IMPROVED PASSENGER COUNTER AND CLASSIFICATION SYSTEM FOR TRANSIT OPERATIONS

Project Final Report
Transit IDEA Project 5

Prepared for
Transit IDEA Program
Transportation Research Board
National Research Council

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September 1996

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EXECUTIVE SUMMARY

An experimental transit vehicle passenger counter was designed from off-the-shelf systems and field tested in a transit vehicle. The experimental system contained two elements: 1) a pressure sensitive mat that mapped, in two dimensional pixel space, the pressure pattern of a foot standing on the mat and 2) a microprocessor recording system that allowed project investigators to record the pressure patterns. Once recorded, the two dimensional pressure patterns or images were analyzed to identify individual foot pressure pattern features. Feature recognition was used in an analysis to identify individual passengers by the pressure patterns that were generated as single and multiple passengers occupied the mat momentarily after paying their fare.

Several performance goals were established for the experimental counter. First, the counter should determine if the passenger was entering or exiting the transit vehicle. Research results show that this capability was achieved. Second, the counter should determine if the passenger was a man, woman, or child on the basis of foot size, pressure distribution, and weight derived from the total pressure distributed over the area of the image. This goal was not achieved due to goal complexity and funding limitations. Third, the counter should determine if two or more persons are occupying the pressure sensitive mat at any given time in order to reduce undercounting of passengers. This performance goal was achieved.

The pressure sensitive mat and the associated recording system were supplied by a commercial vendor. The project investigators wrote special software to perform analysis on the data that was collected in the laboratory and in the field aboard a transit vehicle during normal operations. A neural network algorithm and a digital filter based on centroid motion of the passenger’s foot as it passed across the mat were two analysis techniques that were investigated.

A study was also conducted to determine the potential error sources. This study showed that mothers often carry small children aboard the transit vehicle. This activity biases the weight data collected by the mat and makes passenger gender classification difficult. The system will not count the infant being carried and as a result it will produce incorrect ridership statistics. It was also found that passengers board a transit vehicle carrying packages such as groceries that can bias a weight measurement system. In addition, when passengers board with both hands full of packages they generally will bypass the fare box (at least in the transit system where testing was performed) and put their packages in their chosen seat. After unloading their package(s), the passenger will return to the fare box and pay the driver. It was determined that locating the pressure sensitive mat in the aisle beyond the fare box was not a good idea due to the problem of counting a passenger three times: once as they walk to their seat, once as they return to the fare box to pay, and once when they walk from the fare box to their seat.

It was also determined that there are changes in the trigger operation of the off-the-shelf sensor system and the data memory and storage management system that must be made to ensure that data overflow does not occur at a given stop when many passengers are boarding the transit vehicle. Changing the mat size and configuration so that it will mount in a smaller physical space is also necessary.

The report that follows provides a detailed examination of the progress that has been made toward the achievement of the research goals stated previously. The detailed principles of system operation are also presented.

IMPROVED PASSENGER COUNTER AND CLASSIFIER SYSTEM FOR TRANSIT APPLICATIONS

INTELLIGENT VEHICLE HIGHWAY SYSTEM (IVHS) - IDEA PROJECT TRANSIT-5[i]

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IDEA PRODUCT

A prototype passenger counter system has been developed for use on mass transit vehicles. It can count the number of individuals entering, the number exiting, and determine a passenger's direction of travel. Given this capability, the counter can determine the number of passengers entering or exiting a transit vehicle at any stop. More difficult, but achievable, is the system's capability to determine when more than one passenger is standing on the pressure sensitive mat that serves as the system sensor. One additional research goal (not yet achieved) was for the system to classify passengers with respect to gender and age (adult or child) on the basis of weight and foot size. The hardware and software that support this product and the results of field testing the experimental passenger counter system on a Cobb County Transit (CCT) vehicle will be presented in this report.

CONCEPT AND INNOVATION

This project explores the feasibility and performance of using an off-the-shelf pressure sensitive imaging system developed by Tekscan, Inc. coupled with processing algorithms developed by the technical staff of Greneker and Associates, Inc., to transform pressure sensor data into statistical ridership data. When fully developed, the experimental counter/classifier system would be designed to be integrated with the transit automatic fare box and Global Positioning System (GPS) which is presently being installed on larger mass transit system operator vehicles to improve route planning, produce ridership statistics at each stop, and detect fare box irregularities.

The passenger counter concept under development and test includes two elements: (1) a passenger sensor (a thin mat located on the floor of the transit vehicle in a position where the passengers will be required to stand on the mat momentarily while boarding and paying their fare), and (2) an associated microprocessor that processes the electronic images produced from the pressure patterns of a passenger's shoe resting on the mat. The sensor system (i.e., the mat) utilizes a matrix of pressure sensing points capable of generating a 3-dimensional pressure pattern of a passenger's shoe. The shoe outline is displayed in the 'X','Y' plane and the pressure amplitude of each matrix of each matrix element is displayed along the 'Z' direction. The initial approach to achieve accurate counting of passengers was to identify the pointing direction of shoe images with a trained neural network. However, the trained network misclassified many test signatures due to similarities between entry and exit shoe patterns. This static approach was abandoned in favor of a dynamic approach that utilizes tracking the center motion of the shoe image as a function of time to determine the direction of passenger travel (boarding or exiting). Using this processing system, multiple passengers on the mat can be sensed to solve the problem of undercounting or overcounting.

The system was field tested by installing an off-the-shelf Tekscan pressure mat on the floor of a CCT transit vehicle. Data were collected in real time at each bus stop on a route with medium passenger traffic. Over 130 exit/entry events were recorded and analyzed to obtain test ridership statistics. A video tape recording of passengers walking across the mat was also generated by a video recording system. The video record was used as truth data and as a method to assist in the evaluation of situational events. Single passenger and multi-passenger entry-exit events and multi-passenger simultaneous entry-exit events were identified by the software. It was hoped that the data would provide approximate passenger weight and shoe size to allow the classification of the passenger as a man, woman or small child. After the field test data were analyzed, it was found that this task was too difficult to achieve within the project's funding and schedule.

IDEA PROJECT INVESTIGATION

Neural Net Analysis

The rental of the Tekscan sensor system early in the project was delayed. Hence, a substitute technique was developed to generate shoe images for analysis algorithm development during early testing of the concept of image recognition. These substitute data were generated in the following manner:

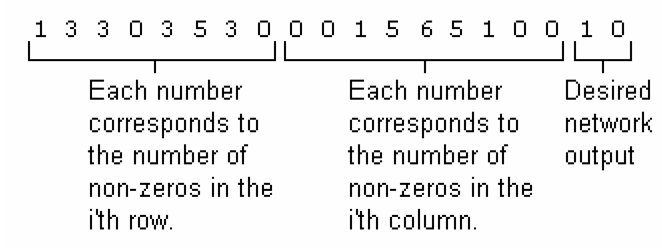
1. The bottom of a small cardboard box was covered with copier toner. The toner was transferred to the bottom of the shoes, and onto paper to leave an

imprint of the shoe pattern. The prints were sprayed with an acrylic sealer to make them "smudge-proof."

2. A desktop scanner was used to scan the prints into a personal computer in the form of bitmap files. These files were imported into the software application CorelDRAW *(1)* to reduce their resolution to 100 rows by 100 columns, a resolution that closely matched the resolution of the pressure sensitive mat.
3. A small randomly selected number of prints were loaded into CorelTRACE *(1)* to create a vector-based image from each bitmap. This allowed scaling as well as mirroring, rotation, etc., within CorelDRAW without loss of resolution. Sixty sets of footprints, each containing two feet, were created. A sample of these footprints is shown in Figure 1.
4. The footprints were converted into 'TBL' files to move each image to the origin, ensure each image had a uniform size, and to add the desired neural net output to the signatures. After this procedure, the 'TBL' files were converted to single-line 'SIG' text files. Each text file contained the signature of one image: a vector whose size was equal to twice the number of rows in the corresponding image. The first half of the signature has components that correspond to each row of the image. The value of each component represents the number of non-zero points on the corresponding row of the image. Similarly, the second half of the signature has components which correspond to each column of the image so that each value represents the number of non-zero points in the corresponding column of the image. This array of numbers is succeeded by a two-number "desired output" required to train the network. As an example of how a 'SIG' signature was created, consider this small bitmap in 'TBL' format:

```
8    (number of rows)
9    (number of columns)
0 0 0 0 1 0 0 0 0          (row 1)
0 0 0 1 1 1 0 0 0
0 0 0 1 1 1 0 0 0          :
0 0 0 0 0 0 0 0 0          :
0 0 0 1 1 1 0 0 0          :
0 0 1 1 1 1 1 0 0          :
0 0 0 1 1 1 0 0 0
0 0 0 0 0 0 0 0 0          (row 8)
```

The resulting signature would be:



5. A program was written and used to "flip" each of the "entering" footprint images to create a set of "exiting" footprint images.
6. Processing identical to that performed in previous steps was performed to create a set of "exiting" 'TBL' files similar to the "entering" 'TBL' files. The exception was the change made in the desired output of the vector which indicated an exiting person to the neural net.
7. "Entering" and "exiting" footprints were concatenated together to create the neural net training file, which contained a total of 60 signatures.
8. Using the NeuralWorks software package *(2)*, a Logicon Projection back-propagation neural network was created. The network had 200 inputs, 30 hidden layer processing elements, and 2 outputs.
9. The training file was repeatedly submitted to the network for a total of 50,000 epochs (cycles through the training file). This training time produced an RMS error level of approximately 0.15.

