USE OF SIMULATION TO DETERMINE CASHIER STAFFING POLICY AT A RETAIL CHECKOUT

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ABSTRACT

Both queuing theory analysis and discrete-event process simulation have often been used, sometimes jointly, to analyze and improve the performance of queuing systems. Queuing theory provides closed-form solutions for various canonical queuing configurations, whereas discrete-event process simulation is highly valuable for analysis of many queuing systems beyond the reach of such closed-form solutions. Since queues are extremely ubiquitous, both queuing theory analysis and discrete-process simulation are frequently and beneficially used by analysts, engineers, and business managers. During the study presented in this paper, discrete-event process simulation was used to analyze, specify, and improve operational policies in a large retail store. Results of the model guided store management toward policies, ultimately proved successful in practice, governing the thresholds of congestion warranting the opening and closing of cash-register lanes during a retail-business day.

INTRODUCTION AND OUTLINE

The objective of this study, as specified jointly by the simulation analysts and a retail store manager, was to assess staffing policies at checkout counters, and thence to select a policy balancing staffing costs against the costs (e.g., in goodwill and repeat business) of overly long customer delays within the checkout queues. Since traditional, operations-research-based queuing theory methods provided only approximations to the non-canonical queuing configuration within the retail store, the study relied extensively upon the power of discrete-event process simulation to provide accurate assessments and comparisons among candidate staffing and operational policies. Applications of discrete-process simulation to retail stores seem rare in the literature, although the issues involved are analogous to those arising in analysis of a customer service center receiving orders by mail, facsimile, and telephone (Chin and Sprecher 1990) or analysis of a fast-food restaurant (Farahmand and Martinez 1996).

First, this paper provides an overview of the queuing system in the context of retail store management considerations and concerns. Next, we describe the input data collection required in support of the study, followed by the construction, verification, and validation of the simulation model. We then conclude by describing the results of the study, the response of the client to receipt of these results, and likely directions for future extensions of this work.

OVERVIEW OF THE QUEUING SYSTEM IN CONTEXT

In the United States culture, household pets (most often dogs or cats) are very popular, and often achieve a psychological status amounting nearly to "members of the family." (Beck and Katcher 1996). Research purporting to prove that ownership of a pet enhances longevity, especially among the elderly and/or infirm (Elgin 1990), has earned much publicity in North America. For several generations, local entrepreneurs turned shopkeepers have operated "pet stores" which sell the actual pet (dog, cat, goldfish, hamster,….) and also sell pet supplies (pet food, leashes, feeding dishes, beds and coverlets,….). Perhaps inevitably, large chain stores have eagerly seized this retailing niche opportunity, just as chain stores have moved into niches such as groceries, hardware, books, and home-office supplies (Davids 1997). The original "Pet Supplies 'Plus'" store, opened in 1988 by Jack Berry and Harry Shallop, has expanded into a chain of more than 175 stores dispersed among 19 of the 50 states (Berman 1998).

Like any retail store, the local Pet Supplies "Plus" store analyzed in this study must devote considerable managerial attention to checkout operations – that is, the staffing level at the checkout registers necessary to provide acceptable promptness of service to customers without undue overhead expense. Long checkout times, and high variance (hence unpredictability) of checkout times annoy customers; annoyed customers, in turn, represent both potential loss of future sales and bad publicity for the store. Psychologically, customers are more concerned with the time spent waiting in line for checkout service (w_Q in traditional queuing-theory notation) than with total wait time plus checkout-service time (w in traditional queuing-theory notation). Yet attempting to reduce w_Q to zero (reducing w to zero is manifestly impossible) would

Proceedings 14th European Simulation Symposium
A. Verbraeck, W. Krug, eds.

typically entail unacceptably high equipment and personnel expenses. Less obviously, a zero value for w_Q is less desirable than a small positive value because retailers typically display small, yet relatively expensive items with high profit margins, in the aisle immediately preceding the checkout register. Certainly, the retailer wants the customer to have time to notice, and make perhaps impulsive purchases of, these items (Mason and Mayer 1978).

The specific decision variable store management wished to establish, with the help of simulation analysis, was the "line trigger length." Since, when more than one checkout lane is open, customers can and will readily jockey among them to join the shortest queue (although reneging is so rare that the analysts ignored it), multiple queues tend to stabilize at approximately equal lengths (Carter and Price 2001). Indeed, the prevalence of jockeying represents one reason preventing the ready application of closed-form queuing theory analysis directly to the manager's decision-making process. The line trigger length is the integer value L_t having the property "When any waiting queue length L_Q (again, traditional notation) reaches length L_t, open another checkout lane." Of course, doing so requires diverting a store employee from whatever other task (e.g., restocking shelves) the employee was doing at the time a queue thus lengthens. With the help of simulation analysis, management wished to establish the best value for L_t.

INPUT DATA COLLECTION AND ANALYSIS

The execution of the simulation model required two fundamental types of data: customer interarrival times and cashier service times.

