehicle. When the downstream loop (marked in yellow in Figure 15) is run a second time to check for skipped first detectors, the skipped detector number is passed to the upstream function, added back to the string of detectors of the upstream detector check, and then the upstream check is offset one additional detector downstream

Right turns are calculated similarly to entrance volumes. For the right turn, the upstream sequence is extended backwards to near the previous upstream entrance (marked in red in Figure 15). The downstream detector sequence (marked in blue in Figure 15) remains the same, and so does the rest of the process.

Exit volumes are calculated in a manner similar to entrance volumes. Like a single entrance detector, a single exit detector also would be prone to numerous false actuations when the camera shifts in the wind, thus was again not seen as a feasible option. Using the inverse of the entrance principles, an upstream detector series starting before the exit and ending to near the exit along the circulating roadway (marked in green in Figure 15) is used in combination with a subsequent series of downstream detectors extending from just after the exit to just before the next entrance (marked in blue in Figure 15). The downstream detector sequence is augmented with the upstream sequence. If the upstream detectors are actuated in sequence but the downstream detectors fail the actuation sequence, the movement is counted as an exit. If the upstream succeeds and the downstream succeeds, this taken to be a non-exiting (circulating) vehicle, as it passed up the exit. The exit process is also repeated twice so as to incorporate the methodology of for skipping detectors. To simplify things, the downstream detectors can be the same as the circulating volume detectors.

An overview of the aforementioned heuristic algorithmic processes is provided in Figure 16.

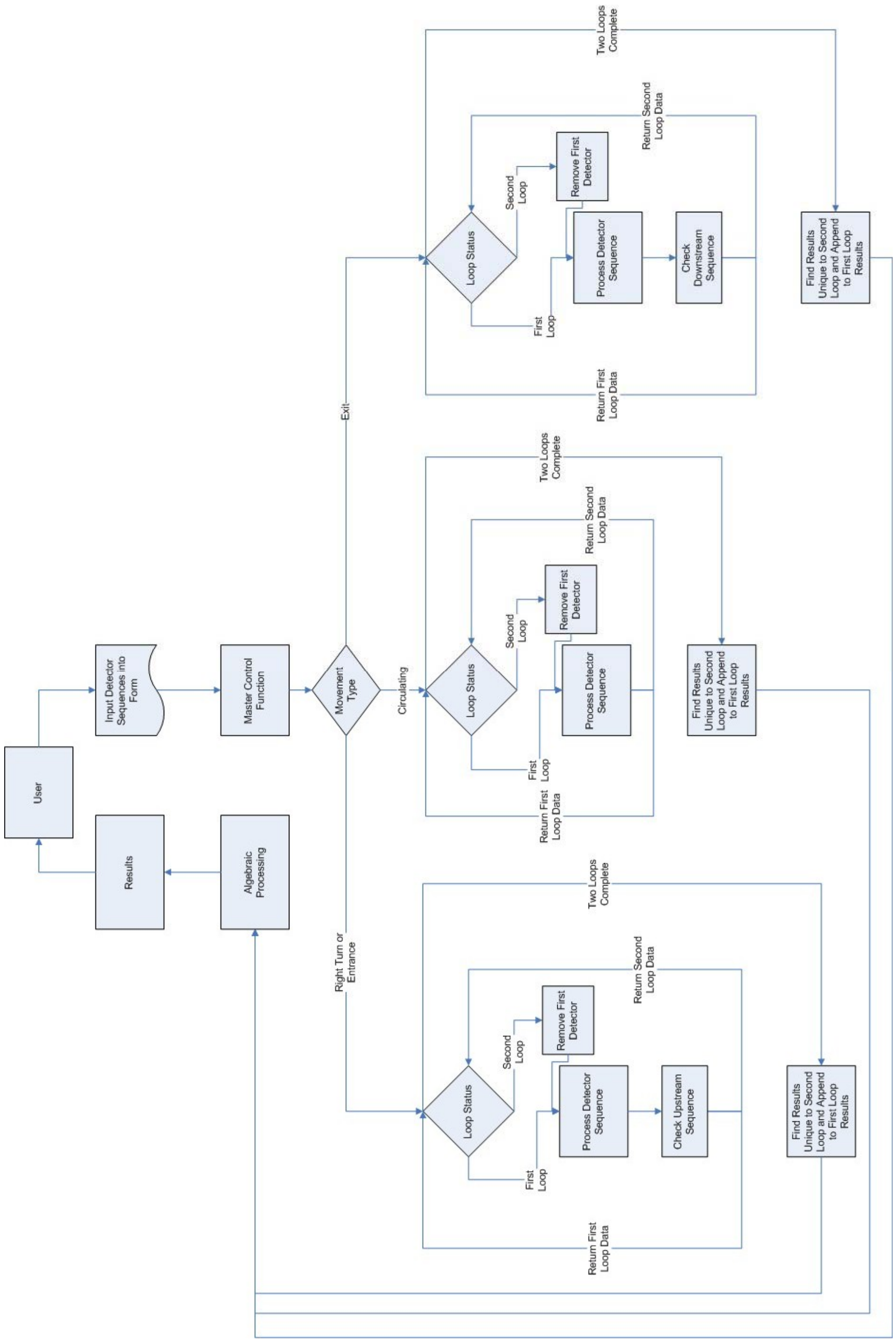
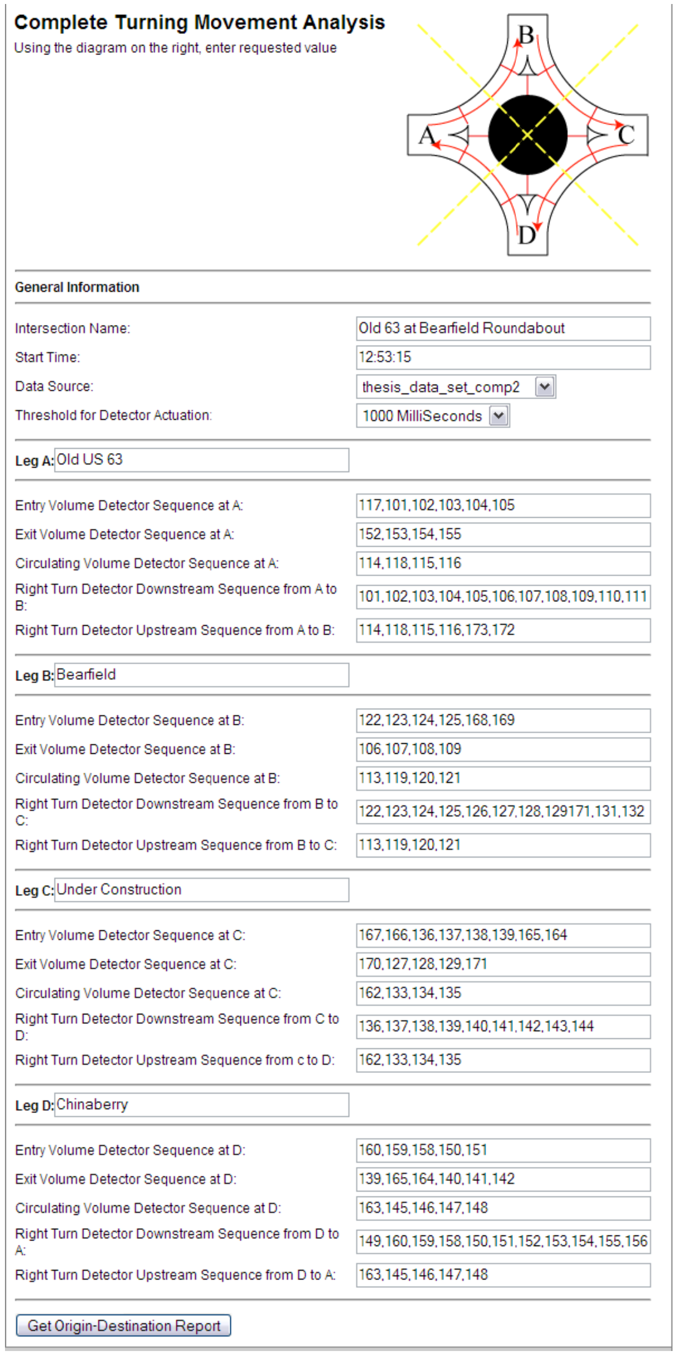