Although the root-mean-square (RMS) error level was low for the training set, the trained network misclassified many of the test signatures it had never seen. After examination of the signatures themselves, it was clear that the type of signature created was not capable of expressing the differences in footprints unambiguously. The following two signatures demonstrate the problem.

Figures 2 and 3 show images and signatures representing shoe pressure patterns entering and exiting, respectively. Note that the signatures are very similar, causing the neural network to misclassify these and other pairs of signatures which appear the same. The images can be distinguished with the human eye, because the human neural network can process 2-dimensional input vectors. An artificial neural net accepts only 1-dimensional input vectors (i.e., the 2-dimensional image must be reduced to a 1-dimensional vector causing loss of information). That loss of information, in turn, is translated into poor neural net performance.

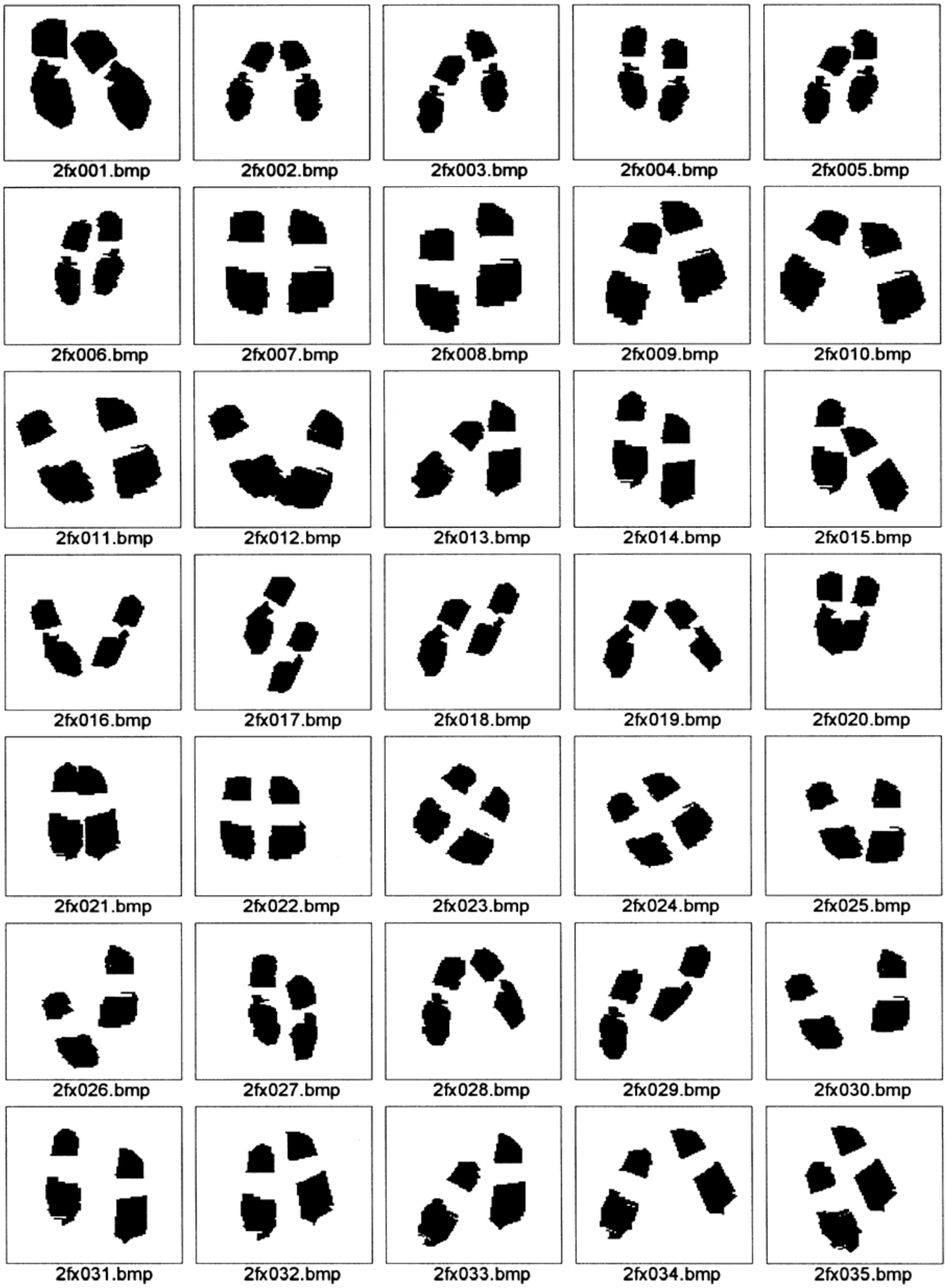


FIGURE 1 Samples of shoe prints used for neural net analysis.

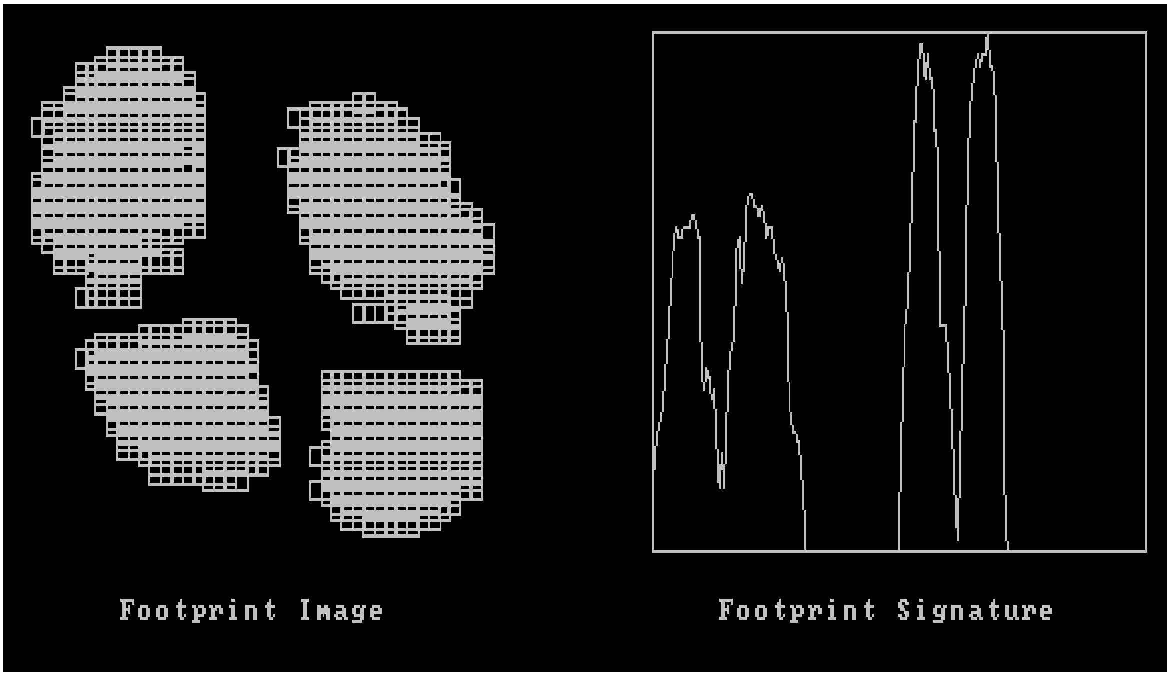


FIGURE 2 Footprint image and neural network signature of entering shoe pressure pattern.

