

Calibration of an Infrared Pedestrian Counting System for Shopping Malls

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Riverwalk Shopping Mall is a festival marketplace located in New Orleans. As part of the pedestrian counting system, photoelectric sensors were installed at the mall entrances to record pedestrian flows entering and exiting the mall. This paper describes the system and presents a nonlinear model that correlates manual pedestrian counts with the corresponding sensor data. Two types of sensor data were recorded: (a) number of sensor breaks and (b) number of busy cycles. The number of sensor breaks was found to be a better explanatory variable than the number of busy cycles, which depends on the size and speed of the object that crosses the sensor beam. Issues relating to model development include simultaneous crossings of the beam by multiple shoppers and the effect of varying entrance widths on model parameters. The nonlinear relationship between actual pedestrian counts and their associated sensor data accounts for simultaneous crossings, and hypothesis testing revealed that the model is invariant under varying entrance widths.

This paper describes a pedestrian counting system and presents the calibration of the counting device for estimating pedestrian flows at Riverwalk Shopping Mall in New Orleans. Riverwalk is a festival marketplace center that consists of apparel shops, specialty retail shops, and a large concentration of food offerings.

DESCRIPTION OF THE PEDESTRIAN COUNTING SYSTEM

The mall has nine entrances. Entrances C through I encompass the retail portion of the mall while Entrances A and B are at the fountain area of the mall. Photoscanners (sensors) were installed at four of the busiest entrances (A, B, C, and I) and connected to a personal computer located in the mall management office. These traffic sensors are designed to record the movements of pedestrians crossing at the entrances. The sensors record the number and duration of infrared beam interruptions caused by pedestrians during every 15-min period.

The sensors (Warner Photoscanners) are high intensity, two-part photoelectric controls that consist of a modulated light-emitting diode light source in one housing and a receiver in the other housing. The receiver is designed with a photo-transistor amplifier and output circuitry. The light source is modulated and the receiver is tuned to that frequency, making it virtually immune to ambient light. The light source operates in the infrared spectrum and is invisible to the human eye. Depending on the response of the photoelectric controls, the

device is capable of sending beams at a rate of over 1,500 cycles per min. By placing the source and receiver side by side at a height of 4–12 in. above the floor at entrances free from obstructions, the device can be used to measure pedestrian flows. However, the sensors cannot distinguish the inflows from the outflows.

CHARACTERISTICS OF PEDESTRIAN FLOWS AT THE MALL

To calibrate the counting system, actual pedestrian inflows and outflows were counted at all entrances. Data were collected from January 28, 1988 to January 30, 1988, between 10:00 a.m. and 6:00 p.m. at 15-min intervals. The 15-min peak mall occupancy for Thursday (January 28, 1988) was 1,449 shoppers; it was 1,663 for Friday. Both the Thursday and Friday peaks occurred between 12:30 p.m. and 12:45 p.m. The Saturday peak occurred between 1:45 p.m. and 2:00 p.m.

Table 1 shows the total number of pedestrians entering the retail portion of the mall for each survey day. On Thursday this was 7,739; 10,219 on Friday; and 17,166 on Saturday. The combined percentage of trips entering through Entrances C and I on each survey day was 74 percent, 75 percent and 66 percent, respectively. The actual count data also revealed that the inflow and outflow at each entrance remain approximately equal.

MODEL CALIBRATION

To develop a model for estimating pedestrian flows at mall entrances, a strong correlation must exist between the sensor data and the actual pedestrian counts. Two types of data were generated from the sensors: sensor breaks and busy cycles. Sensor breaks determine the number of times the sensor beams were blocked during a given time period, while the number of busy cycles measured the amount of time (duration) that the beams were blocked during the same time period. Thus, the number of busy cycles is dependent on the speed and size of the crossing object. Therefore, we would expect a model using the number of sensor breaks to perform better than one using busy cycles.