Figure 16: Schematic diagram of data processing heuristic algorithm

The video processor reports the time of each actuation based on the real world clock time, not the time on the video tape. To make checking for type I and type II errors easier, an additional function was added to convert the time reported to the time recorded. Given a start time for the video, the algorithm will then take the first record returned by the video processor and set it equal to the start time, then compute an offset time by which all the following records can be modified to report the time from the video. As there is sometimes a delay in starting the clip at the same time as the video processor and it recording the first actuation, there can be a lag time between the tape time reported and the actual tape time.

To test the development of this algorithm, several five minute samples were taken from the video data, and then each movement was cataloged, listing the entrance time, and exit time for each vehicle. This provided the baseline for evaluation, and a means by which type I and type II error could be found.

Once the evaluation of the functions was complete, a new user interface was written to simultaneously accept all the detector sequences for the roundabout. This new user interface then repeatedly calls the various data processing functions and returns the result as an origin-destination matrix.



Complete Turning Movement Analysis

Using the diagram on the right, enter requested value

B
A
C
D

General Information

Intersection Name:	Old 63 at Bearfield Roundabout
Start Time:	12:53:15
Data Source:	thesis_data_set_comp2
Threshold for Detector Actuation:	1000 MilliSeconds

Leg A: Old US 63

Entry Volume Detector Sequence at A:	117,101,102,103,104,105
Exit Volume Detector Sequence at A:	152,153,154,155
Circulating Volume Detector Sequence at A:	114,118,115,116
Right Turn Detector Downstream Sequence from A to B:	101,102,103,104,105,106,107,108,109,110,111
Right Turn Detector Upstream Sequence from A to B:	114,118,115,116,173,172

Leg B: Bearfield

Entry Volume Detector Sequence at B:	122,123,124,125,168,169
Exit Volume Detector Sequence at B:	106,107,108,109
Circulating Volume Detector Sequence at B:	113,119,120,121
Right Turn Detector Downstream Sequence from B to C:	122,123,124,125,126,127,128,129171,131,132
Right Turn Detector Upstream Sequence from B to C:	113,119,120,121

Leg C: Under Construction

Entry Volume Detector Sequence at C:	167,166,136,137,138,139,165,164
Exit Volume Detector Sequence at C:	170,127,128,129,171
Circulating Volume Detector Sequence at C:	162,133,134,135
Right Turn Detector Downstream Sequence from C to D:	136,137,138,139,140,141,142,143,144
Right Turn Detector Upstream Sequence from c to D:	162,133,134,135

Leg D: Chinaberry

Entry Volume Detector Sequence at D:	160,159,158,150,151
Exit Volume Detector Sequence at D:	139,165,164,140,141,142
Circulating Volume Detector Sequence at D:	163,145,146,147,148
Right Turn Detector Downstream Sequence from D to A:	149,160,159,158,150,151,152,153,154,155,156
Right Turn Detector Upstream Sequence from D to A:	163,145,146,147,148

Get Origin-Destination Report

Figure 17: Data input form

MIZZOU ENGINEERING

Intersection Name:	Old 63 at Bearfield Roundabout
Start Time:	13:37:40
Data Source:	thesis_data_set_comp3b
Entry Volume	62
Exit Volume	67

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (27)	Bearfield (29)	Under Construction (2)	Chinaberry (9)
Old US 63 (27)	✗	26	2	-1
Bearfield (29)	30	✗	0	-1
Under Construction (2)	-6	7	✗	1
Chinaberry (4)	1	-4	7	✗
Circulating Volume	1	10	38	33

Figure 18: Origin-destination report

Analysis and Results

The study conducted by the research team covered three specific data samples. While over eight hours of video data was recorded for the third generation model, three samples approximately five minutes each in length were extracted for in-depth analysis to verify the feasibility. It was felt that by focusing on several samples of a short duration more analysis would be possible.

Using the third generation heuristic algorithm, the data was analyzed. The procedure began by manually cataloging all the movements in each clip, listing both the entrance and exit times. Cataloging all the movements with entrance and exit times was important so as to compute type I and type II errors. Each clip begins and ends with an empty roundabout so as to have an equal number of entrances and exits. The empty beginning also allowed the video processing unit to correctly set the background state of the virtual presence detectors. After running the video clip through the processing unit, the log file was then cleaned up by removing extraneous information placed in the file, such as the serial number of processing unit. The log file data was then loaded into the MySQL database, and the algorithm run.

Summary information for the video clips is presented in table one and the results of the three samples are presented in tables two through six. In calculating the summary statistics of the errors in table five, a new statistic for false positive actuations is introduced. Conventionally this statistic requires the number of false results correctly reported as false. In this scenario, that translates the number of times the algorithm did not count a movement that did not exist. It was thought that a more meaningful evaluation of false positives, as a percentage of the total results reported (true plus type I errors) would be more appropriate.

Table 1: Video Segment Information

Video Clip	Start Time	Duration	Volume
Clip 1/ Data Set 1	11:24:00	5:31	55
Clip 2 / Data Set 2	12:53:15	5:55	70
Clip 3 / Data Set 3	13:37:40	5:50	64

Table 2: Ground Truth Counts

Sample Data Set #1

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (27)	Bearfield (26)	Under Construction (0)	Chinaberry (2)
Old US 63 (23)	0	22	0	1
Bearfield (28)	25	2	0	1
Under Construction (1)	1	0	0	0
Chinaberry (3)	1	2	0	0
Circulating Volume	4	1	29	28

Sample Data Set #2

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (32)	Bearfield (31)	Under Construction (0)	Chinaberry (7)
Old US 63 (34)	0	28	0	6
Bearfield (31)	30	0	0	1
Under Construction (1)	0	1	0	0
Chinaberry (4)	2	2	0	0
Circulating Volume	3	6	37	31

Sample Data Set #3

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (31)	Bearfield (28)	Under Construction (0)	Chinaberry (5)
Old US 63 (30)	1	27	0	2
Bearfield (31)	28	0	0	3
Under Construction (1)	1	0	0	0
Chinaberry (2)	1	1	0	0
Circulating Volume	1	3	34	30

Summary of All Data

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (90)	Bearfield (85)	Under Construction (0)	Chinaberry (14)
Old US 63 (87)	1	77	0	9
Bearfield (90)	83	2	0	5
Under Construction (3)	2	1	0	0
Chinaberry (9)	4	5	0	0
Circulating Volume	8	10	100	89