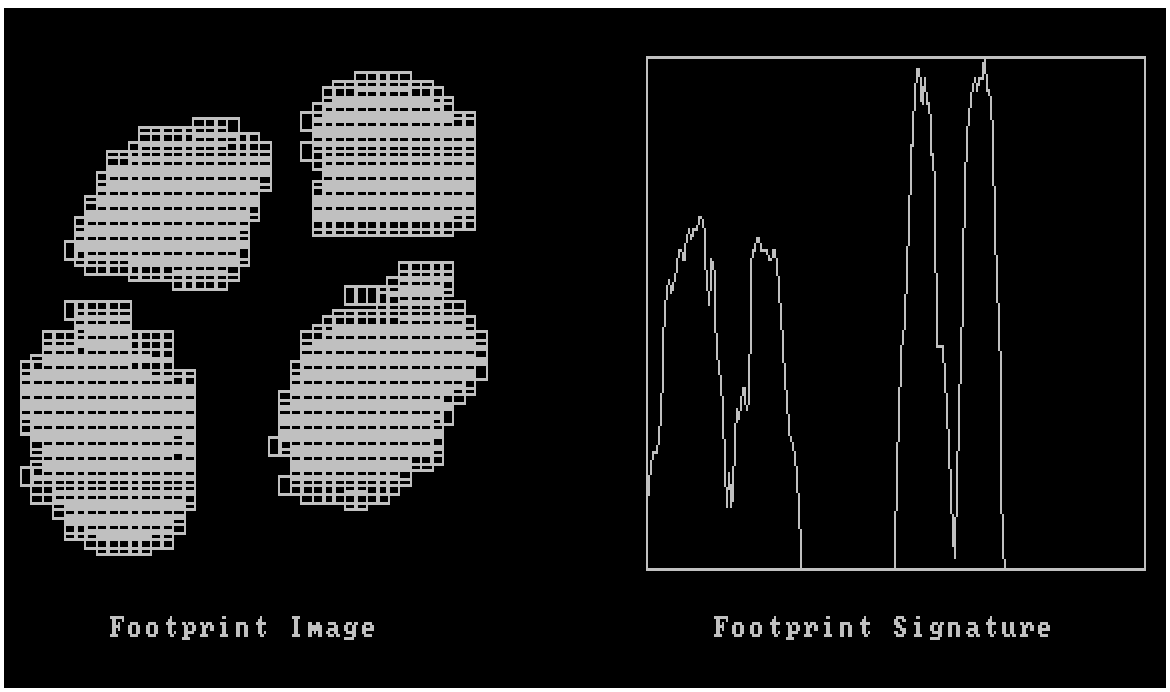


FIGURE 3 Footprint image and neural network signature of exiting shoe pressure pattern.

Centroid Motion

The next investigation was the use of data collected using a pressure sensor system leased from Tekscan, Inc., South Boston, Massachusetts, manufacturer of pressure sensitive mats. The heart of the Tekscan system is an ultra-thin (0.007", 0.18 mm) high resolution tactile sensor matrix mat that measures 21" by 23". The sensor system specifications are shown in Table 1.

TABLE 1 Tekscan System Characteristics

Number of Sensor Cells:	6800/mat
Spatial Resolution:	4 sensors/cm^2
Active Sensor Area:	450 mm x 495 mm
Sensor Type:	Resistive
Sampling Rate:	100 Hz or less
Dynamic Range:	1 to 225 PSI

The objective of this research was to focus primarily on the development of software algorithms that can accurately count the number of passengers entering or leaving the transit vehicle. The initial approach has been to identify the pointing direction of shoe images with a trained neural net. Although the Tekscan system does not provide software that identifies passenger travel direction or passenger classification according to sex and age, a new algorithm, which solves the problem created by the neural net, takes advantage of the dynamic motion of the pressure centroid produced by the Tekscan System. It was noted that a person's normal walking behavior produces a rolling motion of the foot on the pressure mat. Figure 4 shows a frame-by-frame example of this motion, using a bare foot for example clarity. Next, the motion of the shoe clad foot was analyzed from data taken in the laboratory.

For one person entering or exiting the pressure sensitive mat, the centroid will move in the same direction as that person. Plots of the centroid motion in the 'X' and 'Y' plane of the sensor mat are shown in Figures 5 and 6 for subjects exiting and entering, respectively. The filled and unfilled squares denote the stopping and starting points of the centroid motion, respectively. Thus, the centroid displacements along the entering direction are negative, while those for the exiting direction are positive. Table 2 summarizes the total cumulative centroid displacements along the 'X-axis' of 14 people--each walking across the mat, one at a time, in two opposing directions. The current software (utilized for this data) correctly identified the two possible states. However, it was known from observations on a transit vehicle that at times two people step on the mat simultaneously, one entering and the other exiting.

In this case, the centroid motion is displayed in Figure 7. There are other exceptions that have been observed that must be accounted for using a robust identification algorithm. For example, passenger 1 may be standing on the mat looking for his/her fare card while passenger 2 moves around passenger 1, momentarily stepping on the sensor mat. Such situations will have a unique centroid signature if the mat is located in the aisle behind the fare box. Mat location behind the fare box was necessary because of the size of the off-the-shelf mat and electronic assembly. Thus, it is not only the displacement of the centroid along the 'X' dimension that is important, but the displacement along the 'Y' dimension. Plans were made to collect data on an actual transit vehicle to test the processing algorithms. Details of the data collection effort and the resultant ridership statistics are presented in the next section.

Data Collection

The Tekscan sensor mat was installed on a CCT bus. CCT's General Manager, Mr. Eric Estell, and Branch Maintenance Manager, Mr. Wren Mumphrey were extremely cooperative with the authors in planning and executing the field test portion of the project. Figure 8 shows the bus just prior to installation of the sensor mat and data collection system. The large area of the mat (21" x 23") and a raised electronic compartment that ran across the side of the mat prevented installation on one of the much smaller front steps of the bus (a more optimum location). While placement on a step was thought ideal the mat's size and the electronic assembly required the mat to be placed in the aisle near and behind the fare box. The mat was fastened to the floor with double-sided adhesive tape employed in the carpet industry, and it was reinforced on top and around the edges with duct tape to prevent passengers tripping. Figure 9 shows the pressure sensitive mat prior to a thin (0.25") felt shield being added over the top of the mat for protection. Figure 10 shows the final installation of the mat after the addition of the felt shield which was placed over the mat to prevent passengers with rocks stuck in their shoes and those passengers wearing spiked heels from damaging the mat. The entire left front seat was assigned to the experimental system. The data collection system was set up on the seat just above the mat and in a position shown in Figure 11. A video camera was placed on a hand grip bar just above the author's head and it was focused on the mat to document the foot strike sequence of the passenger(s). The video record was used in conjunction with a hand log that was also kept on the statistics of each boarding event.

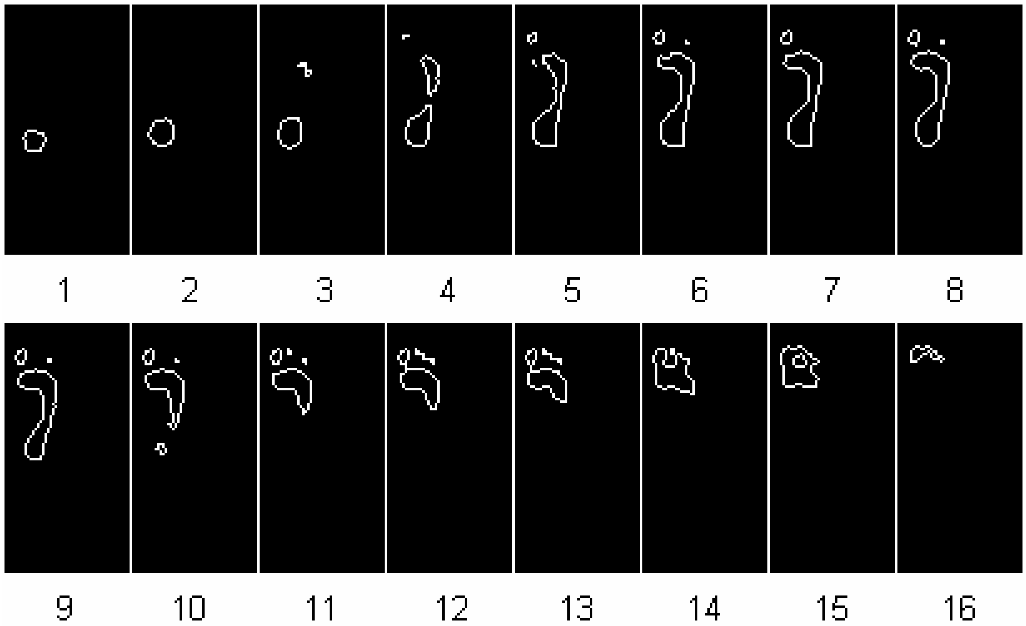


FIGURE 4 Rolling motion of bare walking foot on pressure mat.

