

The logo features the word "IDEA" in a large, bold, serif font. A vertical gray rectangle is positioned behind the letters "I" and "D". Two thin lines extend from the bottom corners of this rectangle, one pointing towards the bottom left and the other towards the bottom right.

IDEA

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**Innovations Deserving  
Exploratory Analysis Programs**

***Transit IDEA Program***

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# **NON-CONTACT SENSOR FOR PASSENGER COUNTING AND CLASSIFICATION**

Final Report for Transit IDEA Project 20

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## INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD

This investigation by Greneker and Associates, Inc., Marietta, GA was performed as part of the Transit IDEA program, which fosters development and testing of innovative concepts and methods for improving transit practice. The Transit IDEA Program is part of the Transit Cooperative Research Program, a cooperative effort of the Federal Transit Administration (FTA), the Transportation Research Board (TRB) and the Transit Development Corporation, a nonprofit educational and research organization of the American Public Transportation Association. The program is funded by the FTA and is managed by TRB.

The Transit IDEA program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

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# **NON-CONTACT SENSOR FOR PASSENGER COUNTING AND CLASSIFICATION**

## **FINAL REPORT**

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## EXECUTIVE SUMMARY

The Transit IDEA Program funded the Transit IDEA-20 applied research project, conducted by Greneker and Associates, Inc. The project developed and tested an experimental approach to count the number of passengers entering and exiting rail transit cars through a wide stream door. The system that was tested consisted of: (1) a radar, and (2) a video camera image capture system. Both were specifically designed for the wide stream door transit passenger counting system.

The Transit IDEA-20 project was a product application investigation as a follow-on to Transit IDEA-5 project, a previous IDEA investigation conducted by Greneker and Associates, Inc. The previous Transit IDEA-5 project was conducted during the period November 1995 through October 1996. The goals of Transit IDEA-5 were the development of a passenger counter for transit applications and to investigate the potential to determine a passenger's station of origin and destination through passenger identification.

The Transit IDEA-5 system used a pressure sensitive floor mat with many small sensor points to obtain an outline of the passenger's shoe, the direction of travel of the shoe, and the weight of the passenger. The data were used to count passengers boarding and exiting. Based on the findings of Transit IDEA-5, a more effective different approach was proposed.

Testing of the Transit IDEA-20 Cyclops system demonstrated that radar is a viable method for counting single passengers entering or exiting anywhere along the wide stream door. Both the radar and the video elements of the Transit IDEA-20 Cyclops system were tested aboard Metropolitan Atlanta Rapid Transit Authority (MARTA) rail rapid transit cars, with wide stream doors, during revenue service. Laboratory analysis was performed on the recorded radar and video test data to determine if wide stream door passenger counts could be extracted from radar and video scene data. It was demonstrated that radar and video are viable method for counting single passengers entering or exiting anywhere along the wide stream door. The technical limitations and challenges associated with using radar and video for passenger count extraction were also evaluated.

## Cyclops Passenger Counting System

### *Radar Element*

The radar operated on a frequency of approximately 24.1 GHz. Both the real and quadrature radar signal channels were recorded. Laboratory analysis of the recorded data determined that the radar could detect the unique signature of the transit door opening and closing, alleviating the need for an independent door actuation sensor. The radar provided resolution sufficient to discriminate the signatures of individual passengers as

they passed under the antenna located on the left side of the MARTA rail car during testing. Direction of passenger travel could be determined using signal processing techniques. Counting multiple passengers simultaneously entering the wide stream door abreast of each other, shoulder to shoulder, is a challenge for the current radar system design.

### *Video Element*

A miniature color video camera was mounted in two positions during tests aboard the rail vehicle. The camera was first mounted over the door on the right side of the rail car to capture the scene of passengers boarding and exiting through the door on the left side of the rail car. The camera was next aligned to observe passengers boarding and exiting through the door (right side) over which the camera was mounted. The imaging system is capable of determining passenger count and the direction of travel of a passenger entering or exiting the rail car. The opening and closing of the rail car door can be detected using the imaging system, alleviating the need for an independent door actuation sensor.

## Station of Passenger Origin and Destination Experiment

The use of video imaging was also evaluated as a passenger origin and destination study tool. Laboratory analysis was conducted on the MARTA test data to determine if a passenger entering a transit vehicle might be recognized later by his or her physical features when exiting the vehicle. This system capability would allow a passenger's origin and destination stations and the time spent by the passenger between the origin and destination stations to be determined. The variability in rail car scene illumination and the lack of control over a passenger's aspect angle during boarding and exiting presented technical challenges to passenger feature recognition that cannot be solved within the scope of the Transit IDEA-20 investigations.

However, a second experimental method to determine a passenger's station of origin and destination was successfully demonstrated in the laboratory. An overhead video camera was used to track test subjects entering and exiting a simulated transit vehicle. Algorithms were developed to automatically assign a unique identification number to each passenger upon entry. In practice, the station identifier and time of the passenger's entry would also be simultaneously associated with the passenger's identification number and stored in the system data base. The video algorithm tracked the passenger to his seat and continued to associate the system-generated identification number with the passenger's image during the seated part of the trip. As the seated passenger rose and walked to the exit, the automated tracking algorithm tracked the passenger to

the exit. When the passenger's image passed out of the door, the file was closed on the passenger. The station identification where the passenger exited and the time of exit was then associated with the passenger's previously stored file. Passenger origin and destination data could be collected and processed at the end of the rail car's operational day. Rider identification and privacy would not be an issue. No passenger image data would be required to be preserved in the data base using this approach.

## **Commercialization of the Cyclops Passenger Counter**

Testing the radar system on MARTA demonstrated that radar is a viable method for counting single passengers entering or exiting anywhere along the width of the wide stream door. However, additional radar system development is required to solve the technical challenges associated with the discrimination of multiple passengers entering and exiting simultaneously in "lock step" and shoulder to shoulder. A second generation radar design, construction, and test program is being considered as a solution to the simultaneous passenger entry challenge.

Testing of the video image processing technique on MARTA demonstrated that the simplest approach to counting boarding and exiting passengers is to equip each of the six rail car doors with a dedicated downward pointing video camera. Analysis of the video data collected during MARTA testing determined that low cost frame masking techniques can be used to isolate specific areas in a scene for single passenger presence and direction of travel. These data also revealed that when two or more passengers enter the wide stream rail car door together in "lock step" or cross simultaneously through the camera's field of view, an image pre-processing routine must first be applied to locate the boundary between passengers. Once the boundary region between passengers is determined and the passenger images are separated in pixel space, the demonstrated simpler image processing techniques can be applied to count passengers and determine their direction of travel.

There are three image processor passenger counter configurations being evaluated for further development during the Cyclops commercialization phase: (1) a combination camera/image processor built into the camera housing to extract passenger counts in real time; (2) a single processor unit installed on each rail car with the capability of processing the images from six cameras simultaneously, and capable of producing passenger counts in real time; or (3) one recording system on each car that is capable of storing imagery from all six cameras for "off car" processing by a central processing unit located at a central location.

It is planned that the final Cyclops system design will be developed by Greneker and Associates, Inc. in

collaboration with a commercial partner who has equipment design and operating experience in the mass transit industry. A transit authority must be identified to receive the first Cyclops wide stream door passenger counter and a decision to produce real time or historical data must be made by the authority before a system design is finalized.

A plan showing the mounting position of the Cyclops elements (cameras, wiring, processors and recorders) on the rail car will first be proposed to the transit authority by Greneker and Associates, Inc. and the commercial partner. The element positioning plan would be approved or modified by the host transit authority. Power supply availability, passenger safety, and operational needs would also be factors that determine final system design. Following installation, the new design will require testing. A single video data collection system, similar to the Cyclops system would be installed on one rail car. Video scene data would be collected under daylight and nighttime operating conditions. The data collected on the host transit authority's rail car would be analyzed. During the analysis process, the degree of variability in the scene would be determined. After the hardware system design is tested aboard the host transit authorities' rail vehicle, the image processing algorithms that extract ridership data from the video image would be finalized using the video scene analysis data from the video collected during testing.

If it should be determined that the data would be recorded on the rail car and analyzed at a central facility operated by the transit authority, the prototype developmental path would be only slightly different. The commercial partners, working with the host transit authority, would develop a design for a six camera video recording system. The recording system would be constructed and installed on a rail car. The recorded data would be analyzed to determine the variability in scene data. A processor would be developed for the transit agency, central data reduction facility use and the image processing algorithms that would be used to extract ridership statistics would be developed and tested in the central processor system. There are other approaches that final Cyclops system development could take during the commercialization process.

## **IDEA PRODUCT**

Two experimental sensors for counting passengers entering and exiting wide stream door transit vehicles and trains were constructed and tested aboard a Metropolitan Atlanta Rapid Transit Authority (MARTA) rail car. These two sensors were incorporated in an experimental system called the Cyclops passenger counting system. A K-band radar sensor with a 6-foot long antenna and a video image capture system were incorporated in the system. The challenge being pursued is the development of a passenger counter for wide stream door vehicles that

will, without additional sensors, detect vehicle doors opening and closing and count of the number of passengers entering and exiting at a given stop. A secondary goal of the project was to investigate the system's capability to determine the origin and destination of individual passengers. This information can be used to increase the efficiency of a rail operation. The concept of determining the origin and destination of an individual rider was demonstrated in the laboratory but has not yet been tested on a rail car that is in passenger revenue service.