Legend:	
	Right Turn
	Left Turn
	Through
	U-Turn

Table 3: Results of Third Generation Heuristic Algorithm

Sample Data Set #1

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (26)	Bearfield (24)	Under Construction (1)	Chinaberry (3)
Old US 63 (24)	-	21	0	3
Bearfield (28)	27	-	0	1
Under Construction (0)	-5	5	-	0
Chinaberry (6)	3	5	-2	-
Circulating Volume	4	1	30	28

Sample Data Set #2

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (31)	Bearfield (32)	Under Construction (0)	Chinaberry (7)
Old US 63 (34)	-	34	-4	4
Bearfield (31)	30	-	0	1
Under Construction (0)	-3	3	-	0
Chinaberry (4)	3	-6	7	-
Circulating Volume	4	5	37	31

Sample Data Set #3

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (27)	Bearfield (29)	Under Construction (2)	Chinaberry (9)
Old US 63 (27)	-	26	2	-1
Bearfield (29)	30	-	0	-1
Under Construction (2)	-6	7	-	1
Chinaberry (4)	1	-4	7	-
Circulating Volume	1	10	38	33

Summary of All Data

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63 (84)	Bearfield (85)	Under Construction (3)	Chinaberry (19)
Old US 63 (85)	-	81	-2	6
Bearfield (88)	87	-	0	1
Under Construction (2)	-14	15	-	1
Chinaberry (14)	7	-5	12	-
Circulating Volume	9	16	105	92

Legend:	
	Right Turn
	Left Turn
	Through
	U-Turn

Table 4: Errors by Type

Sample Data Set #1

DESTINATION ⇒	Old US 63			Bearfield			Under Construction			Chinaberry		
⇓ ORIGIN	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*
Old US 63	-	-	-	20	1	2	-	-	-	-	-	-
Bearfield	-	-	-	-	-	-	0	0	0	-	-	-
Under Construction	-	-	-	-	-	-	-	-	-	0	0	0
Chinaberry	1	2	0	-	-	-	-	-	-	-	-	-
Circulating Volume	4	0	0	1	0	0	28	2	1	27	1	0
Entry Volume	23	1	0	28	0	0	0	1	0	3	3	0
Exit Volume	26	0	0	24	0	3	0	1	0	2	1	0

Sample Data Set #2

DESTINATION ⇒	Old US 63			Bearfield			Under Construction			Chinaberry		
⇓ ORIGIN	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*
Old US 63	-	-	-	26	8	2	-	-	-	-	-	-
Bearfield	-	-	-	-	-	-	0	0	0	-	-	-
Under Construction	-	-	-	-	-	-	-	-	-	0	0	0
Chinaberry	2	1	0	-	-	-	-	-	-	-	-	-
Circulating Volume	3	1	0	5	0	1	36	1	1	30	1	1
Entry Volume	31	3	3	30	1	1	0	1	0	4	0	0
Exit Volume	31	0	1	31	1	1	0	0	0	7	0	0

Sample Data Set #3

DESTINATION ⇒	Old US 63			Bearfield			Under Construction			Chinaberry		
⇓ ORIGIN	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*
Old US 63	-	-	-	23	3	4	-	-	-	-	-	-
Bearfield	-	-	-	-	-	-	0	0	0	-	-	-
Under Construction	-	-	-	-	-	-	-	-	-	0	1	0
Chinaberry	0	1	1	-	-	-	-	-	-	-	-	-
Circulating Volume	1	0	0	3	7	0	32	2	6	29	4	1
Entry Volume	26	1	4	26	3	5	1	1	0	1	3	1
Exit Volume	25	2	7	27	2	1	0	2	0	4	5	1

Summary of All Data

DESTINATION ⇒	Old US 63			Bearfield			Under Construction			Chinaberry		
⇓ ORIGIN	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*	*TRUE*	*Type I*	*Type II*
Old US 63	-	-	-	69	12	8	-	-	-	-	-	-
Bearfield	-	-	-	-	-	-	0	0	0	-	-	-
Under Construction	-	-	-	-	-	-	-	-	-	0	1	0
Chinaberry	3	4	1	-	-	-	-	-	-	-	-	-
Circulating Volume	8	1	0	9	7	1	96	5	8	86	6	2
Entry Volume	80	5	7	84	4	6	1	3	0	8	6	1
Exit Volume	82	2	8	82	3	5	0	3	0	13	6	1

Table 5: Summary of Errors by Movement

Summary of Data Set #1	*TRUE*	*Type I*	*Type II*	False Negative Rate	Detection Rate	Mod False Positive Rate
All Right Turns	21	3	2	8.70%	91.30%	12.50%
Circulating Volume	60	3	1	1.64%	96.77%	4.76%
Entry Volume	54	5	0	0.00%	98.18%	8.47%
Exit Volume	52	2	3	5.45%	94.55%	3.70%

Summary of Data Set #2	*TRUE*	*Type I*	*Type II*	False Negative Rate	Detection Rate	Mod False Positive Rate
All Right Turns	28	9	2	6.67%	93.33%	24.32%
Circulating Volume	74	3	3	3.90%	96.10%	3.90%
Entry Volume	65	5	4	5.80%	92.86%	7.14%
Exit Volume	69	1	2	2.82%	98.57%	1.43%