TABLE 2 Output of Passenger Identification Software

Passenger #	Movement in X Dimension	Decision	Weight
1	-42.6	Entering	172.808 lbs
2	-53.4	Entering	193.000 lbs
3	24.5	Exiting	180.846 lbs
4	38.3	Exiting	161.385 lbs
5	-29.2	Entering	164.727 lbs
6	-37.2	Entering	164.476 lbs
7	-53.6	Entering	183.444 lbs
8	-44.1	Entering	179.880 lbs
9	-89.2	Entering	171.571 lbs
10	92.7	Exiting	143.400 lbs
11	49.4	Exiting	188.636 lbs
12	-48.9	Entering	163.100 lbs
13	38.3	Exiting	167.720 lbs
14	26.7	Exiting	180.000 lbs

Total Entering: 8
Total Exiting: 6

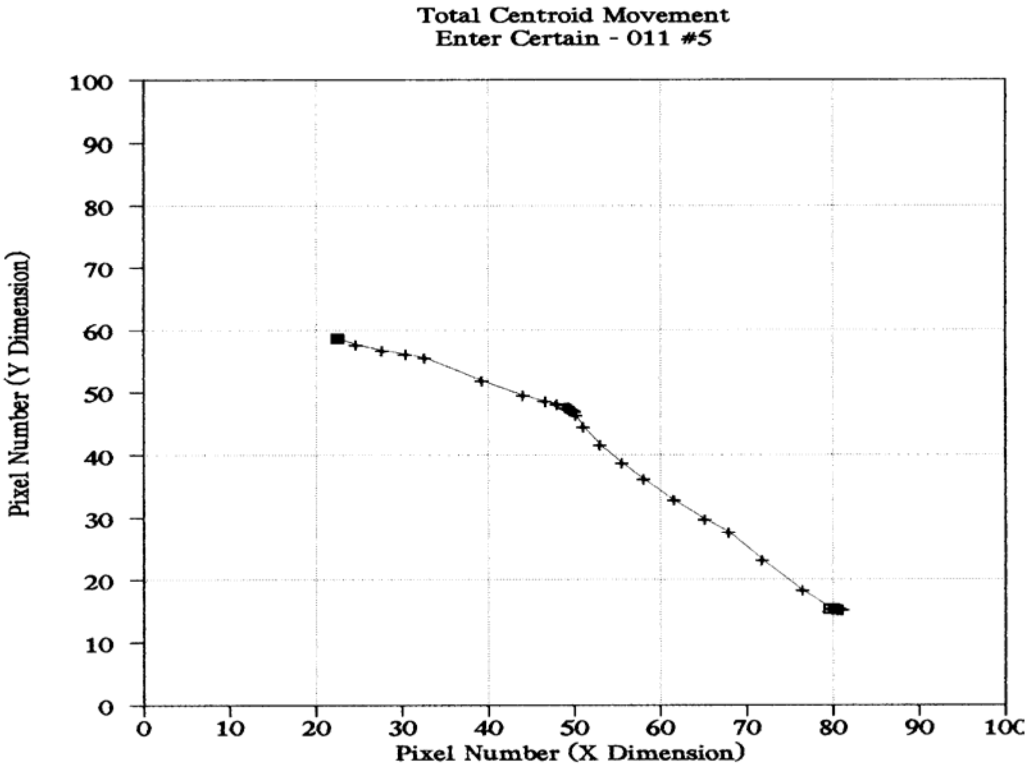


FIGURE 5 Centroid motion for a certain "enter" event.

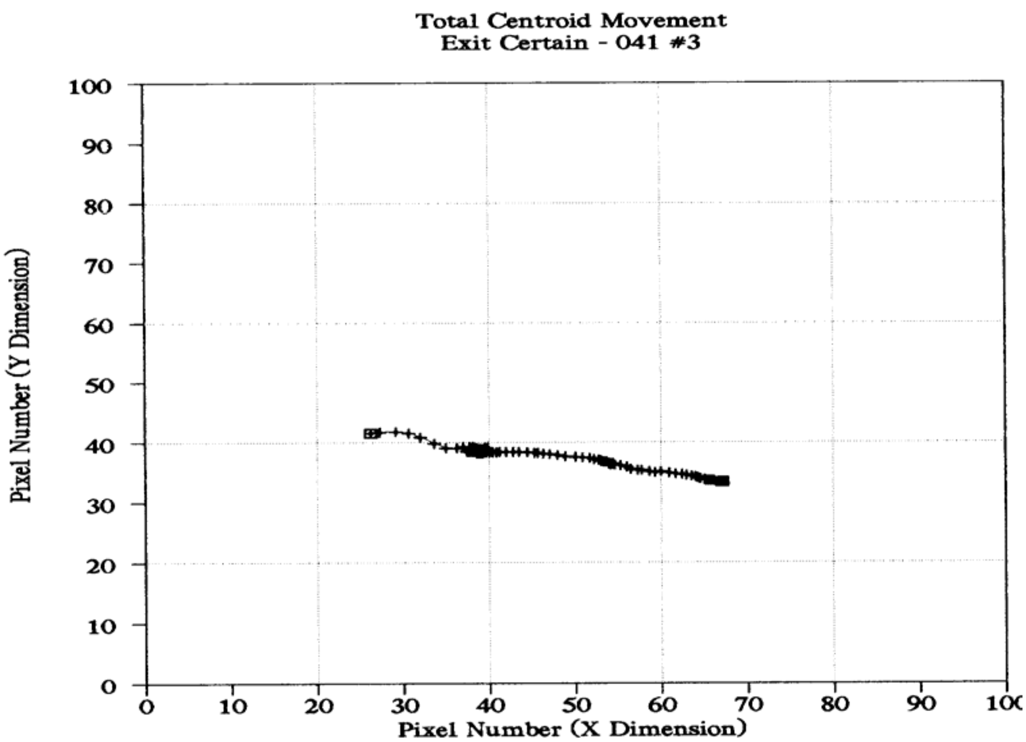


FIGURE 6 Centroid motion for a certain "exit" event.

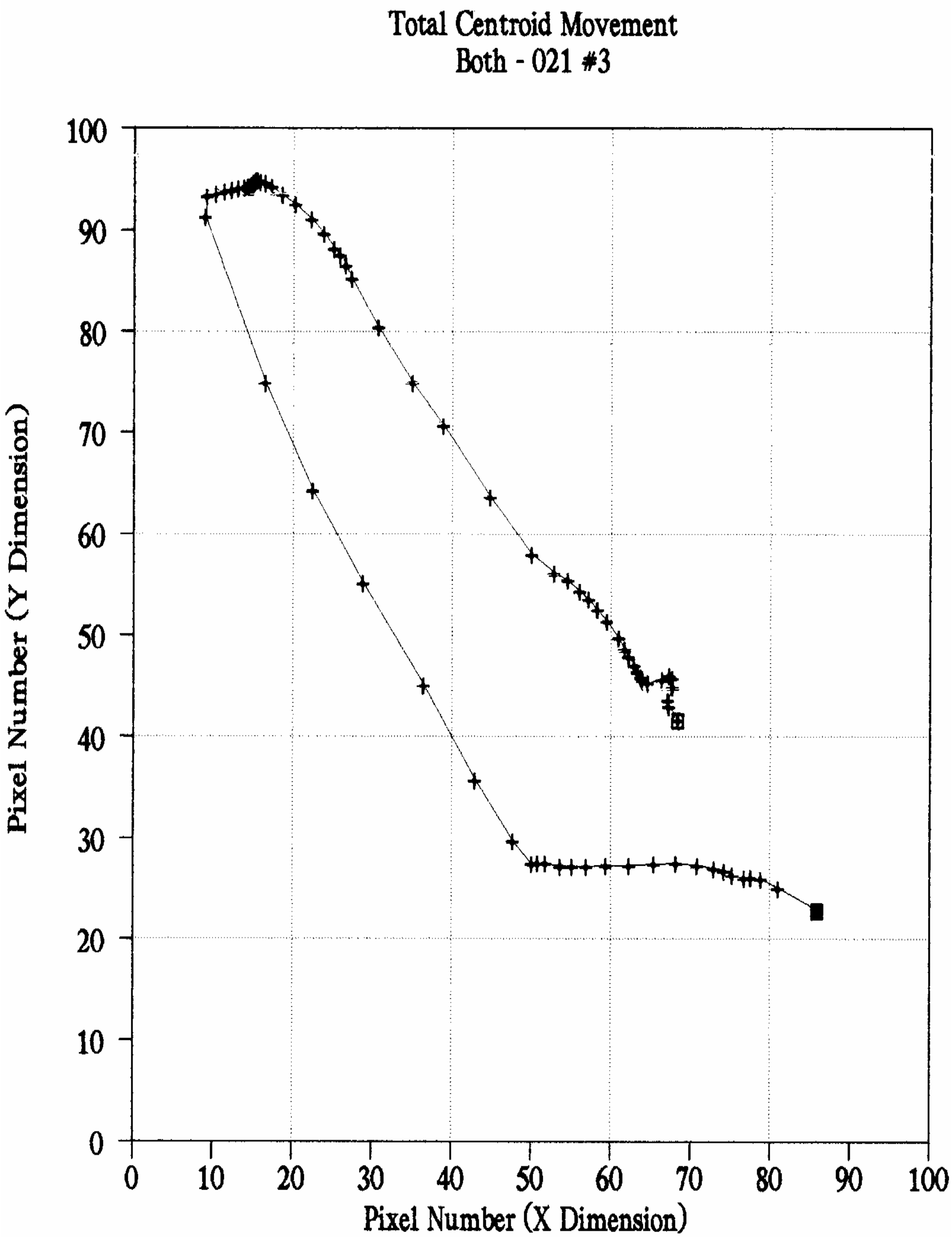


FIGURE 7 Centroid motion for a "both" event.