Collection of customer service time data was effected by either examination of videocassette recordings made of the checkout area as a security enhancement, or by direct on-site observation. Examination of the videotapes worked well when the checkout area was not congested and no more than two checkout lines were open. However, under highly busy conditions, the necessarily careful examination of these tapes became impractical to impossible, so on-site manual data collection was undertaken. The cashiers seemed to feel uneasy and to work faster when being thus observed – an illustration of the Hawthorne effect (Praça 1997). However, the analysts could identify two hypotheses explaining this Hawthorne effect:

a) The cashiers worked faster because they were under observation.
b) The cashiers worked faster because they felt pressured by the long lines.

Ideally, effect (a) would be *ex*cluded from the model, but effect (b) would be *in*cluded. To decide how much of the total Hawthorne effect to attribute to each cause, data collection was repeated for a slack period and the data thus manually collected was compared to data collected from videotapes. The mean difference was attributed to effect (a), and the remainder of the Hawthorne effect was attributed to effect (b).

Collection of customer interarrival time data was likewise done by both examination of videotapes and by direct observation. These data proved immune to the Hawthorne effect. Additionally, the computer-controlled cash registers used by the store provided records of the number of service completions per hour. These service-completion data were used to check the observed interarrival time data for reasonableness and to provide guidance on the variability of interarrival times based on time of day and day of week. This variability was high, since the store is open 9AM – 9PM (0900-2100) Monday through Saturday inclusive and 10AM – 5PM (1000-1700) Sundays. Ultimately the model used two different time-based families of interarrival rates, one for weekdays and one for weekends.

These data, once collected, were analyzed with the statistical package Minitab™ (Ryan and Joiner 2001). Unsurprisingly, the interarrival rates were readily characterized by exponential distributions whose means varied with the time of day and day of the week. Surprisingly, the service times were also nearly exponential; the following plot is a typical example.

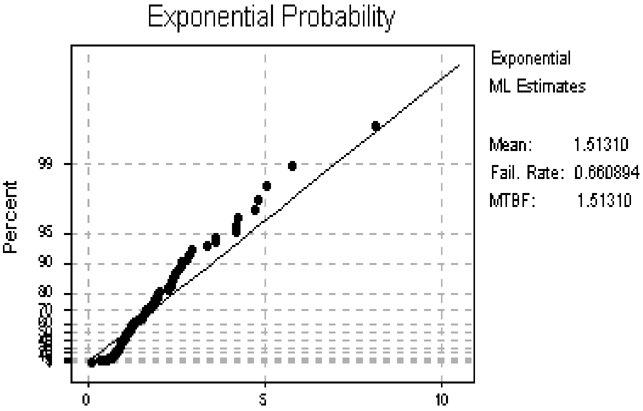

Figure 1: Service Times Deduced From Videotape

Exponentially distributed service times were disconcerting (is the mode of service times really zero?); however, when service time variability is high (as it was here), with specific reasons occasionally provoking an abnormally service time, they are plausible (Hillier and Lieberman 2001). Examples of specific reasons explicitly observed in this context were:

1. The cashier notices that a customer is about to buy a torn bag of dog food – already the bag is spilling its contents a bit – hence the cashier sends another employee to fetch a replacement bag
2. The customer wishes to pay by check, and the cashier's explaining that the customer's name is on a "dishonored checks list" provokes a tiresome, tedious argument
3. An item is on sale for an advertised reduced price not programmed into the computer, causing the customer to insist on the discount; the cashier must summon a manager (laws in many of the fifty U.S.

states assess severe penalties for overcharging customers due to such computer errors).

CONSTRUCTION, VERIFICATION, AND VALIDATION OF THE MODEL

The model itself was constructed rapidly and conveniently using the SIMUL8® simulation software package (Hauge and Paige 2001). Fundamental SIMUL8® constructs used within the model were those for arrivals to the system (called Work Entry Points in SIMUL8®), queues representing the waiting lanes upstream from each checkout station (called Storages in SIMUL8®), workstations representing the checkout stations (called Work Centers in SIMUL8®), and a system-departure point representing customers' leaving the store (called a Work Exit Point in SIMUL8®). The SIMUL8® Conveyor construct was unnecessary to this model, although it is often useful to model basic material-handling processes such as occur in factories. Less obviously, the SIMUL8® Resource construct was unnecessary to represent the cashier at a checkout stand – the Work Center construct represented the cashier directly. The Resource construct would be needed to represent a situation such as "one operator operates and/or repairs multiple machines, which cannot undertake their cycles, or portions thereof, without the operator." Underneath this relatively straightforward superstructure, the model contained a complex infrastructure built using the SIMUL8® "Visual Logic" language. This code implemented choosing, or jockeying to, the shortest available queue – except that it forbid joining a queue of length (L_Q) zero if that queue was just upstream from a currently closed checkout station. Surprisingly, although SIMUL8® contains a "mouse-click" construct instructing a work center to take its next input from the longer or longest of two or more queues feeding it, it does not contain a "mouse click" construct by which a work item (here, a customer) can join the shorter or shortest of two or more candidate queues. This logic also implemented opening an additional register when the trigger length L_t was reached, and sending waiting customers to that newly available and initially empty queue. Likewise, this code also implemented closing a register when service demands declined back below the trigger threshold. This extensive code was implemented within a "logic station" of zero cycle time. Since work centers in SIMUL8® hold a perhaps disproportionate portion of the power to include and exploit Visual Logic code, it is often necessary to include such zero-cycle-time logic stations within a SIMUL8® simulation model.