Summary of Data Set #3	*TRUE*	*Type I*	*Type II*	False Negative Rate	Detection Rate	Mod False Positive Rate
All Right Turns	23	5	5	17.86%	82.14%	17.86%
Circulating Volume	65	13	7	9.72%	95.59%	16.67%
Entry Volume	54	8	10	15.63%	84.38%	12.90%
Exit Volume	56	11	9	13.85%	87.50%	16.42%

Summary of All Data	*TRUE*	*Type I*	*Type II*	False Negative Rate	Detection Rate	Mod False Positive Rate
All Right Turns	72	17	9	11.11%	88.89%	19.10%
Circulating Volume	199	19	11	5.24%	96.14%	8.72%
Entry Volume	173	18	14	7.49%	91.53%	9.42%
Exit Volume	177	14	14	7.33%	93.65%	7.33%

Table 6: Errors by Absolute Percent

Data Set #1

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63	Bearfield	Under Construction	Chinaberry
Old US 63	-	5%	-	-
Bearfield	-	-	#DIV/0!	-
Under Construction	-	-	-	#DIV/0!
Chinaberry	200%	-	-	-
Circulating Volume	0%	0%	3%	0%
Entry Volume	4%	0%	#DIV/0!	100%
Exit Volume	0%	11%	#DIV/0!	50%

Data Set #2

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63	Bearfield	Under Construction	Chinaberry
Old US 63	-	21%	-	-
Bearfield	-	-	#DIV/0!	-
Under Construction	-	-	-	#DIV/0!
Chinaberry	50%	-	-	-
Circulating Volume	33%	17%	0%	0%
Entry Volume	0%	0%	#DIV/0!	0%
Exit Volume	3%	0%	#DIV/0!	0%

Data Set #3

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63	Bearfield	Under Construction	Chinaberry
Old US 63	-	4%	-	-
Bearfield	-	-	#DIV/0!	-
Under Construction	-	-	-	#DIV/0!
Chinaberry	0%	-	-	-
Circulating Volume	0%	233%	12%	10%
Entry Volume	10%	6%	100%	100%
Exit Volume	16%	4%	#DIV/0!	80%

Summary of All Data

DESTINATION ⇒ / ⇓ ORIGIN	Old US 63	Bearfield	Under Construction	Chinaberry
Old US 63	-	5%	-	-
Bearfield	-	-	#DIV/0!	-
Under Construction	-	-	-	#DIV/0!
Chinaberry	75%	-	-	-
Circulating Volume	13%	60%	5%	3%
Entry Volume	2%	2%	300%	56%
Exit Volume	7%	2%	#DIV/0!	36%

Table 7: Summary of Errors by Absolute Percent

Summary of Data Set #1	*Error*
All Right Turns	4%
Circulating Volume	3%
Entry Volume	9%
Exit Volume	2%
All Measured Volumes	4%

Summary of Data Set #2	*Error*
All Right Turns	23%
Circulating Volume	0%
Entry Volume	1%
Exit Volume	1%
All Measured Volumes	3%

Summary of Data Set #3	*Error*
All Right Turns	0%
Circulating Volume	8%
Entry Volume	3%
Exit Volume	3%
All Measured Volumes	3%

Summary of All Data	*Error*
All Right Turns	10%
Circulating Volume	4%
Entry Volume	2%
Exit Volume	0%
All Measured Volumes	3%

$$\frac{|(Type\ I - Type\ II)|}{(True + Type\ II)} * 100$$

Equation 2: Mean Absolute Percent Error

$$\frac{True}{Ground\ Truth} * 100$$

Equation 3: Detection Rate

$$\frac{Type\ II}{(True + Type\ II)} * 100$$

Equation 4: False Negative Rate

$$\frac{Type\ I}{(True + Type\ \ I)} * 100$$

Equation 5: Mod Fale Positive Rate

In studying the output of the heuristic algorithm, negative volumes may be reported. In the equations publihed by the FHWA (Rodegerts, 2006), conservation of flow is a fundamental assumption. If the data placed into the equations does not conserve traffic flow, the equations will return a negative values for left turns and through movements so as to balance the flow.

After the evaluation, a follow up was done on the type I and type II errors to attempt to find an explanation. The most prominent cause was the camera shifting in the wind. That video data processor works with the assumption that the video camera remains steady. When the wind shifts the camera briefly, it causes the detectors to shift position, often off the roadway, thus causing false acutuations. Several times a wind event during a vehicle's progression through the roundabout triggered in sequence, the coresponding upstream or downstream detectors, thus causing the movement to be nullified. In other situations if a vehicle is following too close behind another vehicle and the headway between vehicles is less than the latency time of the video processor (one second), the detectors may remain on, instead of turning off, then turing on again. If this happens more than twice in the progression sequence, the algorithm will discard the movement due to too many detectors being skipped.