FIGURE 8 Cobb County Transit vehicle that was used during field testing of the counter system.

FIGURE 9 The pressure sensitive mat installed on the floor of the vehicle.

FIGURE 10 Data collection system set-up on the left front passenger seat just above the mat.

FIGURE 11 Passenger approaches the sensitive mat after paying his fare.

The computerized data collection system was powered by a DC to AC power converter that was wired into the vehicle's 12V onboard power supply. Following installation and check-out of the experimental system, the bus on which the system was installed replaced the bus that was servicing Route 10 of the Cobb Community Transit System. Route 10 was selected because it had a moderate passenger load and it was reasoned that the front seat, occupied by two of the authors and the data collection system, would not be needed. Figure 11 shows two passengers entering the bus and approaching the mat.

The bus made two complete circuits of the entire route from the Marietta, Georgia city square to Cumberland Mall, a commercial shopping center located approximately 10 miles south of the square. Each round trip lasted approximately two (2) hours and data was collected for the entire period. Approximately 150 entering and exiting events were captured during the period. All passengers entered at the front of the bus to pay the fare and most exited at the rear where there was no instrumentation. Thus, entering events outnumbered exiting events. The software that was supplied by Tekscan was used to record the pressure patterns produced by each event. After the bus door was closed and no passengers were on the pressure sensitive mat, the data were transferred to the hard disk of the data collection system. The routine of collecting data at each stop and storing data during bus movement was satisfactory in most cases. However, when passenger traffic was exceptionally heavy at some bus stops, the memory buffer would fill to its limit and, as a result, the remaining exiting and entering passengers were not recorded.

A handwritten log was maintained for each event registered in the data collection system in addition to the video tape record. An example of this log is shown in Table 3. Parameters recorded on the log sheets included the file number assigned by the data collection system, the passenger or event number (assigned sequentially), the event vector (entering, exiting or both), the passenger's sex, the passenger's approximate age (classified according to adult or child) and any comments that were relevant to the data collection effort.

Data Processing

The data collected on the bus were analyzed with the aid of two computer programs developed by Greneker and Associates, Inc. The first, called the "Window" program, was used to determine the transition points between passengers. This program was needed because the sensor system, when activated by pressure, collects data frames continuously until the pressure falls below a threshold, until the random access memory buffer in the computer is full, or until the operator applies the "Stop" command. In either case, the output is a nearly continuous sequence of data frames similar to a motion picture. Each frame is a snapshot of the pressure distribution at a particular instant in time.

Under normal circumstances, the passenger currently registered by the sensor field steps off the mat before the next passenger steps on. Hence, the total pressure decreases to zero between passenger registration. However, there are situations where the force on the mat is not reduced to zero because the next passenger is registered by the mat sensor before the first passenger leaves. In that case, the low force period is compared to a minimum weight (WMIN = 20 pounds) and minimum time window (TMIN = 20 frames). Because each frame is obtained by the computer in 1/60th of a second, the total time for twenty frames is 0.33 seconds. In this manner, weight, area, total pressure and peak pressure were read and plotted as a function of time. These quantities are output by the Tekscan software. An example of event separation output by the "Window" program for area, peak pressure, total pressure and weight for the complete data file DATA011 is shown in Figures 12, 13, 14 and 15.

Data for each event were processed further to determine the total center of force movement in the 'X' direction (Δx). Δx corresponds to the center of force motion when the heel of a shoe makes contact with the mat and leaves at the tip of the toe. Δx may be positive or negative and, thus, the sign of Δx is correlated with an entering ($-\Delta x$) or exiting ($+\Delta x$) event. A typical center of force motion for an exit and enter event is shown in the previous Figures 5 and 6. The open and closed squares at each end of the track signify the start and stop points for each event, respectively. An exit/entry event was identified with certainty when Δx was between a value of 20 and 100, where 100 was the total number of sensors that could be activated in succession in both the 'X' and 'Y' direction of the mat. When the number of sensors activated in the 'X'-direction fell below 20, (i.e., $-20 \leq \Delta x \leq 20$), the event was labeled uncertain. In that case, the decision for entry or exit was based on two observed parameters: the sign of Δx and the magnitude of the Euclidean distance $(\Delta x^2 + \Delta y^2)^{1/2}$. The decision logic is shown in Table 4.

TABLE 3 TRB Data Collection Log

File Name	Passenger #	Enter/ Exit (E/X)	Female/ Male (F/M)	Adult/ Child (A/C)	Comments
DATA051	30	X	M	A	Passenger resting on mat
DATA061	31	X	M	A	
	32	E	F	A	
	33	E	F	A	With baby in arms
	34	E	F	A	
DATA071	35	E	M	A	
	36	E	M	A	
DATA081	37	E	F	A	
DATA091	38	E	M	A	
	39	E	M	A	
	40	E	M	A	
DATA101	41	-	-	-	Missing passenger description
	42	X	F	A	
	43	X	F	A	
	44	X	F	A	

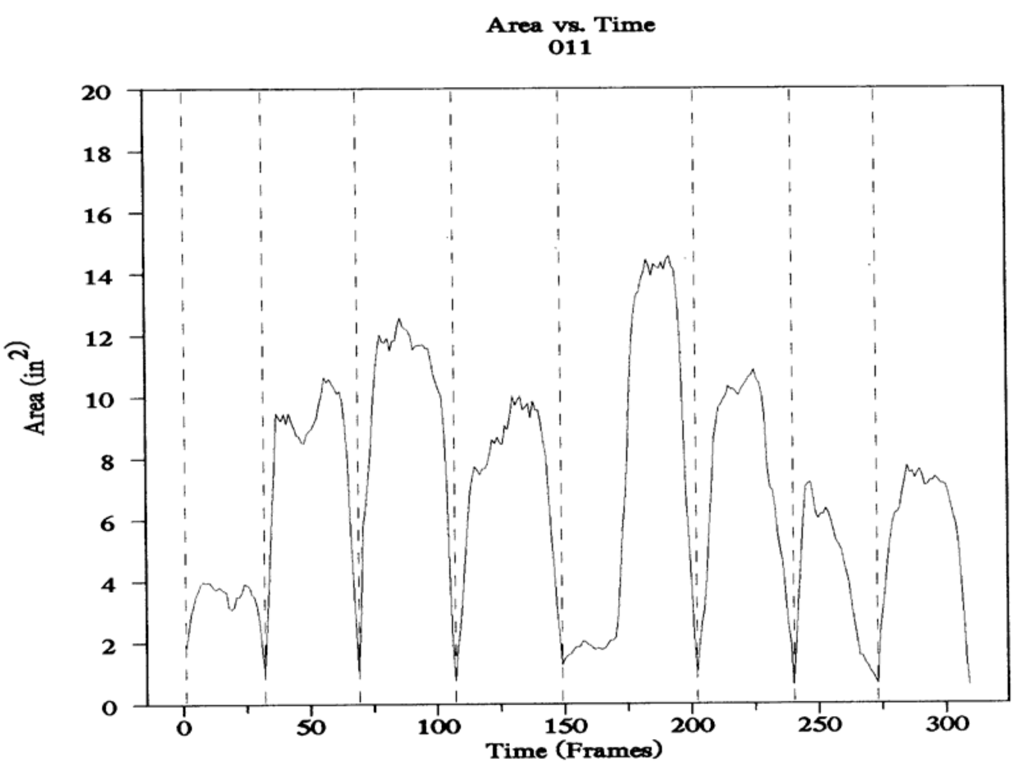


FIGURE 12 Total area under pressure separated by events.