## CONCEPT AND INNOVATION

The Transit IDEA-20 project was conducted as a Product Application investigation as a follow-on project to Transit IDEA-5, a previous IDEA investigation conducted by Greneker and Associates, Inc. during the period November 1, 1995 through October 31, 1996. The goals of Transit-5 were the same as the current goals of Transit IDEA-20 but used a technique other than radar and video imaging to count passengers. A pressure sensitive floor mat with many small sensor points was used to obtain an outline of the passenger's shoe, the direction of travel of the shoe, and the weight of the passenger. Algorithms were developed to allow the floor mat data to be used to identify passengers by shoe size, weight, and stride characteristics. The data were also used to count passengers boarding and exiting.

The mat-based system was tested during revenue service on a Cobb County Transit Authority bus. This project demonstrated that the pressure sensitive mat could provide the data needed for both passenger counting and origin and destination studies. However, the supplier of

the pressure sensitive mat and the associated computer interface hardware could not meet price projections that would make the mat a viable commercial product. In addition, the lifetime of the mat was short when used for passenger counting. Rocks stuck to the sole of shoes, shoe nails, spike heels and other sharp objects could damage the small sensors built into the mat. A final report on the use of the pressure mat passenger counter and classifier system was prepared and was subsequently published by the Transportation Research Board, IDEA Program.

During the testing of the pressure sensitive mat, a radar was developed for mounting over the door of the bus to determine when the door opened. An analysis of the radar signatures produced by passengers boarding and exiting provided proof that the radar alone could determine the point in time when the bus door opened and closed, as well as the direction of travel of the boarding and exiting passengers. The radar was also capable of providing passenger counts. This serendipitous discovery was the inspiration for the Transit-20 investigations using radar as a sensor. The ability to use a single video camera to capture a scene of all passengers passing through a wide stream door provided the incentive to use video imaging for counting passengers entering and exiting through a wide stream transit door.

A survey of passenger counter products indicated that the capability to count passengers entering and exiting a transit vehicle equipped with a wide stream door is still not a commercial reality. This technical challenge was also considered when the goals for Transit-20 were established, as shown in Table 1.

**TABLE 1 Goals of Transit-20**

• Develop a low cost radar based passenger counter for regular and wide stream doors
• Optimize the radar to detect doors opening and closing
• Develop algorithms to determine if passenger is entering or exiting
• Design two radar antennas, one for wide stream doors and the other for regular doors
• Develop a video vision-based passenger counter for wide stream and regular doors
• Conduct laboratory investigations to determine a passenger's origin and destination
• Test both systems in the laboratory and demonstrate operability
• Develop a plan to test system on a MARTA rail vehicle
• Test system on a MARTA rail vehicle according to the plan
• Analyze the data that the MARTA tests produce
• Develop approach to achieve passenger counting
• Report findings

## IDEA PROJECT

A homodyne radar system was designed to operate at approximately 24 GHz. The amplifier circuits were designed to pass the Doppler frequencies produced when the radar is mounted over the door and passengers are moving underneath the antenna. A slotted waveguide antenna design was developed using consultants as sub-contractors. A contract machine shop was used to develop one 6-foot long antenna for use during wide stream door testing and a 2-foot long antenna for use during testing the radar on transit vehicles with regular width doors.

A color video camera with over 400-line resolution capability was specified for use with the system after two color cameras with 400-line resolution were tested. The 400-line camera provided high resolution and the color capability provided another dimension for discrimination of passenger features when the image data were used for passenger recognition.

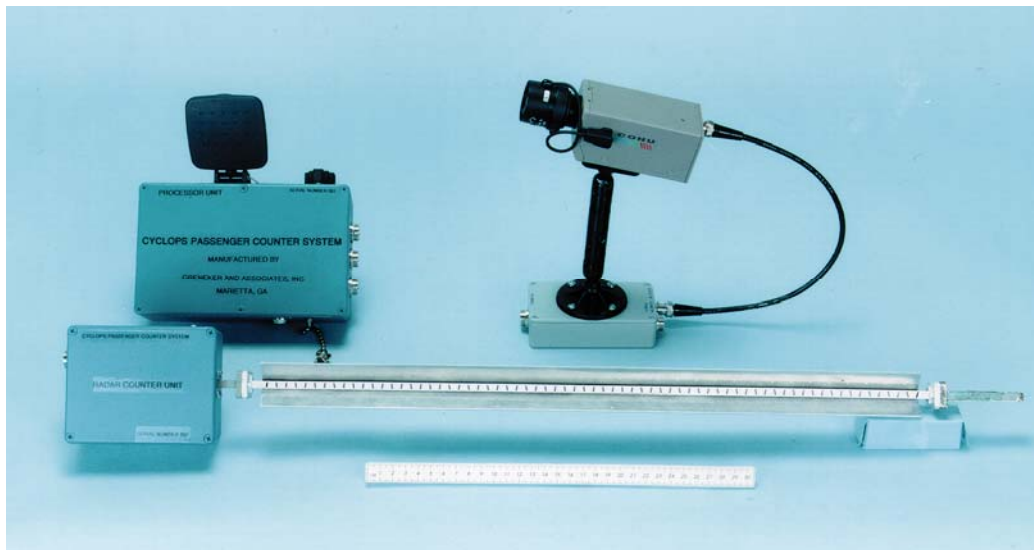
A control unit was built for the system. The control unit contained a voltage regulator for the radar transmitter and a 2.4 GHz wireless link. The wireless link

transmitted both video and radar produced data over a distance of several hundred feet so that the data collection system could be located anywhere on the rail car. The portability provided by the wireless link eliminated the necessity to run wires in the rail car.

A data recording system was developed using a video recorder with two digital recording channels. This system was powered by a 12-volt battery pack so that it was portable and could be located anywhere on the rail car during the data collection phase. The wireless link or wiring between the control unit and the data recording system could link it to the control unit.

Figure 1 shows the completed Cyclops system without interconnecting cables. The radar and the 2-foot long antenna are shown in front of the control unit (upper left) and the camera (upper right). The recording system is not shown.

After assembly, the Cyclops system was tested for operability in the laboratory. The radar data were recorded and analyzed. The Joint Time Frequency analysis tool developed by National Instruments, Inc. was used as an analysis tool for the radar data.



**FIGURE 1 Cyclops system showing radar, 2-foot antenna, control unit, and camera system.**

The video system was tested in the laboratory more extensively than the radar system because the video analysis software required development before test results could be analyzed. In addition, one of the Transit-20 goals was to conduct laboratory investigations to investigate if a passenger's origin and destination can be determined using video data. This early phase of the investigation was sub-contracted to Dr. Otto Rausch who was assisted by Mr. Danny Diaz. The first approach to determine the originating and destination points of each

passenger's travel was to determine unique features that appeared in the video scene generated by each passenger when boarding. The results of these laboratory tests to determine if a passenger's origin and destination could be determined are presented in a later section.

The Transit IDEA-20 research project was presented to MARTA personnel by Gene Greneker during a meeting held at MARTA in March, 1999. The TRB senior program officer, Mr. Harvey Berlin, was present at that meeting, as was Mr. Tom Kowalski, Vice President of



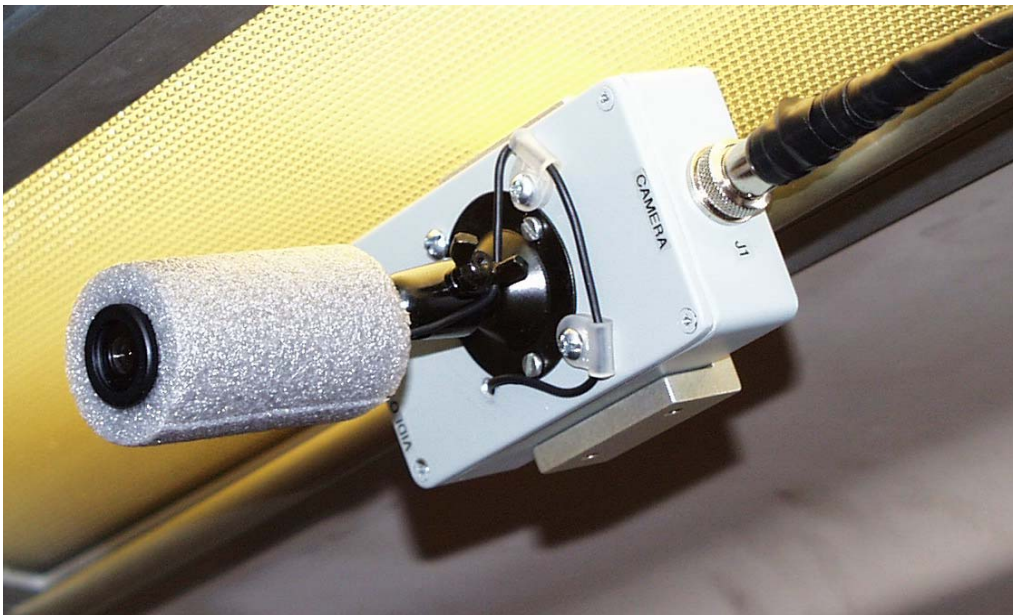
Urban Transportation Associates and member of Greneker and Associates, Inc.'s Expert Review Panel. MARTA personnel were briefed on the test program. It was determined that MARTA would assist Greneker and Associates, Inc. to conduct the testing.