Application of Methodology

To make application of the aforementioned methodology developed in the third generation model several steps should be undertaken. These steps include, site planning, equipment setup, and data evaluation. Each step requires consideration and methodical execution.

Prior undertaking an analysis using this methodology, one needs to evaluate the roundabout site. As this methodology requires access to the central island and the ability for a camera system to be placed within sight of all the approaches and exits, locations with sculptures or large trees would not be optimal locations. An additional consideration is to ensure that all the yield lines for entry are within approximately eighty five feet of the center (one hundred and seventy foot diameter). Note that this dimension is not the inscribed circle diameter. If a location has a larger size, a larger dome mirror would be needed. If necessary, a right of way permit may also need to be secured from the proper authorities. During testing of the system, the City of Columbia requested that the research team notify the emergency command center prior to set up as a courtesy in case any motorists phoned the police about an unusual device located in the right of way. As this system is built on a foundation of equations which assumes no u-turns are made, this too should be a consideration. Locations where the u-turn volume is significant, this methodology would likely prove unsuitable.

Once the planning is taken care of, the set up of the equipment can occur. The POST trailer should be positioned so that when the mast arm is upright, it is in alignment with the center of the roundabout. In connecting the wires to the video tape recorder and camcorder, it is important to make sure that all connections are snug and secure. Tape may be used to secure the wires inside the “L” shaped support struts. The camera attachment can then be bolted onto the POST trailer. Ensure that the bolts are fastened securely. In transit and in mounting, the camera mount may have shifted, so it is critical to double check that the center of the camera lens is parallel to, and is in alignment with the center of the dome mirror. Before raising the mast arm, check that the camcorder is operational, has the correct date and time, and that the lens is clean. Once the mast of the POST trailer is moved into the vertical position and fully extended, the mast arm should be rotated about the periscope like mount so that the struts do not obfuscate any approaches or exits. By connecting the camcorder to a video tape recorder in the POST trailer cabinet, tape changes can be easily made throughout the day so as to not disturb the setup, as keeping a consistent setup will make the data processing much easier.

After collecting the video data, the final step is to extract the turning movements from the video footage. Using a commercial off-the-shelf video processor such as Autoscope, paired with a video tape recorder, one can then find a video frame without traffic to use as the baseline and then overlay the presence detectors in a radial manor along the inscribed circle, and at each exit.

Typically the video processor will assign each detector an identification number. Manually note the identification numbers for each sequence of detectors and upstream detectors where appropriate.

Conclusions and Future Research

This test is a proof of concept and feasibility study. While the system developed is not without flaw, it was able to show conclusive evidence that using the right combination of off-the-shelf parts, automated techniques for turning movement studies at roundabouts are not just a dream, but are possible. The error rates ascertained appear to be reasonable and it is conjectured that these error rates would be less than that of team of people who manually count the traffic at a roundabout. To the knowledge of the research team no study has been published estimating the accuracy of human counting methods at roundabouts. Dixon, however, did analyze several analytical methods in his study, including errors. Dixon lists error for various roundabout counting methods based on mean absolute percent error. The methods Dixon considered include, Bi-Proportional (BP), Factored Survey (FS), Algebraic Solution (ALGS), and Sequential Quadratic Programming (SQP). Though the paper comments on video processing techniques, no error analysis was conducted, and accommodations for classifying type I and type II errors were not made.

Table 8: Volume Estimation Error from Dixon's Study (2007)

Sample	Method	Interval Size (min)	Mean Absolute Percent Error
1	ALGS	5	17%
2	ALGS	15	14%
3	ALGS	30	15%
4	FS	5	64%
5	FS	5	30%
6	FS	5	17%
7	FS	15	56%
8	FS	15	23%
9	FS	15	13%
10	FS	30	40%
11	FS	30	22%
12	FS	30	12%
13	BP	5	52%
14	BP	15	65%
15	BP	30	62%
16	BP	5	53%
17	BP	5	23%
18	BP	5	15%
19	BP	15	46%
20	BP	15	21%
21	BP	15	13%
22	BP	30	36%
23	BP	30	19%
24	BP	30	11%
25	SQP	15	25%
26	SQP	15	111%
27	SQP	30	306%
28	SQP	30	175%
29	SQP	5	21%
30	SQP	5	26%
31	SQP	15	15%
32	SQP	15	15%
33	SQP	30	12%
34	SQP	30	12%

Dixon’s Algebraic Solution (ALGS) category most nearly matches the scope of this study. Dixon reports a range between 14-17% mean absolute percent error in sampling the right turns, while in this study the similar error statistic in the range of 3-4%, a reduction in absolute percent error by approximately 77%.

A notable achievement of this study is the right turn detection rate. This study found that out of 81 right turns in the same data, 89% were correctly detected. The research team feels that this is a significant contribution to the engineering community. While the other volumetric measurements such as entrance, exit, and circulating volumes may be captured with other means such as pneumatic tube, or tape switch counts, turns cannot be captured. If one attempts to create a matrix of equations so as to build upon the FHWA equations, with a determinant of zero. Thus the result is an underspecified system of equations, which cannot be solved. The breakthrough in this research is that at a 89% detection rate, for the missing ingredient required to compute an origin-destination matrix for a roundabout. While both Dixon and Eisenman do not specifically mention a right turn movement error rate, this rate for a right turn is a 5% improvement over Dixon’s success rate (100% - error rate).