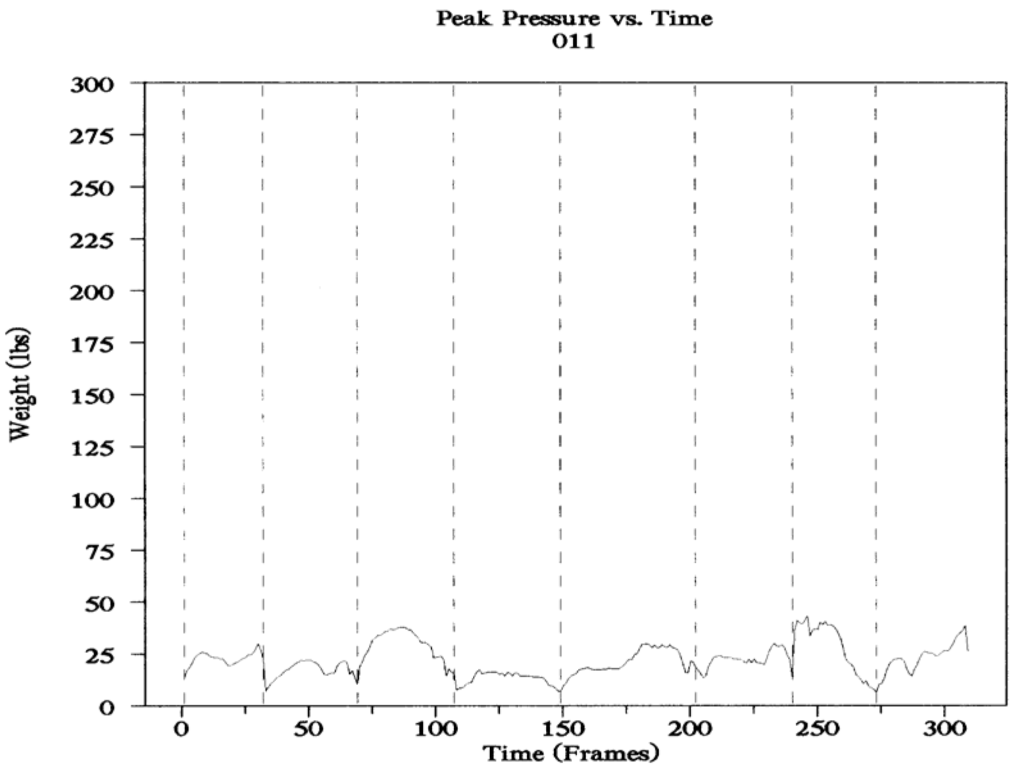


FIGURE 13 Peak pressure separated by events.

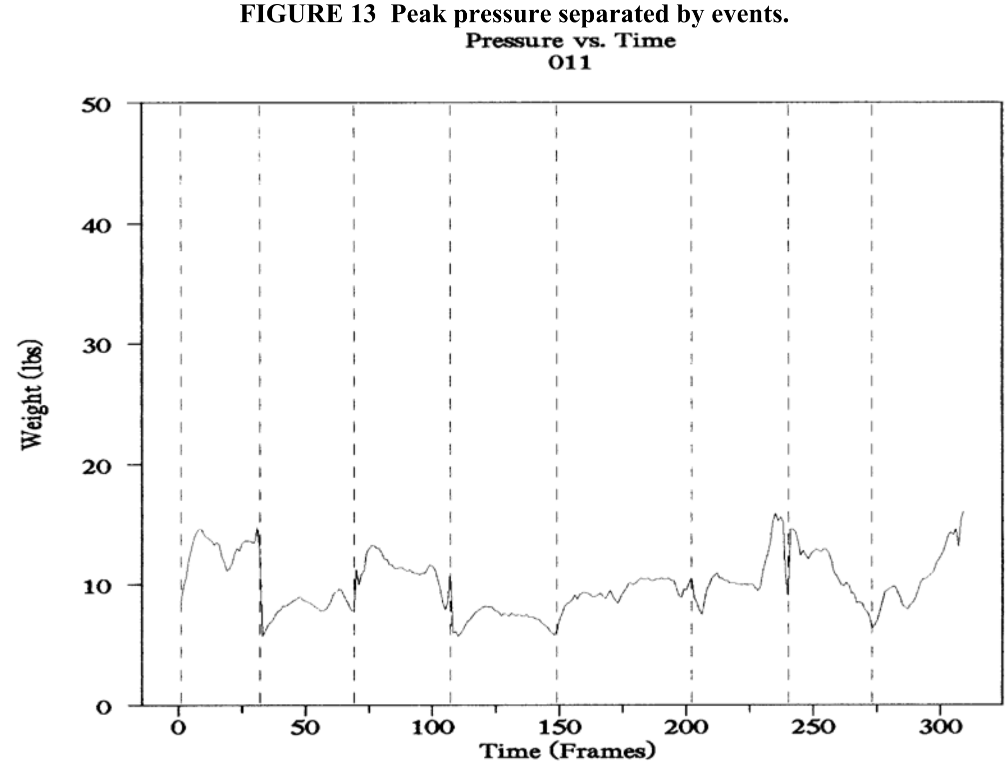


FIGURE 14 Average pressure separated by events.

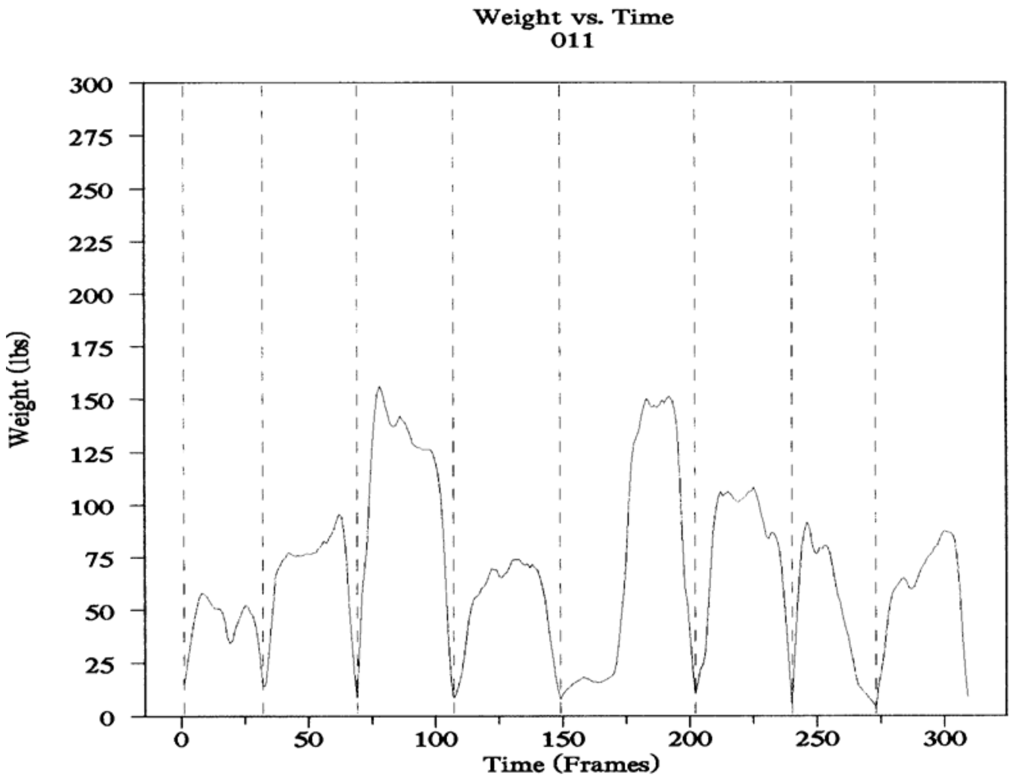


FIGURE 15 Applied force separated by events.

TABLE 4 Decision Logic

Δx Magnitude	$(\Delta x^2 + \Delta y^2)^{1/2}$ Magnitude	Decision
+ Large $\lvert\Delta x\rvert > 20$	Small (<75)	Exit Certain
- Small $\lvert\Delta x\rvert < 20$	Small (<75)	Enter Uncertain
+ Small $\lvert\Delta x\rvert < 20$	Small (<75)	Exit Uncertain
- Large $\lvert\Delta x\rvert > 20$	Large (>75)	Both Exit and Entry
+ Large $\lvert\Delta x\rvert > 20$	Large (>75)	Both Exit and Entry
- Small $\lvert\Delta x\rvert < 20$	Large (>75)	Both Exit and Entry
+ Small $\lvert\Delta x\rvert < 20$	Large (>75)	Both Exit and Entry

The center of force motion for events labeled uncertain exit and uncertain entry (i.e., $|\Delta x| < 20$ and $(\Delta x^2 + \Delta y^2)^{1/2} < 75$) are shown in Figures 16 and 17, respectively. In some cases, two passengers, one exiting, the other entering, passed each other simultaneously. In that case, the total centroid movement displays a track with a larger Δy. Hence, $(\Delta x^2 + \Delta y^2)^{1/2}$ is large, usually > 75, and the analysis program will output the decision "Both" (i.e., entry and exit simultaneously). A typical "Both" event is shown in Figure 7. The data analyzed in this manner were recorded on a file-by-file basis as shown in Table 5.