Verification of the model (checking that it is built correctly) proceeded via several methods: examination of the animation (which initially detected customers rushing to an empty queue just upstream from a closed checkout station – of course, they stayed there indefinitely), taking individual event-steps through the model, and, perhaps most important, extensive structured walkthroughs, as vigorously recommended by (Weinberg 1971) of the complex Visual Logic code.

Validation of the model proceeded, in concert with store management, by comparing L_Q and w_Q as predicted by the model with observations from recent days in the store, as collected on videotape and also available by inference from the computer log files maintained by the checkout stations. In these validation runs, the model was instructed to open and close checkout stations as was actually done during the day used for comparison. Those openings and closings were often ad hoc, predicated upon a shortage of employees, a sudden increase in amount and loudness of grumbling among the customers waiting in the checkout lane(s), or queues of customers long enough to encroach upon shopping areas. After correcting several inconspicuous but significant errors and enhancing the model, these validations were successful to within 5%. Additionally, the total number of people served by the collective checkout stations per day, as predicted by the model, was within 3% of the total number served according to the computer records automatically maintained by the cash registers.

RESULTS AND CONCLUSIONS

This simulation model was analyzed as a terminating system, with the natural length of runs twelve hours (Monday – Saturday case) or seven hours (Sunday case), inasmuch as the store opens "empty and idle" each morning (Banks et al. 2001). Fifteen replications were run for each case and 95% confidence intervals were constructed for the system performance metrics of importance to the store management. Results, as indicated in the tables below, specified the increase in average waiting times (w_Q) as queue trigger length (L_t) increased.

	Weekday $L_t = 2$		
Waiting Line	Low 95%	Average	High 95%
#1 w_Q	1.10	1.16	1.23
#2 w_Q	0.49	0.55	0.61
#3 w_Q	0.84	1.16	1.48
	Weekday $L_t = 3$		
	Low 95%	Average	High 95%
#1 w_Q	1.45	1.55	1.65
#2 w_Q	1.25	1.39	1.53
#3 w_Q	0.61	1.05	1.49
	Weekday $L_t = 4$		
	Low 95%	Average	High 95%
#1 w_Q	2.05	2.18	2.32
#2 w_Q	1.54	1.75	1.96
#3 w_Q	0.73	1.28	1.83

Table 1: Queue Times in Minutes for Cash Registers with 95% CI, Weekdays

	Weekend $L_t = 2$		
Waiting Line	Low 95%	Average	High 95%
#1 w_Q	1.25	1.28	1.32
#2 w_Q	0.56	0.62	0.68
#3 w_Q	0.84	0.99	1.15

	Weekend $L_t = 3$		
	Low 95%	Average	High 95%
#1 w_Q	1.73	1.82	1.90
#2 w_Q	1.35	1.48	1.62
#3 w_Q	0.94	1.41	1.87

	Weekend $L_t = 4$		
	Low 95%	Average	High 95%
#1 w_Q	2.48	2.58	2.67
#2 w_Q	1.81	1.95	2.09
#3 w_Q	0.97	1.50	2.03

Table 2: Queue Times in Minutes for Cash Registers with 95% CI, Weekends

Next, it was a routine matter to examine Work Center (checkout station) utilizations to determine additional staff percentage effort required for various values of the trigger value L_t. These results appear in Table 3.

	$L_t = 2$	$L_t = 3$	$L_t = 4$
Cashier 2	22	23	21
Cashier 3	5	2	1
Total	27	25	22

Table 3: Additional Staff Percent Effort Required

On the basis of these results, store management decided upon the policy of setting L_t to 3. Under that policy, the average of w_Q is slightly greater than one minute, reassuringly less than the annoyance threshold but still allowing the customer to notice, and perhaps to purchase, items, very often items of high profit margin, displayed just ahead of the checkout station (Horowitz and Shilling 1989). Also, the additional staffing effort, considered as a percentage, is small.

INDICATED EXTENSION OF MODEL

On the basis of both experience and theory, the analysts recommended that store management implement a single waiting queue leading to the next available checkout station. Such queues are common in banks and post offices, but not in stores where many customers are pushing shopping carts possibly laden with heavy and/or bulky items. It remains to convince management of the quantitative benefits of this alternate queuing system; revision of the model will make that demonstration possible. The analysts also discussed with management the often readily perceived unfairness of the current system. Typically, when a previously closed checkout station opens, the waiting customers most readily able to jockey to its queue are those at the *ends* of the current queues, yielding, in practice, a last-in-first-out (LIFO) queuing discipline. As a counterpoint, store management believes that architectural changes would be required to thus convert the queuing system.

ACKNOWLEDGMENTS

The authors are most grateful to Professor Onur Ülgen, Industrial and Manufacturing Systems Engineering Department, University of Michigan – Dearborn; and to two anonymous referees, for suggestions improving the clarity, cohesion, and exposition of this paper.

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