The second issue of model development was simultaneous crossings of the entrances. For example, two or more pedestrians may pass through an entrance with only one pedestrian blocking the sensor beams. In this case, the multiple crossings that take place simultaneously will be recorded as a single break. Thus, a nonlinear relationship could exist between the

actual number of crossings and the associated number of sensor breaks. Multiple crossings at the entrances were further complicated by the varying widths of entrances.

Linear regression was used to relate the actual pedestrian flows to the corresponding sensor data. Three model forms were calibrated:

$$\text{Linear: } y = a + bx$$

$$\text{Multiplicative: } y = ax^b$$

$$\text{Exponential: } y = \text{Exponent}(a + bx)$$

where y is the two-way pedestrian count by 15-min intervals, and x is the number of sensor breaks by 15-min intervals.

Two types of independent (explanatory) variables were considered: number of sensor breaks and number of busy cycles by 15-min intervals. Table 2 summarizes the results of model performances as measured by the R^2 values. As expected, models with number of sensor breaks as the explanatory variable performed consistently better than those using number of busy cycles as the explanatory variable.

Comparing the R^2 values among models, it was found that the multiplicative model outperformed all the others except

TABLE 1 TOTAL NUMBER OF PEDESTRIANS

Day	Date	(1)	(2)	(3)	(4)
		Total			
		Total	Entered	Total	(3) as a
		Entered	Retail	Entered	
		Mall	Portion	Through	
		(A to I)	(C to I)	C & I	of (2)
Thur	01-28-88	10,982	7,739	5,706	73.7%
Fri	01-29-88	15,371	10,219	7,690	75.3%
Sat	01-30-88	25,090	17,166	11,363	66.2%

TABLE 2 MODEL PERFORMANCE: THE VALUES OF R-SQUARED

Independent Variable	Model Form *	Entrance Locations				
		A	B	C	I	All
Number of Sensor Breaks by 15-min. intervals	L	0.85	0.80	0.69	0.92	0.83
	M	0.86	0.85	0.65	0.93	0.87
	E	0.82	0.81	0.67	0.88	0.81
Number of Busy Cycles by 15-min. intervals	L	0.73	0.79	0.03	0.91	None
	M	0.84	0.81	0.06	0.92	None
	E	0.64	0.77	0.001	0.88	None

* L = Linear, M = Multiplicative, and E = Exponential

TABLE 3 APPLICATION OF THE MODEL

Sensor Data from Special Day					Estiamted 2-Way Volumes			
Time	Sensor				Entrance			
	A	B	C	I	A	B	C	I
10:00-10:15	22	19	25	17	130	110	150	97
10:15-10:30	20	11	24	19	117	60	143	110
10:30-10:45	23	12	23	13	136	66	136	72
10:45-11:00	26	17	35	8	156	97	217	42
11:00-11:15	19	17	28	20	110	97	170	117
11:15-11:30	28	20	42	19	170	117	266	110
11:30-11:45	27	26	50	41	163	156	323	259
11:45-12:00	44	35	66	42	280	217	440	266
12:00-12:15	41	36	71	83	259	224	477	567
12:15-12:30	51	32	69	105	330	197	462	736
12:30-12:45	62	41	74	83	410	259	499	567
12:45-13:00	66	51	83	87	440	330	567	597
13:00-13:15	56	53	87	95	366	344	597	659
13:15-13:30	72	47	107	90	454	156	529	492
13:30-13:45	56	47	87	70	309	156	484	388
13:45-14:00	68	26	78	73	454	156	529	492
14:00-14:15	48	26	72	59	309	156	484	388
14:15-14:30	55	27	75	49	359	163	417	273
14:30-14:45	57	34	69	42	373	210	462	266
14:45-15:00	43	26	65	43	273	156	432	273
15:00-15:15	53	27	63	43	344	163	417	273
15:15-15:30	45	28	69	35	287	170	462	217
15:30-15:45	56	24	57	39	366	143	373	245
15:45-16:00	46	27	57	39	294	163	373	245
16:00-16:15	43	17	46	22	273	97	294	130
16:15-16:30	50	25	67	25	323	150	447	150
16:30-16:45	47	18	63	29	301	104	417	176
16:45-17:00	44	23	59	27	280	136	388	163
17:00-17:15	72	29	57	26	484	176	373	156
17:15-17:30	47	17	54	30	301	97	352	183
17:30-17:45	41	20	50	21	259	117	323	123
17:45-18:00	45	20	44	23	287	117	280	136