The example in Table 5 displays the event number of the total Δx movement, the decision made by the algorithm, the weight determined from the total pressure multiplied by the total area activated (i.e., total sensors activated) and the adult/child recording transferred from the data collection log. The three question marks after an enter or exit signify an "Uncertain" decision. Also, note that there appears to be little correlation between the weight of a person (determined from the sensor data) and the log classification of adult or child. It did not matter whether the weight was derived from peak pressure, average pressure or total force. Clearly, adult/child identification is not recommended on the basis of the current weight results. One reason for the problem with weight measurement is the fact that the integrated pressure applied during one event depends on the amount of weight applied to the foot that activated the mat. This weight varies from frame to frame and is not an accurate assessment of the total weight of the person. An accurate weight may be obtained only if both feet rest on the mat simultaneously.

Table 6 summarizes the results of the analysis and compares these results with entries transferred from the data collection log. The first three columns, marked Actual Data, show the total number of passengers that entered and exited the bus as confirmed by the data collection log. The next three columns show the output decisions of the Mat Analysis program. The final column, labeled 'Error', shows the difference between the actual data and the program decisions. Note that out of a total of 131 events analyzed, two events were misclassified. Both misclassifications occurred when the Δx motion was very small, i.e. $|\Delta x|$ □~ 2.0. An error occurs if, for example, a passenger activates the mat with only the tip of the front of their shoe and skips the mat entirely with the other foot.

In this case, there may be a slight backward motion as the passenger increases the pressure on the shoe tip while stepping across the mat, giving a false sign for Δx and, hence, a false identification. This problem may be avoided by placing the mat on the second step at the front entry of entry of the bus. Placement of the mat on the second step will force a significantly larger portion of the passenger's shoe onto the mat to support the passenger's weight with one foot to avoid slippage.

PLANS FOR IMPLEMENTATION

The primary difficulty encountered in adapting the Tekscan software to the passenger counter application was the lack of a trigger indicator and the limited memory buffer.

For example, as the software collects data, a user definable trigger determines when weight is on the mat so that only useful data are collected. As presently implemented, however, the software does not record trigger activations in the data files, making it difficult to interpolate where the frames corresponding to a particular event begin and end. This problem could be corrected simply by including one data point below the trigger value each time the trigger is deactivated.

The second difficulty arises from the manner in which the software accumulates data. Because the software holds all data in a random access memory buffer until data collection is terminated or the buffer is full, the number of possible data points is limited. The problem is exacerbated by the software's inability to make use of more than 4 megabytes of memory. Due to these limitations, it is presently necessary to manually initiate data collection at each bus stop, and then to manually save the data to hard disk after the buffer has been filled (often before passengers have finished entering/exiting). Enabling the software to use from 8 to 16 megabytes of memory could provide sufficient storage to hold all data collected at a particular bus stop. The software could be under automatic control indefinitely if the data were spooled automatically to the hard drive between stops.

For a more streamlined operation, it would be preferable to have a non-graphical skeletal interface which simply collects data during periods of activity and creates and stores information files (center-of-force, peak pressure, etc.) in between stops. This would eliminate the necessity for human input, and allow continuous operation.

The correction of these major limitations, plus other minor alterations to the control software as well as resizing the sensor mat could provide a practical implementation of the passenger counter.

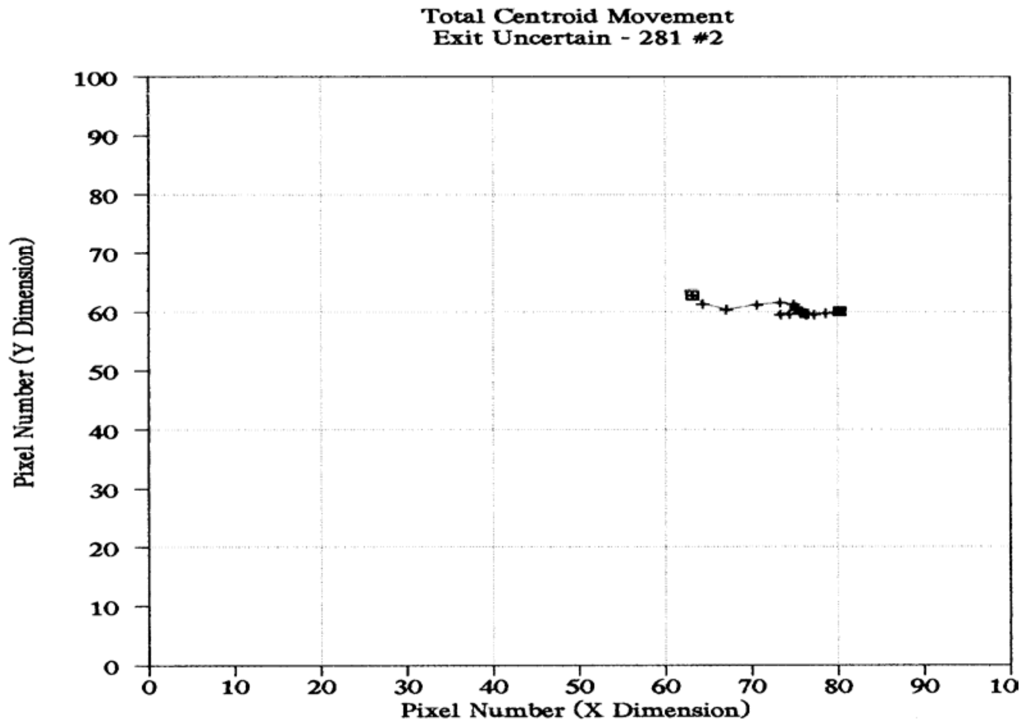


FIGURE 16 Centroid motion for uncertain “exit” event.

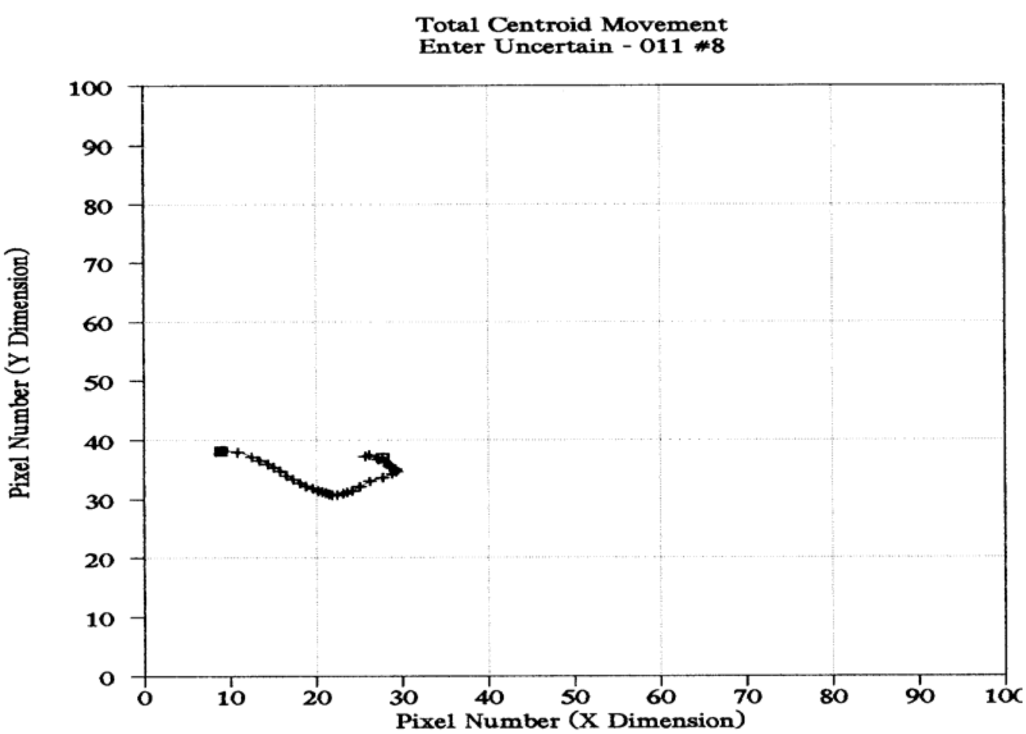


FIGURE 17 Centroid motion for uncertain “enter” event.