MARTA requested that Greneker and Associates, Inc. generate a test plan outlining how the Cyclops would be tested on a MARTA rail car. Mr. Dan Estep of MARTA assumed the responsibility for arranging Cyclops testing by MARTA. MARTA approved the test plan in August, 1999; however, MARTA was involved in system testing for Y-2K problems and determined that Cyclops testing could not begin until the end of September. Sporting events being held during October and November in Atlanta caused rail cars to be very heavily loaded with passengers during the prime test times and testing was postponed by MARTA until the first weekend in December. During the time that Greneker and Associates, Inc. was awaiting a test date, system-mounting brackets were designed and developed for the controller, radar and video camera. Cables that connected the radar and video camera to the controller were reworked from the lengths used during laboratory

testing to the lengths required to connect the system when it was installed on the rail car.

The door on the rail car was measured. The door opening was 78.5 inches high and 50 inches wide. The ceiling of the rail car was 82 inches above the floor. Handrails ran vertically from floor to ceiling on each side of the door. The top of the handrails came to within 13 inches of the side of the rail car at the top of the handrail. The mounting brackets were designed to clamp to the top of the handrails. A scissors extension was used to allow adjustment of the radar and video camera's distance from the ceiling and wall of the rail car.

Measurements determined that the high resolution television camera, purchased for laboratory testing, extended down below the door of the rail car. This condition proved to be dangerous because passengers could strike the camera with their heads. The problem was solved by the purchase of a miniature color camera, which, after a change in mounting hardware, eliminated the possibility that a passenger could strike the camera with his or her head. Figure 2 shows the camera mounted over the right door of the rail car.



**FIGURE 2 Miniature video camera mounted over the right door of the rail vehicle.**

Referring to Figure 2, the miniature camera (black circle) extends from the grey foam pad. The camera is mounted on a swivel mount so that it can be pointed at the opposite door or pointed straight down to observe passengers entering or exiting the rail vehicle from a vertical view. The only constant illumination was the fluorescent light tubes over the camera. The nature of the fluorescent lighting was such that the color temperature was not ideal, as can be seen in the data that appear in a later section. There were times when the train was above

ground and outside of the covered station area and the car was brightly illuminated by sunlight. The color balance improved greatly when sunlight illuminated the rail car through the windows.

Figure 3 shows the radar and antenna mounted over the left door of the rail car. The scissors mount allowed the antenna to be positioned over the door to allow safe passenger entry and exit. Referring to Figure 3, the radar

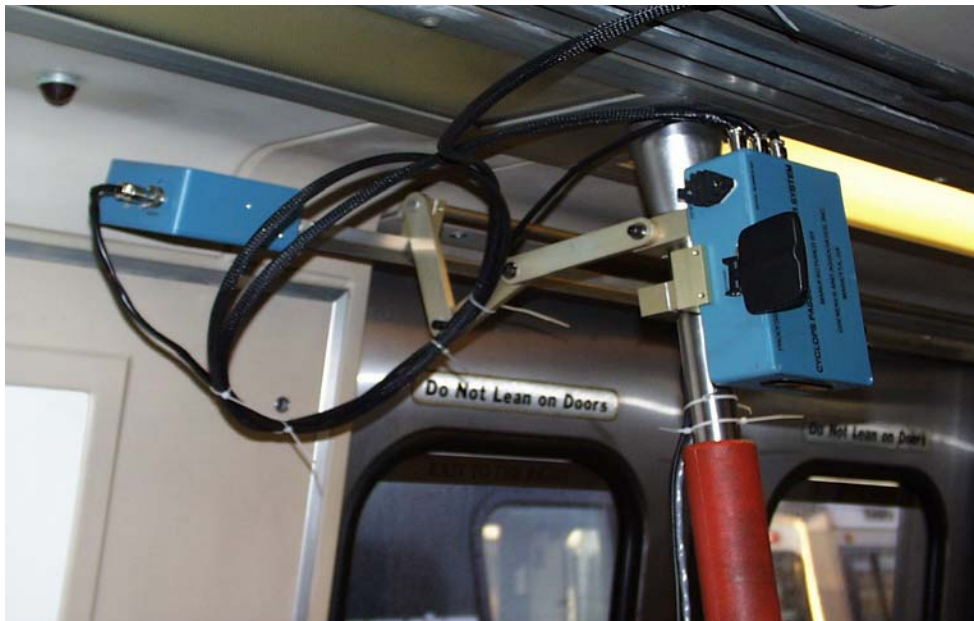


is housed in the blue box in the upper left of the photograph. The antenna extends 6 feet over the door. The control unit is mounted on the handrail at the base of the radar clamp position.

Figure 4 shows the view of the control unit in close up perspective. The radar and camera both plug into the control unit. The antenna of the video/radar wireless data link is shown on the side of the control unit. The wireless data link was included so that the Principal Investigator

could move around in the car if passenger crowding toward the front seats became a problem.

Figure 5 shows the radar antenna extending over the rail car door from a different perspective than shown in Figure 3. Referring to Figure 5, the scissors clamp is positioned so that the slotted waveguide antenna is positioned at the top of the rail car door. Operation of the radar in this position ensures that a tall passenger will not strike the antenna.



**FIGURE 3** The radar, antenna, and control unit mounted at top of the vertical handrails.



**FIGURE 4** Control unit mounted on hand rail. The wireless link antenna is black object.



**FIGURE 5 Radar slotted waveguide antenna extends across the door at door top level.**

## **STATION ORIGIN AND DESTINATION DETERMINATION**

A laboratory experiment was conducted to determine if the Cyclops system could be used to develop passenger origin and destination data, one requirement of the Transit-20 contract.

The collection of rail system passenger origin and destination data currently requires that entry and exit turnstiles be located at each rail station. Each passenger must enter their ticket each time that they pass into and out of the system. Tickets must be coded for electronic identification, a time stamp must be applied when each entry or exit event occurs and data from both entry and exit turnstiles must be collected electronically on a daily basis. The entry events must be correlated to exit events as a final step. Correlated turnstile information allows a rail transit authority to determine the time that an individual passenger enters the system, the station of entry, and the station and time of the passenger's exit. Turnstile data do not provide information regarding the identification of the train or actual rail car that a passenger boarded or the train's occupancy distribution.

Greneker and Associates, Inc. developed two approaches to provide the origin and destination of each passenger boarding a rail car. Both approaches were evaluated in the laboratory environment using variants of the Cyclops passenger counter that is described in this report. The first variant approach considered was passenger feature recognition. The features of each boarding passenger would be extracted from the video data and stored in digital memory along with the stop

where the passenger boarded. Each time a passenger exited, that passenger's features would be captured and compared to the previously recorded feature based record in the data base. When a feature match was made, the origin and destination of the matched passenger would be recorded. No images of the passengers would be recorded permanently ensuring that there are no privacy issues associated with the system.

Experiments in feature extraction were conducted in the laboratory. The results proved to be sensitive to variations in illumination levels and color balance. The illumination and color balance on a rail car can vary over a wide range. When the train is in underground stations, the illumination source is primarily the fluorescent lighting in the car. When the rail car is above ground, the primary illumination is from sunlight in the daytime and interior lighting at night. The challenge of illumination and color balance variability can be solved, but other problems associated with securing a useful passenger image must be solved for the feature extraction technique to be successful.

One primary challenge that was not solved was how to locate a camera to observe the same features of a passenger when boarding and when exiting. For example, a camera located over the opposite door through which a passenger boards provides several frames of the passenger's face. These frames can be used to extract a feature set for matching. However, when the passenger exits, the same camera will capture the back of the passenger's head, a perspective that does not capture the same features that were captured during the boarding event. As a result, the passenger's features captured

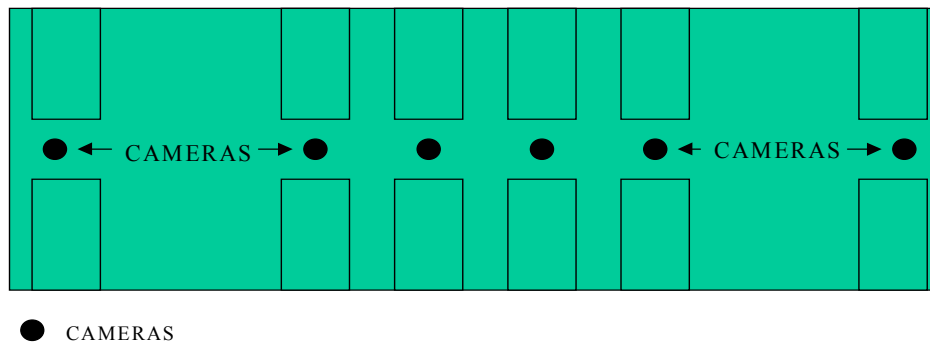
during the boarding event will not be matched and the correlation process will fail.

There is another problem associated with the feature extraction approach to determining a passenger's origin and destination. The video camera can only be mounted in a limited number of locations and positions on a rail car where there is no threat of vandalism. The threat of vandalism requires that an attendant ride with the system or that the camera be hidden or housed in an armored case. Passenger safety requirements dictate that the camera be located in a position where the passenger cannot accidentally strike the camera causing injury to their head or upper extremities. A second approach to passenger origin and destination studies was investigated that could be made to work under all conditions. This method was successfully tested in the laboratory.