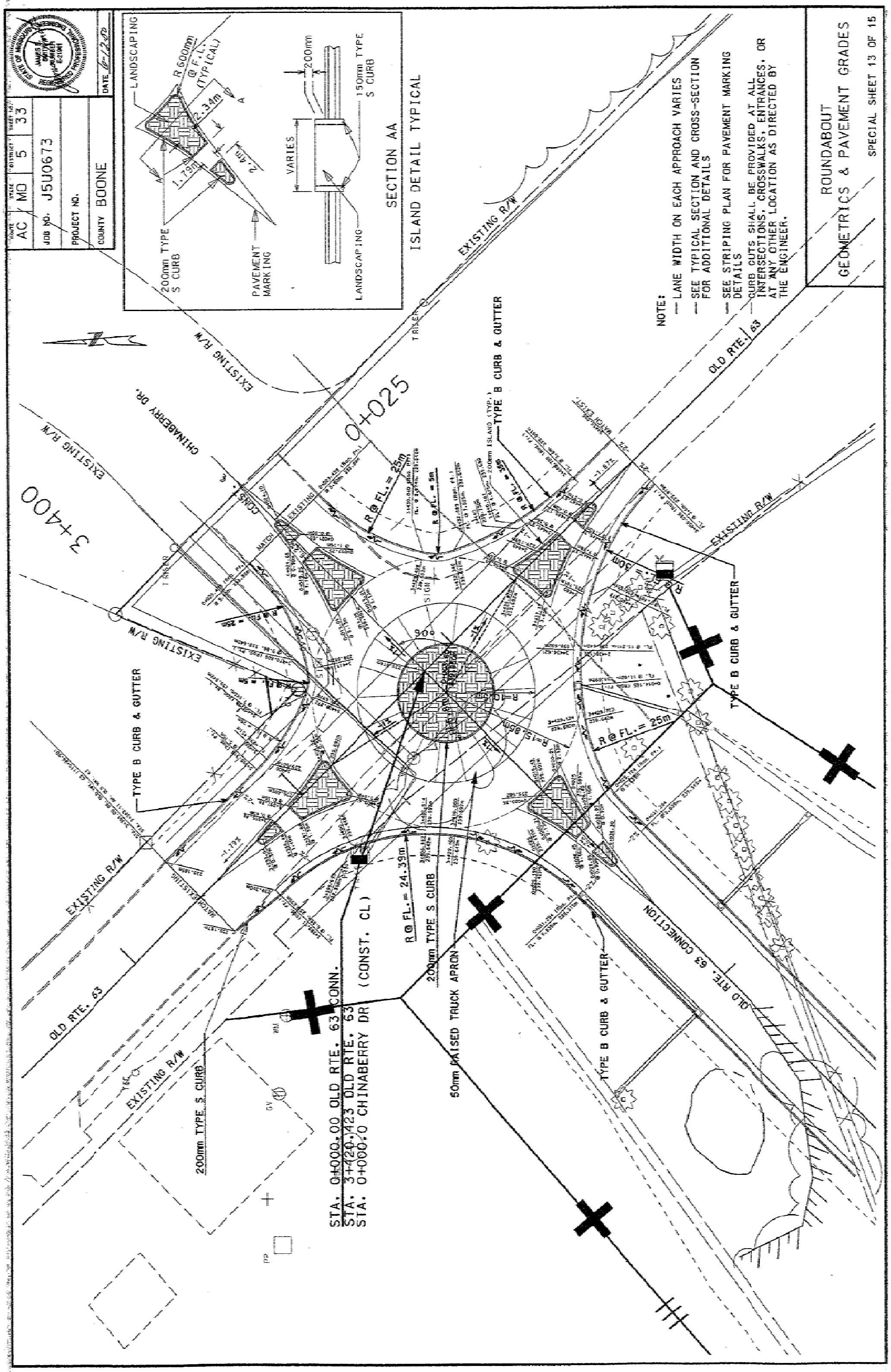
The implications of this research are quite broad. Beyond simply the technical achievements, this research has the potential to slash costs and increase safety for conducting a turning movement equivalent count at a roundabout. Using this automated method there would not be a need for placing a small army of traffic counters in danger while observing the roundabout. Instead the traffic counters are replaced with a team of two individuals to setup and position the data collection device (POST trailer with camera-mirror attachment). After the device is set up, these individuals are able to attend to other business while the system is counting. Albeit, every couple of hours, a maintenance check may be needed to change batteries or data collection media (e.g. tapes or DVDs). A drawback is that the data would not be immediately available and planners needing this information would have to wait for the results to be processed. This wait time can be budgeted into a project timeline making it a non-existent cost. However, if the time comparison is made against manual data extraction from a video, this technique would certainly deliver the results much faster. For comparison, in cataloging the vehicles in the sample data, each clip of just over five minutes consumed in excess of two hours. Additionally, a comparable cost savings would come from a reduction in man-hours required to extract similar data.