TABLE 5 Output of Mat Analysis Program

File:
011

Event	Δx Movement	Decision	Weight (lbs)	Adult/Child	Area (in^2)
1	–12.8	Entering ???	51.1	A	3.6
2	–34.1	Entering	80.2	A	9.5
3	–49.7	Entering	135.5	A	11.5
4	–39.9	Entering	67.4	C	8.9
5	–57.1	Entering	141.5	A	13.7
6	–35.3	Entering	98.5	A	10.1
7	–43.9	Entering	80.5	A	6.3
8	–18.8	Entering ???	78.9	A	7.0
Total Entering:	8				
Total Exiting:	0				

File:
021

Event	Δx Movement	Decision	Weight (lbs)	Adult/Child	Area (in^2)
1	13.5	Exiting ???	107.6	A	8.6
2	–60.3	Entering	15.4	C	1.6
3	17.5	Both ???	104.1	C	10.7
4	–33.1	Entering	73.0	A	6.3
Total Entering:	3				
Total Exiting:	2				

File:
031

Event	Δx Movement	Decision	Weight (lbs)	Adult/Child	Area (in^2)
1	–15.6	Entering ???	84.3	A	4.9
2	73.6	Exiting	92.7	A	7.3
3	–79.0	Entering	72.6	A	6.3
4	–87.5	Entering	74.9	A	10.0
5	–16.8	Entering ???	59.8	A	4.9
Total Entering:	4				
Total Exiting:	1				

TABLE 6 Summary of the Database Analysis

				Program Decision			
Actual Data							Error
Data File	Entering	Exiting	Both	Enter	Exit	Both	
11	8	0	0	8	0	0	0
21	2	1	1	2	1	1	0
31	4	1	0	4	1	0	0
41	8	1	0	7	2	0	1
51	0	1	0	0	1	0	0
61	3	1	0	3	1	0	0
71	2	1	0	2	1	0	0
81	1	1	0	1	1	0	0
91	3	0	0	3	0	0	0
101	2	6	0	2	6	0	0
111	1	3	0	1	3	0	0
121	7	0	0	6	1	0	1
131	0	1	0	0	1	0	0
141	3	3	0	3	3	0	0
151	2	1	0	2	1	0	0
161	7	0	0	7	0	0	0
171	1	3	0	1	3	0	0
181	6	1	0	6	1	0	0
191	9	0	0	9	0	0	0
201	2	0	0	2	0	0	0
211	0	7	0	0	7	0	0
221	2	0	0	2	0	0	0
231	2	2	0	2	2	0	0
241	4	1	0	4	1	0	0
251	2	2	0	2	2	0	0
261	3	4	0	3	4	0	0
271	1	3	0	1	3	0	0
281	0	5	0	0	5	0	0
291	0	1	0	0	1	0	0
Total	**85**	**45**	**1**	**83**	**47**	**1**	**2**

CONCLUSIONS

The pressure mat currently employed for a passenger counter can identify separate entry and exit events, as well as simultaneous entry-exit events. The current probability of misidentification is 0.01, as determined from the current data base. A better estimate of this probability may be obtained from an expanded data base that contains at least 10^4 to 10^5 events. Thus far, a prototype system comprised of an off-the-shelf sensor and data collection system has been applied to the problem. It is anticipated that if the prototype system were engineered into a product, a dedicated and automated processor would be used to collect the data at each stop. Between stops, the collected data would be processed and the complex, memory filling frames of two dimensional pressure data would be reduced to simple entry or exit statistics. Input to the counter system from a GPS positioning system would identify the bus stop where the ridership statistics were taken. Thus, the files that would be transferred to the operator of the mass transit system would be very compact compared to the pressure data that are required for initial processing.

It was also determined that a better way to isolate the trigger that starts the data collection cycle of the process must be developed. Additional research is required to develop a strategy to improve event trigger reliability. One solution to the trigger problem is to modify the Tekscan trigger routine to provide a trigger option for the passenger counter application.

Relocation of the mat to the middle step at the front door of bus is being considered as one approach to limit the number of passengers who can be on the mat at any given time. Relocation of the mat to the doorway would reduce the probability of double counting passengers as they go to their seat, set down packages, and then return to the fare box to pay (crossing the mat twice), a practice allowed by sympathetic drivers of the CCT buses.

FUTURE RESEARCH DIRECTION

The Phase I research effort described in this report achieved all but one of the primary goals (gender classification by weight measurement) established for the project. Despite the project's successful conclusion, it was also determined that the use of a contact sensor presents implementation challenges to solve such as sensor mounting limitations, accelerated wear of the sensor due to heavy foot traffic, potential liability considerations due to the elevated nature of the sensor's surface, and a solution to the change of sensor measurement accuracy with use. While these technical challenges can be solved during the commercialization process, the capability to use a non-contact sensor has always been considered advantageous.

Two primary requirements must be met by a non-contact sensor for passenger counter applications. First, a non-contact sensor will be required to detect each passenger entering or exiting the front door of the transit vehicle and second, the sensor will be required to determine the direction of travel of each detected passenger. It was also determined that if a non-contact sensor could be developed to provide this information, much of the software that has already been developed for this completed project would be directly applicable for use with a non-contact sensor. For example, a non-contact sensor's ability to detect the presence of a boarding or exiting passenger is equivalent to a passenger stepping on the pressure sensitive mat (as done in the current system and registered by the present software). Assuming that the non-contact sensor can determine the direction of travel, the passenger's action can be classified as an entrance or exit event by the existing software. During field testing of the pressure sensitive mat system, a serendipitous discovery was made that suggested that a homodyne radar could serve as a replacement sensor system for the mat.

A downward pointing homodyne radar unit was mounted on the transit vehicle ceiling over the second step. The purpose of the radar was to serve as a simple event trigger to back-up the pressure sensitive system. The radar data were collected to determine if the radar could serve to "arm" a software trigger in a final mat-based product. Data from the radar were collected during field testing aboard the transit vehicle using a laptop computer and an analog to digital sampling card to convert the analog Doppler data to a digital format for storage. When the data from the radar were reduced, it was discovered that the radar system had been able to determine passenger presence and the passenger's direction of travel on the basis of radar signature. This discovery has been explored to determine if a non-contact radar sensor can be used to replace the floor mat contact sensor.

The initial results of radar data analysis are very encouraging. The analysis indicates that there is a high probability that the radar could replace the floor mat sensor. Additional analysis shows that the existing software already developed for use with the mat system to determine passenger presence and direction of travel across the mat could, with input data format modification, determine passenger presence and direction of travel from the radar signature data.

Given these unexpected but serendipitous results, Greneker and Associates, Inc. proposes that a Phase II research program be conducted to determine the viability of the use of a homodyne radar as the non-contact passenger sensor. This short deviation from final product development will provide results on which a trade study can be based to determine which type of sensor system is best to use as the final sensor. A research plan is being developed at the present time to determine the applicability of the radar for passenger counting purposes.

INVESTIGATOR PROFILE

Mr. E. F. Greneker served as the Project Director. He received a BS Degree from Georgia State University and an MS Degree in the field of City Planning from the Georgia Institute of Technology. He is President of Greneker and Associates, Inc., a Georgia corporation. He has been employed by the Georgia Institute of Technology, Georgia Tech Research Institute (GTRI), for the past 25 years as a Principal Research Associate. During his 25 year career with the Institute, he has served as the Project Director of over 30 major sponsored projects at GTRI. He has directed several transportation related projects utilizing radar. He directed a project sponsored by the State of Georgia Department of Transportation (GDoT) to study ways to detect a ship on collision course with a bridge spanning the waterway. He also managed a project sponsored by the National Highway Safety Administration (NHTSA) to prepare training material for police radar instructors. He served as the Project Director of an in-vehicle signing project to develop the Safety Warning System™ (SWS) to warn motorists of highway hazards by transmitting textual warning messages to motorists using radar detectors. He is currently directing a project for the Federal Highway Administration (FHWA) and GDoT to determine the effectiveness of the SWS. He holds two U.S. Patents and has one Patent currently pending. He is a Senior Member of the International Electrical and Electronics Engineers (IEEE) Inc., and is a member of the Sigma-Xi Research Society and the American Meteorological Society. He is the author of over 60 technical reports and technical symposium papers.

REFERENCES

1. CorelDRAW (1993), Corel Corporation, 1600 Carling Ave., Ottawa, Ontario, Canada K1Z8R7.
2. Professional II/PLUS software (1993), Neural Ware, Inc., Penn Center West, Pittsburgh, PA, 15276.

NOTES

[1]This IDEA project was started in January 1996 and was completed September 1996. IDEA Project Advisor: Dr. K. Thirumalai