Four assumptions must be met for the second method to provide origin and destination data: (1) there must be a seat for each passenger in order for the passenger to be registered in the system's data base; (2) each passenger must take a seat after boarding; (3) the passenger must remain in their seat until shortly before reaching the exit

station; and (4) there must be room for multiple miniature cameras to be installed between the top of the rail car and the false ceiling of the rail car. There are conditions that may preclude the four assumptions from being met at all times of rail transit operation. For example, during rush hour, many passengers may be forced to stand and these passengers will not have a seat. This challenge may not be a problem assuming that the standing passengers remain in their starting positions until they are ready to exit. A second consideration is the ramifications of installing a number of small cameras in the space between the rail car roof and the false ceiling.

Figure 6 shows how the multiple cameras might be located between the top of the rail car roof and the false ceiling of the rail car. Referring to Figure 6 a camera would be located in a position so that the two seats each side of the camera could be continuously observed. A single camera would provide surveillance of four seats in the standard rail car seating configuration where two seats are located on each side of the aisle. Any passenger standing in the aisle could also be observed by the closest camera.



**FIGURE 6 View from top of rail car showing video camera locations.**

Greneker and Associates, Inc. conducted a laboratory experiment to demonstrate the overhead camera concept as part of the statement of work of the Transit-20 contract. A camera was placed over three seats in the laboratory. The scene generated by the overhead camera is shown in Figure 7.

Referring to Figure 7 (A), the first passenger enters the simulated rail car. The tracking number 1 is automatically assigned to the first passenger by the image processing algorithm. In Figure 7 (B), passenger 1 takes his seat as passenger 2 is entering to take his seat, at which time tracking number 2 is assigned. In Figure 7 (C) passengers one and two are seated and their assigned tracking numbers are shown. The software controlled counter data in the upper left of the frame of 7 (D) shows that two passengers have entered in their order of appearance (1 in and 2 in).

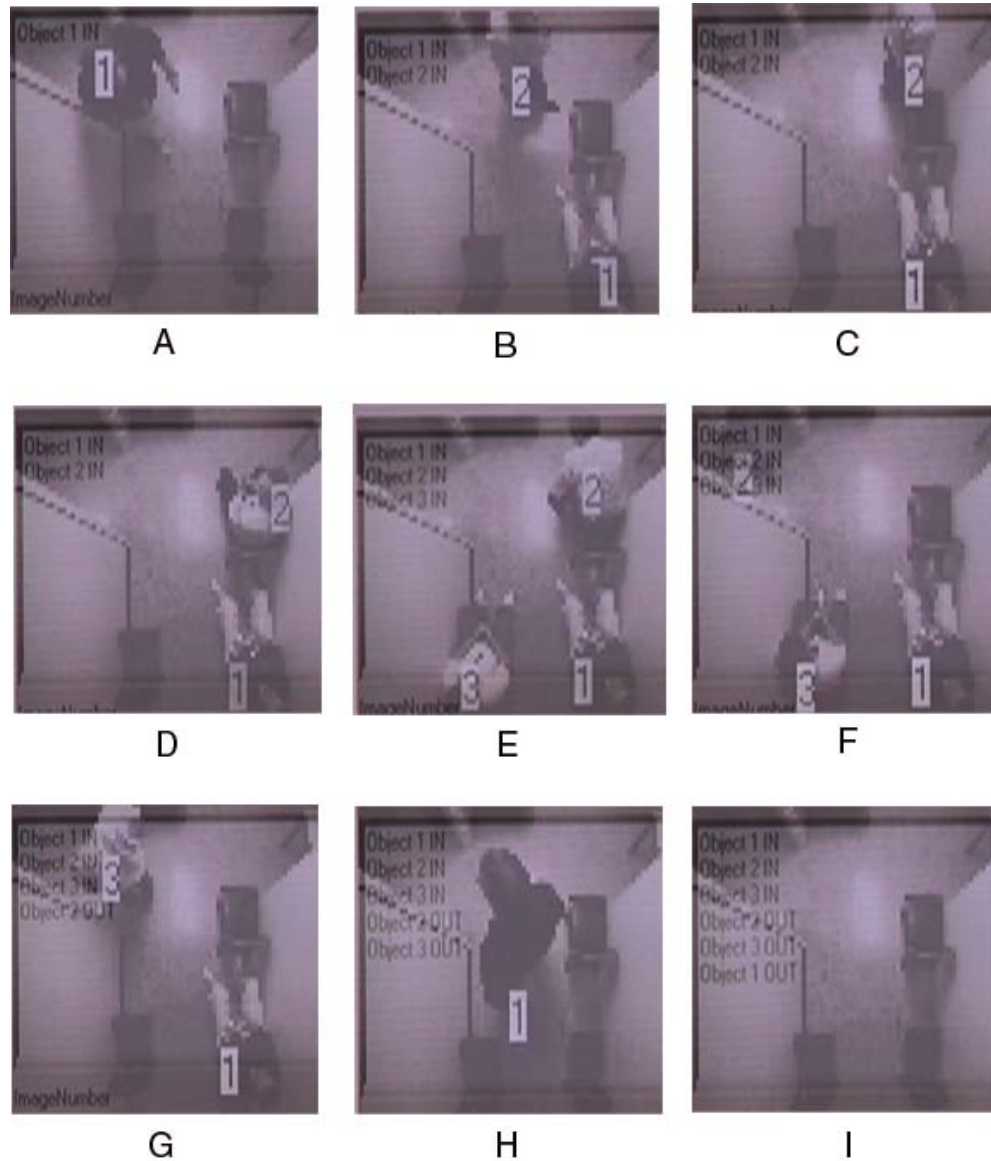
Figure 7 (E) shows passenger 3 seated and passenger 2 is starting to leave. Figure 7 (F) shows that passenger 2 is almost out of the door while passengers 1 and 3 remain seated. Figure 7 (G) shows passenger 3 approaching the door while passenger 1 remains seated. The passenger counter in the upper left of the frame shows that passengers 1, 2, and 3 are in and passenger 2 is out. Figure 7 (H) shows passenger 1 starting to exit. Figure 7 (I) shows that all three seats are empty. The passenger counter shows that passengers 1, 2, and 3 are in and passengers 2, 3, and 1 are out. The counter data demonstrates that the capability of the system to automatically track and recognize the order of passenger entry and the order of passenger exit. In practice, the entry and exit events would be associated with a station name and time stamped.

Implementation of the origin and destination system that was demonstrated in the laboratory would require



that small cameras be mounted between the top of the rail vehicle and the actual ceiling. Small color cameras with wide angle lens are available for \$100 in quantity, thus

economics are not a factor in the implementation of this system.



**FIGURE 7 Laboratory demonstration of one approach for origin and destination studies.**

The scene data could be recorded on the car or processed in real time on the car. If the scene data were recorded for later analysis, the scene from each camera would be multiplexed on to a single video frame. The recorded data would be removed and analyzed at frequent intervals using a central processor. The central processor would extract daily ridership statistics including the origin and destination information, as well as seat occupancy information between stations. As image processing systems become more compact and less costly, on board real time processing of the image data will be cost competitive with the central approach of

image processing. Onboard real time image processing to determine seat occupancy provides a second use for seat occupancy data that are being generated in real time.

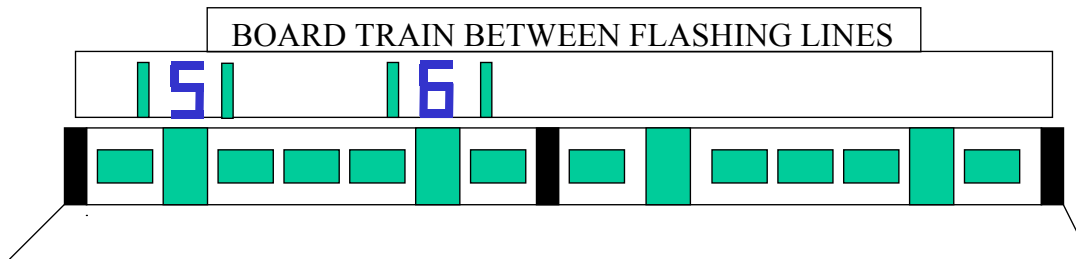
### **INCREASE IN RAIL OPERATION EFFICIENCY**

Many rail system operators do not allow a passenger to move from one car to another car for safety and security reasons. The impact of this practice is that some cars will be crowded with standing room only conditions while other cars on the same train may have empty seats.

Greneker and Associates, Inc. has developed an approach that would allow the overhead variant of the Cyclops passenger counter, shown in Figure 6, to be used to distribute the passenger loading.

The overhead passenger seat occupancy system would determine which seats are occupied and which are not occupied after the train stops at each station. The system could generate an almost real time seat occupancy

estimate for each car on the train. The data would be digitized and transmitted to the next station to allow passengers to cue at locations along the platform where the cars with available seats would load once the train arrived at the next station. Figure 8 shows a concept of how passengers might be advised of where to load on the platform.



**FIGURE 8 Sign at station showing passengers where to board and number of seats.**

Referring to Figure 8, an inexpensive lighted sign informing the passengers to "Board between flashing lines" would be mounted above an electronic display board on the station wall in a position where it could be viewed by all passengers above the arriving train. An electronic display would be located below the inexpensive sign. Flashing (green) vertical bars would be located over the doorway of the car(s) that have empty seats. In the example case the signs advise passengers that 5 seats are available in the front portion of the first car and 6 seats are available in the rear of the first car. There are no seats available in the second car except those seats being vacated by exiting passengers.