In the future several opportunities exist for continuing research. The first area would be to study the accuracy of manual field counts compared with a baseline count extracted from video. Such a study would provide a better baseline comparison, particularly for agencies or firms that use manual count techniques. Another way to extend this research would be to experiment with mirrors of various shapes. The half spherical dome mirror was chosen for its ease of availability and low cost. However circular mirrors of other shapes are known to exist. One suggested possibility would be to experiment with hyperbolic and conic shaped mirrors. Perhaps, the most obvious extension of this research would be to conduct experiments on larger, multi-lane roundabouts, as well as to increase the sampling size.

An additional consideration for future research would be to find the optimal locations and minimum number of detectors needed. In this research, more detectors than were absolutely necessary were used for the sequencing. While there would certainly be tradeoffs of quality of results versus time saved placing detectors, finding the critical mass needed would help to further minimize agency costs. Another tradeoff that lends it's self to further research is in ascertaining the optimal length of virtual detector. As the detector increases in width spanning the circulating roadway, the more likely false actuations from wind are possible. Such a false actuation would result from the edge of the detector being "pushed" over the pavement of the circulating roadway thus causing part of it to extend into adjacent property; the change in color would thus actuate the detector. Related to the number of detectors, the research team also hypothesizes that vehicle classification might be able to be extracted using similar methodology.

In summary, the research team has achieved with remarkable success proving that automated systems for turning movement counts at roundabouts can be crafted solely from standard off-the-shelf components. Building upon previous research of the greater transportation engineering community, this study has successfully extended that research into a ground breaking system. It is hoped that the techniques used in this research can be built upon in the future to establish an industry standard practice for conducting turning movement counts at roundabouts.

Appendix A: Old US 63 at Bearfield Roundabout Schematic Diagram



(Valleroy, 2006)

References

Dixon, Michael P and Abdel-Rahim,et. al. (2007). *Field Evaluation of Roundabout Turning Movement Estimation Procedures*. American Society of Civil Engineers, *Journal of Transportation Engineering* Vol. 133 No. 2, 2007.

Eisenman, S. and G. List (2005). *A Technique for Data Collection and Estimation of Turning Movements at Roundabouts*. Proceedings of the 84th Annual Conference of the Transportation Research Board, 2005, Washington D.C.

Google (2007). Google Earth (Software), Mountain View California.

Helix Camera (2007). *.3x Fisheye Adapter for Canon GL1 / GL2*, <http://www.helixcamera.com/Video/century/dsfewagl.html> (July 17, 2007).

---. (2007), *.55x WA Adapter for Canon GL2 / GL1 with Standard 20X Lens*, <http://www.helixcamera.com/Video/century/ds55wagl.html> (July 17, 2007).

Leight, Shawn (2006). *Halls Ferry Circle Evaluation and Conceptual Redesign*, Transportation Engineering Association of Metropolitan St. Louis (TEAM), 2006 TEAM Transportation Fair, <http://www.teamstl.org/other%20documents/TransportationFair/2006HallsFerryCircle.pdf > (July 17, 2007).

List, George (2006). *Roundabouts in the United States,* National Highway Cooperative Research Program Project 03-65, Poster, Presented at the 85th Annual conference of the Transportation Research Board, 2006, Washington D.C.

Remote Reality (2007). *OmniAlert360™ Perimeter Monitoring System* < http://www.remotereality.com/content/view/48/120/> (July 17, 2007).

Robinson, Bruce and Rodegerdts, Lee (2000). *Roundabouts an Informational Guide*, US Federal Highway Administration, Report FHWA-RD-00-067, Washington D.C.

Rodegerdts, Lee (2006). *Roundabouts in the United States*, National Highway Cooperative Research Program Project 03-65, Transportation Research Board, Report 572.

Russel, Eugene, Rys, Margaret et. al. (2000). *Modeling Traffic Flows and Conflicts at Roundabouts*, Mack-Blackwell Rural Transportation Center, University of Arkansas, Report MBTC 1099 < http://www.mackblackwell.org/research/finals/arc1099/framereport1099.html> (July 17, 2007).

Transportation Research Board (2000). *Highway Capacity Manual*. Transportation Research Board, National Research Council, Washington, D.C.

Valleroy, Chris M (2006). *Old 63/Bearfield Rd. Roundabout*. Email to author (December 19, 2006).

Waldenmaier , Gene (2006). Phone interview with author (March 6, 2006).

Xu, Bo and Wolfson, Ouri (2003). *Time-Series Prediction with Applications to Traffic and Moving Objects Databases*. Proceedings of the MobiDE'03, 3rd ACM International Workshop on Data Engineering for Wireless and Mobile Access, San Diego CA, Sept. 2003, pp. 56-60.