for the Entrance C model using number of sensor breaks as the explanatory variable. The high R^2 values of some of the models indicated a strong correlation between the actual counts at the entrances and their corresponding sensor data. The poor performance for the Entrance C models was due to bad sensor data at that location. At Entrance C, the traffic sensor was installed too close to the door; therefore, whenever the door was opened, the beams were blocked. The parameters of the multiplicative model using number of sensor breaks as the explanatory variable are given below:

Parameter	Entrance Location			
	A	B	I	A + B + I
$\ln a$	1.422	1.455	1.468	1.432
b	1.119	1.100	1.098	1.111

These parameters are consistent and in the same order of magnitude for Entrances A, B, and I, which have varying widths. The results revealed that the width of an entrance may not have any effect on the model parameters.

HYPOTHESIS TESTING

To test whether entrance width has any effect on model parameters, a statistical test approach based on the "extra sum of squares" principle (*1*) was used. The test postulates that the model parameters, a and b , are invariant over various data sets, which are characterized by the width of the entrance. The procedure is to develop a model for each individual data set (unrestricted model) and to develop a common model for the pooled data set (restricted model). The ratio of the difference in residual sum of squares between the restricted and the unrestricted models relative to the residual sum of squares of the unrestricted model follows an F distribution. The F -ratio for the test of invariance of parameters a and b was calculated to be equal to 0.369 and, therefore, highly insignificant. The hypothesis of a common value of a and b cannot be rejected. That is, the model parameters are invariant relative to the width of the entrance. The recommended model developed using the pooled data from entrances A, B, and I is a nonlinear model as follows:

$$y = \text{Exponent}[1.432 + (1.111) \ln(x)] \quad (1)$$

where

y = two-way pedestrian flow volumes during a 15-min interval, and

x = the associated number of sensor breaks for the same interval.

APPLICATION

A hypothetical example is developed to illustrate the use of the model. Assume that the mall management has launched

a special marketing effort on a Friday and they would like to know the percent increase in the number of shoppers resulting from the effort.

Table 3 shows the sensor data recorded on the event day and the two-way pedestrian flow volumes estimated by the model. For example, for Entrance I during the interval 10:00 a.m.–10:15 a.m., the two-way pedestrian flow volumes were calculated as follows:

$$y = \text{Exponent}[1.432 + (1.111) \times \ln(17)] = 97$$

If each pedestrian crosses a sensor twice, the number of one-way pedestrian crossings at Entrances C and I would be $21,933/2 = 10,966$. Comparing 10,966 pedestrians that use Entrances C and I with only 7,690 pedestrians (see Table 1) using the same entrances during the survey day (Friday, January 29, 1988), there would be an increase of 3,276 pedestrians (or 43 percent) as a result of the special event.

CONCLUSIONS

A pedestrian counting system for shopping malls was described and a model for estimating pedestrian counts at shopping mall entrances was presented using sensor data obtained from photoelectric sensors. The sensor records two types of data: (a) the number of sensor breaks and (b) the number of busy cycles. The number of sensor breaks was found to be a better explanatory variable than the number of busy cycles, because sensor breaks are not dependent on the size and speed of the object crossing the beam. The nonlinear relationship between the sensor data and pedestrian crossings of the model addresses the issue of simultaneous crossings by multiple shoppers. The hypothesis test showed the model is invariant under changing entrance widths.

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REFERENCE

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