Two techniques could be used to ensure that the electronic bars were always positioned correctly. The flashing vertical bars and seat availability numeric indicators could be located along the station wall at a fixed spacing to ensure that one was over each door of a fixed length train. Given this situation, the engineer would be required to stop the train at a specific location at each station. More flexibility could be provided if the indicator system included an entire series of illumination areas along the length of the station display unit that could be activated to form flashing vertical bars and the numeric indicating available seats at any location along the length of the station display. In practice the system would provide multiple flashing vertical bars as well as the numeric data.

In summary, the laboratory experiment using an overhead camera demonstrated that a simple seat occupancy system could be developed as a variant to the basic Cyclops passenger counting system. The system could supply passenger origin and destination data in addition to seat occupancy data. The data could be

processed on the rail car in real time or recorded for delayed processing. When image processing technology has advanced to the point that multiple camera, real time on board image processing is cost effective, the data can be used to cue passengers to empty seats within a given car. The ability to cue passengers regarding available seating within a rail car will allow more efficient rail operation and will provide passengers more comfort during peak revenue time rail operations.

## TESTING THE CYCLOPS ON A MARTA RAIL CAR

The Cyclops system was tested on MARTA on December 3, 1999 during revenue service. The system was mounted on a train that was scheduled for operation from the College Park, Georgia shop. When the Cyclops system was mounted and checked for safety, the train entered revenue service at the Atlanta Hartsfield International Airport station and traveled one complete circuit along the South to North MARTA line, returning to the airport station where it was taken out of service. The train was taken to the College Park shop where the Cyclops equipment was removed from the train.

A hand log was kept by the author (Principal Investigator) during the test trip. The hand log was used to record the number of passengers boarding and exiting the train at each stop. The video camera system that was part of the Cyclops also recorded the same information for each stop. Passenger boarding and exiting occurred on either the right or left side of the train, depending on station configuration. The radar was over the left door and the video camera was over the right door. Both doors were the first doors on the first car on the train when going from South to North. The system was on the last

doors of the last car in the train when the train direction reversed from North to South. There were four other doors on the rail car through which passengers could board or exit.

Referring to Table II, there were a total of 20 boarding events and 30 exiting events that were recorded through the two doors that were equipped with the Cyclops system during the train's South to North run. There were a total of 14 boarding events and 12 exit events that were recorded through the two doors that were equipped with the Cyclops system during the train's North to South run. Data were recorded continuously from the time the train left the Hartsfield International Airport until it returned. Thus, there are considerable data for testing the system's immunity to false door opening indications and false counts caused by passengers walking near the doors during rail car movement. Illumination levels changed over a wide range during testing which will also allow robust testing of the door opening and passenger count algorithms. While a much larger data base of boarding and exiting events will be required to prove that the Cyclops can operate under all conditions, the data base collected on MARTA on December 3, 1999 is sufficient for initial signal processing and image analysis algorithm development.

## DATA ANALYSIS

Two data sets were analyzed: (1) radar and (2) video imagery. The radar had two output channels. One channel was the inphase (I) channel and the other was the quadrature (Q) channel. The Q channel was 90 degrees out of phase with the I channel. When a complex Fast Fourier Transform (FFT) is used to compute the time varying Doppler frequencies generated by passenger entry, the direction of travel of the passenger can be determined in relation to the radar. Imagery showing passenger activity was recorded on the video track of the recorder as the I and Q data produced by the radar were recorded on the two audio tracks of the video tape recorder. As a result, the scene of passengers boarding and exiting were available to the analyst when the radar data were being analyzed.

Figure 9 shows the scene data that were recorded when a passenger was entering the rail car door under the radar. The image data allowed the analyst to determine when the passenger was approaching the antenna, when the passenger walked under the antenna, and when the passenger began to move away from the antenna. Joint Time Frequency Analysis (JTFA) was used to check the quality of the radar data.

Figure 10 shows the JTFA of the I channel radar data produced as the passenger shown in Figure 9 boarded the rail car.

**TABLE II. Total Passenger Boarding and Exit Events Recorded by Cyclops**

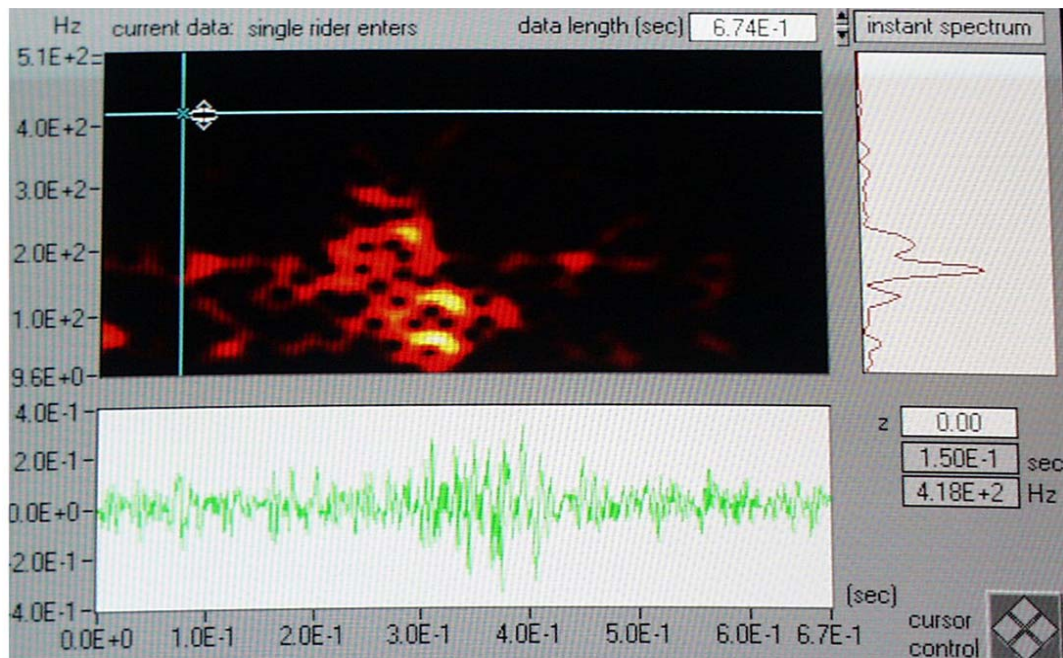
STATION NAME	SOUTH TO NORTH		NORTH TO SOUTH	
	Boarding Events	Exiting Events	Boarding Events	Exiting Events
Airport	1	1	0	1
College Park	1	0	1	1
East Point	5	0	1	0
Lakewood	0	3	1	1
Oakland City	0	0	2	2
West End	2	0	0	0
Garnett	2	0	1	1
Five Points	4	4	0	2
Peachtree Center	0	1	2	0
Civic Center	0	0	0	0
North Avenue	0	3	1	1
Midtown	0	0	0	0
Arts Center	0	4	2	2
Lindberg	5	4	1	1
Lenox	0	2	1	1
Brookhaven	0	0	0	0
Chamblee	0	8	1	0
Doraville	0	3	0	0
<b>TOTALS</b>	<b>20</b>	<b>31</b>	<b>14</b>	<b>12</b>



**FIGURE 9 Image of passenger boarding and passing under radar antenna.**

The green plot at the bottom of Figure 10 is the time domain signal from the I channel. Time increases from the left to the right in the time domain plot and time (in

units of seconds) is shown across the bottom of the time domain plot. The scale along the 'Y' axis (left margin) is relative amplitude of the time domain signal.



**FIGURE 10 JTFA plot of radar data of passenger boarding.**

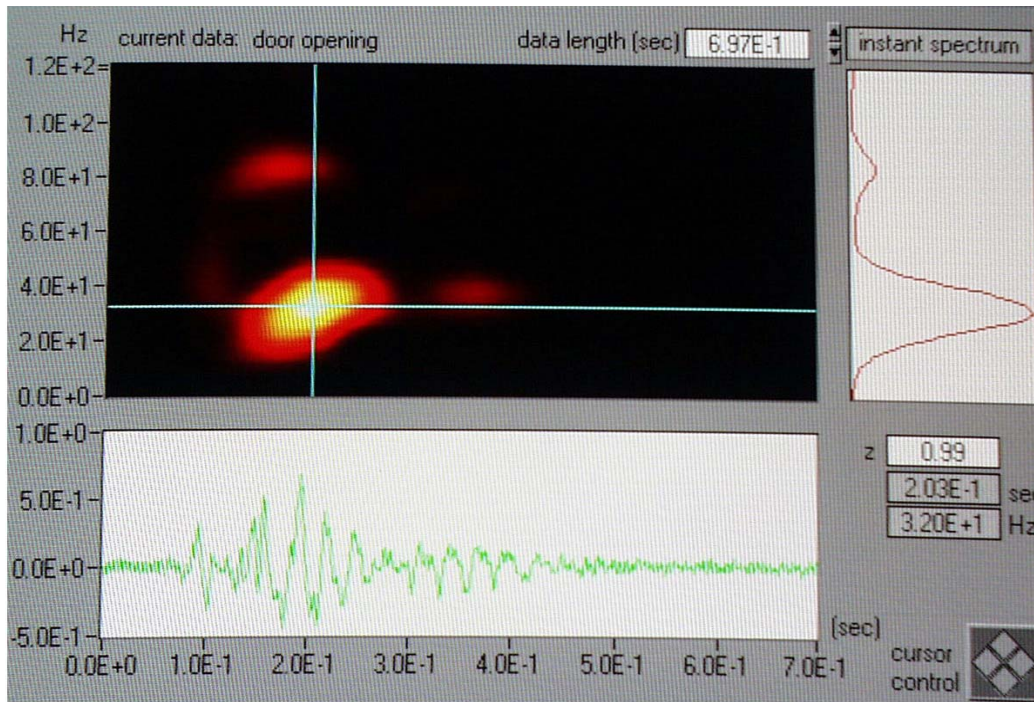


A false color plot of the frequencies contained in the time domain plot is shown above the time domain plot. The false color coding indicates the relative amplitude of the frequency components contained in the time domain signal. Black represents the lowest amplitude of the frequency components, while yellow represents the highest amplitude of the frequency components. Red represents an intermediate signal level between the two extremes. The position of a false color feature along the 'Y' axis of the frequency plot (left margin) indicates the frequency contained in the time domain signal at any point in time. The extent of the false color feature in the vertical direction indicates the width of the frequency spectrum. The point where the feature occurs in frequency space is also the same point where the same feature occurs in the time domain signal below the false color frequency plot.

The JTFA plot of the passenger boarding event starts at the left of the plot frames of Figure 10. The amplitude of the signal increases as the passenger approaches the door and moves into the main beam of the antenna where the maximum transmitter power is concentrated. The passenger is directly under the antenna at a point four seconds from the beginning of the data. This is the point of maximum frequency and maximum relative signal amplitude.

The false frequency plot in Figure 10 shows a very complex frequency spectrum. There are small isolated false color features. The first appears at a frequency of approximately 8 Hz and within the first 100 milliseconds of the data. The next appears at a frequency of approximately 19 Hz after an elapsed time of 1 second. The third isolated feature appears at a frequency of approximately 5 Hz after an elapsed time of approximately 1.25 seconds. These isolated features are thought to be generated by arm or leg motion of the boarding passenger.

The passenger's body and head moving under the radar antenna generates a broad spectrum of frequencies from approximately 30 Hz down to almost 1 Hz. These high amplitude frequency components occur at a point approximately 3 seconds into the data set and each of the 3 maximum features is colored coded yellow. These 3 maximum amplitude points occur at 25 Hz, 13 Hz and 5 Hz. The radar can also detect the rail car door opening and closing. Figure 11 shows the JTFA of the rail car door opening. The largest amplitude frequency component (yellow) occurs after approximately 2.03 seconds have elapsed and the frequency is 32 Hz. The 'X' and 'Y' cursors have been centered on the maximum feature in the false color image. One instantaneous frequency spectrum is computed for the point where the cursors intersect. This instantaneous spectrum is shown in the box on the right side of Figure 11.



**FIGURE 11 Joint Time Frequency plot of radar detected door opening sequence.**

## CONVERSION OF RADAR DATA TO PASSENGER COUNTS

JTFA analysis of numerous passenger boarding and exiting events showed each to be very similar to the event shown in Figure 10 with regard to the complex spectrum that is produced. Analysis of numerous rail car door opening and closing events demonstrated that all door opening and closing events were very similar in appearance when analyzed using the JTFA. There is enough difference in the radar signatures of the door opening and closing events and the passenger boarding/exiting events that the two events would not be confused by the final processor algorithm that is being evaluated.

The analysis of the radar data using the JTFA to quickly visualize the frequency and amplitude features that are generated when a passenger boards or exits or the rail car door opens is very useful to the analyst. The analyst can use the feature set suggested by the JTFA to develop a radar passenger counter algorithm. The feature set that is used must be unique to the desired event. For example, the radar often detected passengers moving parallel to the antenna as they were cueing to exit the rail car. This activity began before the train reached the station and this activity was detected by the radar. However, the Doppler frequencies generated by the passengers moving near the antenna did not generate the same frequencies that were generated when a passenger moved under the antenna. The amplitude of the signal was less than when a passenger moved under the antenna during entering or exiting the rail car.

Passenger movement inside of the rail car can generate false counts. The use of two sequential algorithms can solve this problem. The first algorithm tests for the door opening event. The door opening algorithm establishes a loop that first computes the Fast Fourier Transform (FFT) for every 512 points of data digitized by the analog to digital converter (ADC). The output real array is tested to determine if there is a strong clustering of data around the 40 Hz spectral line, with an amplitude that exceeds an established threshold. This simple door opening detection method works because the door opens at a very repeatable controlled speed and the spectrum that the opening door produces is very repeatable in both amplitude, frequency and time history.

It is only after the door opening event has been detected that the passenger counter algorithm is activated. Once activated, the passenger counter algorithm continuously computes the FFT. A second routine searches the array containing the transformed data to determine if the feature set that identifies a boarding or exiting passenger is present. Once the feature set is detected in the transformed data, the direction of passenger movement is determined. The direction of

movement determines if the detection is a boarding or exiting event.

The passenger counter algorithm can be inhibited in two ways. The closing door can be detected and the passenger counting algorithm is inhibited until the door re-opens or a timer can be initiated that will inhibit the passenger counter algorithm after a pre-determined amount of time has elapsed from the point where the door opening event was first detected.

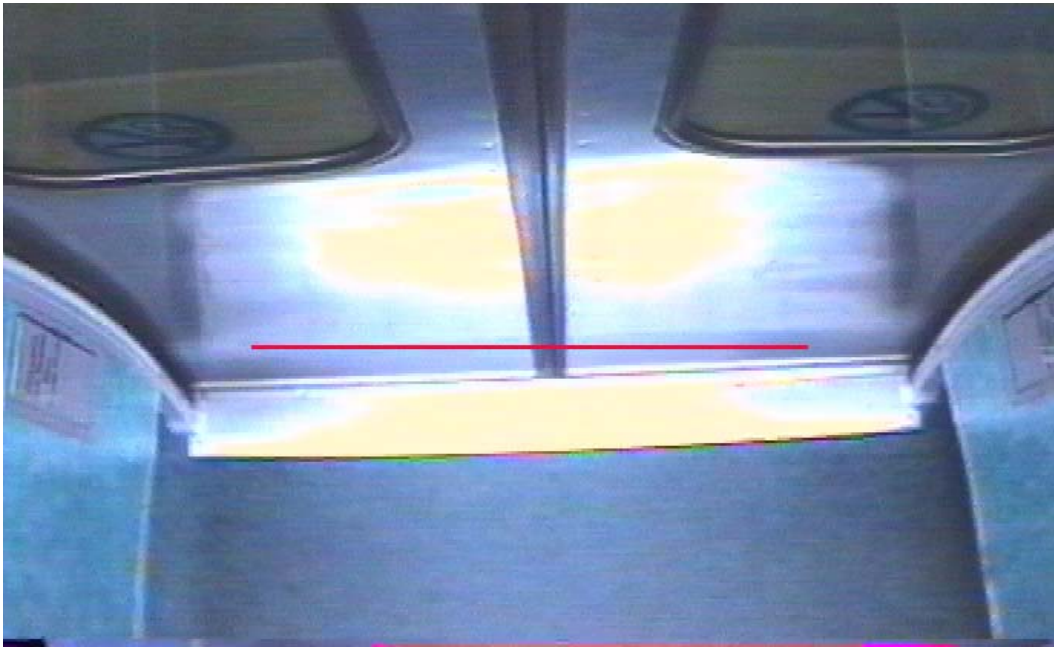
The use of these simple approaches for passenger counting works well when the passengers have several feet between themselves and the next passenger when boarding or exiting. More challenging is the case where one group of passengers is boarding while another group of passengers is exiting (see the later section on technical challenges). Getting an accurate count for this situation is still a signal processing challenge that Greneker and Associates, Inc. is attempting to solve.

## IMAGE PROCESSING FOR PASSENGER COUNTING

Two video camera mounting techniques were used to determine which was best for passenger counting using image processing. The camera was first mounted over the train's right door and was adjusted to capture the scene of passengers entering the door on the left side of the train. Problems were encountered when trying to process the cross door scene and extract meaningful data. Data were next collected from the camera over the right rail car door with the camera pointing down at the floor. The image produced by the downward pointing camera produced more information and less false alarm sources than the cross door image.

All image data were first analyzed using National Instrument's IMAQ Vision Builder to analyze scene data and experiment to determine how best to extract passenger counts and door opening events. Vision Builder allows the user to extract data from a scene to determine the illumination levels and colors that are present, and test various standard image processing techniques to identify the best to use to extract the desired information from a scene.

The first image processing task was the development of a door opening detector. An analysis routine that determined the intensity of each pixel in a single horizontal scan line was developed. Figure 12 shows the placement of the single video scan line sample area on the door. This area was chosen only after many frames of video were analyzed. First, the illumination level on the door was analyzed when the rail car was in sunlight and also when shielded from sunlight by tunnels. It was found that the maximum illumination in the scene was provided by the overhead fluorescent light for both cases and the minimum illumination always occurred at the rubber seals on the leading edge of each door.



**FIGURE 12 Single video scan line sample area imposed on bottom of rail car door.**

Figure 13 shows the results of the single scan line analysis. The image captured by the video camera is presented in the right column. An intensity/pixel position plot is shown in the left column. The relative intensity of one scan line taken from an area indicated by the red line in Figure 13 is plotted along the 'Y' axis. Each pixel in the image can have a value between 0 and 255 with a level of 255 representing the brightest part of the scene.

Referring to Figure 13, time increases from the top to the bottom of the figure. The reflective surface of the door produces a relative illumination value of approximately 200 while the black rubber seals at the edge of the door produce a relative value of approximately 110. The illumination level difference of approximately 90 units between the reflective area of the door and the rubber seals can be tracked along the sample line as the door opens wider with time. As the door opens, the dark areas created by the door seals move away from the center of the frame changing the illumination level of the pixels from bright to dark (200 to 110 units).

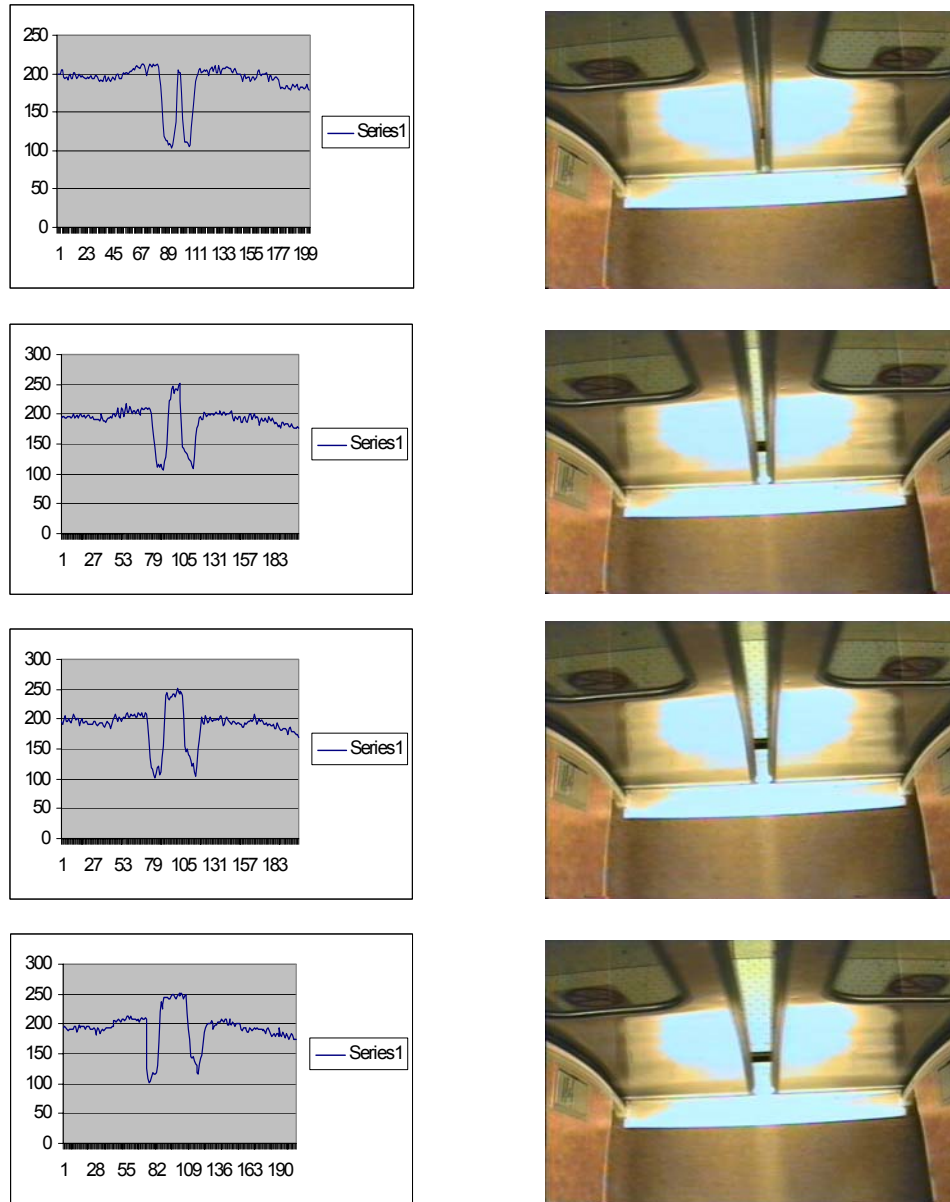
The results of the analysis demonstrated that a simple approach could be used to detect not only the opening of the door but also the direction of movement of the door using simple logic. Instead of sampling all pixels in the sample line, eight discrete sample points were established within the line. One single pixel sample point was placed on each of the locations of the black door seals when the door was closed. Three single pixel sample points were spaced at approximately 6 inches apart along the sample line starting at a point 6 inches behind the first sample

point positioned on the door seals. The illumination levels at each sample point were monitored. As each door seal moved through a sample point, the illumination value would drop from a value of 200 to a value of 110 and then return to the value of 200. A threshold detector and simple logic allowed the direction of door opening to be monitored. This approach detected door opening in all of the example cases.

## **VIDEO SYSTEM PASSENGER COUNTING**

Analysis was performed using the horizontal pointing camera that was video recording the opposite door on the left side of the rail car. Mounting the horizontal aligned camera to record the opposite door scene presented technical challenges that using a vertical pointing camera did not present. This conclusion was reached only after the two approaches to video camera mounting were analyzed using data collected during testing of the Cyclops on the MARTA train.

After the analysis was performed, a decision was made to develop the counting algorithms using the downward pointing camera over the right door of the rail car. Figure 14 shows a passenger boarding under the vertical camera. Referring to Figure 14, a passenger boards under the downward pointing camera. The red and blue line are the two areas where the scene illumination intensity are monitored. Just as with the door opening detector, the illumination levels of discrete pixels within the sample lines were monitored



**FIGURE 13** Illumination value on left and corresponding scene on right side of page.

As the passenger boarded, the pixel sample points in the red scan line changed illumination value as the passenger's body passed through the sample area. The same illumination pattern occurred several frames later in pixel monitor areas positioned along the blue line. The direction of travel was determined by the order in which the sample lines were encountered. For example, a red then blue sequence indicated that the passenger was boarding. A blue first and then red sequence indicated that the passenger was exiting. This approach worked well when single passengers were boarding or exiting.

## TECHNICAL CHALLENGES

Greneker and Associates, Inc. has demonstrated how door opening detection and passenger counting can be achieved, using both radar and image processing when passenger traffic is light. There are technical challenges that must be solved during the commercialization of the Cyclops wide stream door passenger counter. For example, when passengers are spaced apart as they move under the radar antenna, the simple approach developed for passenger counting using radar is adequate. However, when there are multiple passengers simultaneously entering and exiting, as shown in Figure 15, the simple radar processing approach fails to provide an accurate





**FIGURE 14** Overhead downward pointing camera view of boarding passenger.



**FIGURE 15** Multiple passengers enter and exit simultaneously under radar antenna.

count. Greneker and Associates, Inc. is developing a more robust signal processing approach to attempt to

solve the challenge presented to the processor when multiple passengers are entering and exiting.

The development of a very robust video image processing algorithm capable of extracting passenger counts when passengers board simultaneously or exit simultaneously is in the developmental stages and will be completed during the commercialization phase of the project. Figure 16 shows an example of two passengers boarding together. The passenger on the left is wearing a white sweat shirt that blends with the background and the passenger on the right is wearing a black jacket and black

pants. The high contrast between passengers causes the camera's auto-iris control to set the camera's sensitivity to a non-optimum value. However, the high contrast between passengers also allows the two passengers to be separated through image processing. Greneker and Associates, Inc. is investigating the most dynamic approach to isolate multiple individuals when they enter the wide stream door shoulder to shoulder.



**FIGURE 16 Two passengers enter the wide stream door almost together.**

Exploiting scenes by using different intensity thresholds to separate one passenger from the other during simultaneous boarding or exiting events was used and limitations were discovered.

Referring to Figure 17, the passenger is wearing a white fur hat. The establishment of several thresholds to separate passengers entering or exiting simultaneously may result in this passenger being counted twice if there are not other methods used to ensure that the passenger identification algorithm keeps both the high and low contrast parts of the passenger's image together. Greneker and Associates, Inc. is currently experimenting with a motion tracking algorithm that tracks the entire area within an image that represents the passenger's image. One technique being investigated is correlating

the various areas within a passenger's image by grouping image areas on their velocity and direction of movement.

## **USE OF EXISTING SECURITY CAMERA DATA**

A second approach to passenger counting that has been investigated by Greneker and Associates, Inc. involves the use of imagery already captured by a security camera on-board a transit or rail vehicle. Video sequences taken from a security recording system obtained from the system's manufacturer, Prima Facie®, Inc., were evaluated to determine if the sample rate and quality provided useful imagery for passenger counting. Figure 18 shows a frame of the Prima Facie®, Inc., security system imagery.



**FIGURE 17** Single target comprised of high contrast image features.



**FIGURE 18** Passenger boarding and entry recorded by Prima Facie®, Inc., video security system.



Referring to Figure 18, there is a slight distortion in the image because a very wide angle lens is used to capture as much of the scene inside the bus as possible. The image quality is good. There is a technical challenge to using security camera data for passenger counting. The frame update rate of the current system is too slow to use the system's recorded imagery for passenger counting. Discussions with Prima Facie®, Inc., indicate that it may be possible to increase the frame rate. The impact of increasing the frame rate and therefore storage capacity of the Prima Facie®, Inc., data storage system is currently being evaluated.

There are advantages to Greneker and Associates, Inc. using security camera imagery for passenger counting on trains and buses where the security equipment is already installed. The installed equipment has been tested and ruggedized to survive the demanding transit environment. The image data are already available to the security system equipped transit operators. As a result, transit personnel could remove the data storage medium and submit it to an image processor on a daily basis to extract passenger counts at little or no extra cost to transit operations. Greneker and Associates, Inc. is exploring the use of existing transit and rail on-vehicle security video systems to provide passenger counts as one possible additional approach to commercialization of the Cyclops system.

## FINAL CYCLOPS DESIGN

The Cyclops system tested on MARTA consisted of both a radar and a video camera image capture system; both designed for wide stream door passenger counting. Testing on MARTA demonstrated that radar is a viable method for counting single passengers entering or exiting anywhere along the wide stream door. However, additional radar system development is required to solve the technical challenges associated with the discrimination of multiple passengers entering and exiting simultaneously in "lock step" and shoulder to shoulder. The development of radar as a wide stream door passenger counter will be addressed during the commercialization phase of the project. It is currently planned that Greneker and Associates, Inc. will concentrate on the development of the video camera wide stream door passenger counter as a first product during the commercialization phase.

Rail cars operated by MARTA are similar to those operated by other transit authorities in the United States. The findings determined during Cyclops testing on MARTA should generally apply to other U.S. transit system's rail cars. However, there are also rail car specific factors that must be known before Cyclops video system image processing algorithms can be finalized. For example, the rail transit operating authority must make initial decisions regarding where cameras can be mounted and how power and video cables can be routed within the

rail car. Cyclops installation complexity, passenger safety and video system security must be considered. There are other factors that are not under the control of the operating authority. These include variability in scene illumination due to the car moving from sunlight into the darkness of a tunnel, rail car vibrational effects, and passenger behavior around the door. Each factor can affect system count accuracy. These unknown variables must be defined by performing limited testing on the transit system where the Cyclops will be installed.

## The Use of Video for Passenger Counting

Testing of the video image processing technique on MARTA demonstrated that the simplest approach to counting boarding and exiting passengers is to equip each of the six rail car doors with a dedicated downward pointing video camera. Fortunately, technological advances have lowered video camera prices from those of a decade ago. Test results demonstrated that an inexpensive (\$100 in quantity) video camera, typical of the one tested, has sufficient resolution to count passengers. Test results also demonstrated that when a downward pointing camera is used, the fluorescent lights, normally mounted over each rail car doorway, is an adequate illumination source for passenger counting during low ridership levels when spacing exists between boarding and exiting passengers.

Analysis of the video data collected during MARTA testing determined that low cost frame masking techniques can be used to isolate specific areas in a scene for single passenger presence and motion analysis. Simple image processing techniques that will detect the door opening sequence, a single passenger's presence and the direction of travel of the single passenger (exit or entry) were demonstrated using analysis software routines. More complex multiple passenger boarding scenarios require a more rigorous image processing approach than the approach demonstrated using simple image processing techniques.

The MARTA tests revealed that when two or more passengers enter the wide stream rail car door together in "lock step" or cross simultaneously through the camera's field of view, an image pre-processing routine must first be applied to find the boundary between passengers. There must be sufficient contrast between the clothing of each passenger or other unique discriminants to allow passengers entering shoulder to shoulder to be separated. Once separated, the simpler already demonstrated approach to determine passenger direction of travel could be applied.

Each stage of image processing that is required to implement a specific function impacts the time required to process a frame of data. The number of video frames that can be captured each second is determined by the time required for the processor to execute the passenger

count extraction algorithm. The frame capture rate that a processor must achieve while executing the passenger count algorithm determines processor internal complexity and speed. The number of cameras that the video processor must service simultaneously for a specified complexity level and the required processor speed determines processor cost.

## **COMMERCIALIZATION OF THE CYCLOPS WIDE STREAM DOOR PASSENGER COUNTER**

The commercialization of the Cyclops passenger counter is the next goal of Greneker and Associates, Inc. When a commercial partner with transit system experience has been identified, decisions must be made about the final Cyclops system design specifications. Participation by a rail rapid transit operating agency during the final design of the Cyclops system is also desirable. The final design must also be tested over an extended period on a rail transit car in revenue service. Many technical decisions must be made regarding the final design and configuration.

There are three alternative image processor configurations being evaluated for further development during the Cyclops commercialization phase: (1) A combination camera/ image processor built into the camera housing to extract passenger counts in real time; (2) A single processor unit installed on each rail car with the capability of processing the images from 6 cameras simultaneously, designed to produce passenger counts in real time; or (3) One recording system on each car that is capable of storing imagery from all six cameras for "off car" processing by a central processing unit located at the yard. The recorded data would be removed from the train daily. The approach would not produce real time data but would provide the rail operating authority daily ridership data. Each approach has advantages and disadvantages, also an associated cost trade-off. The three alternative approaches are discussed below.

### **Self Contained Camera/Processor**

A self contained camera/processor unit can produce boarding and exit counts for each door using image processing algorithms that are resident in the unit. Currently there are several manufacturers of these self contained combined camera and processor units that contain a small video camera that captures image data and sends the image data to the image processor located in the same camera housing. The captured image would be processed by a Greneker and Associates, Inc. proprietary algorithm resident in image processor memory. After processing, the resulting data would be sent to the camera/processor's serial port where it can be extracted. The frame capture rate for this type system depends on the complexity of the processing, but frame

rates of between 10 and 30 frames per seconds are achievable if the passenger counting algorithms are not complex. The advantage of this approach is that the ridership data is available in real time. This capability could be used to provide ridership data on demand and can provide individual rail car occupancy data between stations. The self contained nature of the camera/processor system alleviates the need for wiring between an onboard central image processor or a six camera recording system. Power and a data network or radio data transmission system is required if near real time ridership data capture and transmission to central control or the next station is the purpose of the system design.

The distributed architecture of 6 camera/processor units can be an advantage. The distribution of processors also distributes the image processing load across all six camera/ processor systems. The video camera and processing functions are both located in the same housing, and should either function fail, the entire system fails, but only for one door. All passenger counts for the host rail car are not lost if one of the self contained camera/processor fails for one door and graceful system degradation is assured. Camera/processor self tests can be developed to inform rail maintenance personnel of the camera/processor's failure. The cost of these self contained camera/processors are still over \$3,000 dollars each, in quantity. However, as technology matures and competition increases among the manufacturers, prices will decrease for the self contained systems.

### **Single Onboard Image Processor**

A second approach being considered for Cyclops image processing uses one central processing unit to simultaneously process the images produced by six cameras. Real time ridership data can be provided to a data network that links all cars of the train to the transit authority's central operations center, via a radio link. This arrangement provides ridership data on demand and can provide individual rail car occupancy data between stations, as does the previous Camera/Processor approach. The statistics can be also be stored at the network hub for delayed collection, if desired.

The use of a single processor unit with six inexpensive cameras may currently be more cost effective than using 6 individual camera/processors. The primary advantage of using a single relatively expensive single processor is that system capability can be increased slightly, as needed, by adding more memory, mass storage devices or a network interface. The disadvantage is that video bandwidth wiring and control cables must be installed on the transit vehicle between the 6 cameras and the central processing unit. The central processor must be located in a protected area where it will not be vandalized and power must be provided to that area of the rail car for the system's operation. If the processor unit itself fails, there is no ridership data produced for any of the six doors. If a

camera fails, the failure will be detected by a system self-test conducted at scheduled times by the processor. The self-test routine can identify the faulty camera and send the fault message forward for human evaluation. During the failure period, the data for the door covered by the defective camera is lost.

### **An Onboard Video Recorder**

The placement of a video recorder on each rail car alleviates the need for onboard video image processing. Recording of the video data does require that the video data be collected each day and processed at a central processing facility. Onboard data recording eliminates the capability of using Cyclops data for the generation of real time ridership information between stations or the transmission of near real time ridership data via a network interface. The cost of an onboard recording system for 6 cameras is currently less than an onboard processing system. The train operator might be assigned the duty of removing the recording medium from each recorder on each car and taking the recorded media to the central data reduction facility for ridership statistics processing after each shift change. This would be a disadvantage of this alternative. The information that the system produces during the data reduction phase is historical information and it can not be used for real time applications such as car occupancy advisories.

### **Considerations in Selecting an Approach**

The final Cyclops system design must still be developed by Greneker and Associates, Inc. working with the partner who has experience in the transit industry. A transit authority must be identified to receive the first Cyclops wide stream door passenger counter in advance of final system design. Arrangements must be made with the transit authority to design the first operational

prototype system for their system. The decision to produce real time or historical data must be made on the basis of transit authority needs. Cyclops system element placements must be proposed by the developers and approved or modified by the transit authority. After the final system design is completed, it must be tested on a rail car in revenue producing service. Video scene data must be collected under daylight and nighttime operating conditions. The data collected on the host transit authority's rail car must be analyzed. During the analysis process the degree of variability in the scene data must be determined. Scene illumination variability, rail car vibrational effects, installation limitations, power supply source location and type would be determined. Once the hardware system design is finalized, the image processing algorithms that extract ridership data from the video image would be finalized.

If it were determined that the data would be recorded on the rail car and analyzed at a central facility operated by the transit authority the prototype developmental path would be only slightly different. The commercial partners, working with the host transit authority would develop a design for a six camera video recording system. The recording system would be constructed and installed on a rail car. Testing would occur during revenue service. The recorded media would be analyzed to determine the variability in scene data. A processor would be developed for the central data reduction facility use and the image processing algorithms that would be used to extract historical ridership statistics would be developed and tested in the central processor system. There are other approaches that final Cyclops system development could take during the commercialization process, however, the outlined approach, or a variation of the outlined approach is thought to be the lowest risk approach