Optimizing the service configuration with the least total cost approach

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Abstract *Presents an approach to optimize the service configurations of a student canteen utilizing computer simulation and a total cost function that incorporates both the cost of services and the cost of waiting. The cost of waiting is measured in terms of the impact of waiting on the customer satisfaction and the resulting changes in future repurchases. By collecting data of waiting time and customer satisfaction from a student canteen, first evaluates the impact of waiting time on customer satisfaction and future purchase frequency. Subsequently develops a simulation model to simulate the service processes and waiting line behavior at the student canteen. By varying the number of servers at the two different stages of services and calculating the total cost per customer served, the performance of the system was optimized considering both the service cost and the cost of waiting in term of its impact on future purchases. The approach presented can be used with modification in designing service configurations for a variety of service organizations.*

Introduction

Waiting for service is becoming increasingly common in our daily lives but its effects on service performance evaluations are still relatively limited in business literature. Existing research has suggested that waiting for service is a negative experience for customers and speed of service is becoming a very important service attribute (Katz *et al.*, 1991; Roslow *et al.*, 1992). In addition, waiting may imply significant marketing costs in terms of the detrimental impact of waiting on customer perceptions of the service quality and the corporate image of the service firm (Kostecki, 1996; Pruyn and Smidts, 1998). However, the exact impact of waiting on total cost for any real life problems is often mathematically intractable and difficult to evaluate meaningfully and accurately.

Prior studies generally suggest that the negative impact of service waiting can be controlled by better operational designs and/or perceptions management (Katz *et al.*, 1991; Taylor, 1994, 1995; Jones and Peppiatt, 1996; Davis and Heineke, 1998). The common approach is to first design an efficient operational plan to minimize the actual service waiting time until the cost of

reducing waiting time is greater than the benefits of doing so (Fitzsimmons and Fitzsimmons, 1998). Alternatively, service managers may manipulate the customers' perception of time they have spent waiting in line. Maister (1985) and Parasuraman *et al.* (1985), among others, have established a large body of research suggesting that customer satisfaction is based on the perceived rather than actual service waiting time.

This research attempts to extend the prior studies by Davis and Maggard (1990) and Davis (1991) by evaluating the total cost of two-stage service system and determining the number of servers to minimize the total cost. In our two-stage service system, customers need to wait for purchasing meal tickets (stage 1) and then wait again for exchanging their tickets for food at other nearby facilities (stage 2). As a two-stage service process, there are several important managerial issues in the design and staffing of the service delivery system. For example, are customers equally satisfied with the same amount of waiting time in each stage of the process? If not, what staff strategy should the service manager consider to improve customer satisfaction and profitability?

In this study, we first evaluated the impact of waiting time on customer satisfaction and future purchase frequency using data collected from a student canteen. We also developed a total cost function that incorporates the cost of services and the cost of waiting in term of its impact on future purchase frequency. Subsequently we developed a simulation model to simulate the service processes and waiting line behavior at the student canteen. By varying the number of servers at the two different stages of services and calculating the total cost per customer served, we were able to optimize performance of the system considering both the service cost and the cost of waiting in terms of its impact on future purchases. This approach integrated the marketing perspective of customer satisfaction and the operations management perspective of service cost in designing the service system. Survey data from the field studies allowed a more accurate and realistic estimation of the model parameters and enabled us to determine the optimal number of servers at each facility in the two-stage service system.

Literature review

In studying a typical, two-stage fast food operation, Davis and Maggard (1990) stated that there were two opportunities for the customers to wait during their visit. The first (Q_1) was the initial wait in line prior to placing an order. The second (Q_2) was the time from when the order was placed to when the order was actually received. As the filling of the order took place without interaction with the customer (i.e. "behind the scene"), the service time was incorporated into the waiting time. The service time for stage 2 was considered to be instantaneous while customers were waiting to pick up their orders.

The purpose of Davis and Maggard's study was to determine which of these two waiting times, Q_1 or Q_2 , had a higher correlation with customer satisfaction. After collecting on-site waiting and service time data and requesting customers to complete a self-administered questionnaire, they

developed a customer satisfaction index (CSI) using factor analysis. Once the CSI was defined and matched with individual observed waiting time data, they could determine the nature of the relationship between customer satisfaction and waiting time. Their linear regression analysis showed that customer satisfaction was inversely related to waiting time. Moreover, by comparing the regression equations for stages 1 and 2, they found that a customer's wait prior to entering stage 1 had more impact on customer satisfaction than the wait in stage 2. Their findings imply that the prompt taking of orders is more important than the time waiting for their order to be processed in determining customer satisfaction.

In another related study, Davis (1991) took a step further to determine how long a customer should wait to be served by proposing a total cost model. The total cost model strove to minimize the cost of having a customer wait and the cost of providing good service in a single stage process. A major refinement of his prior model was made by Davis to include a measure of customer satisfaction with waiting time, which was subsequently used to develop a waiting cost function.

Three levels of satisfaction were used in Davis' total cost model corresponding to a range of CSI values. A measure of customer satisfaction was obtained with a customer survey instrument with multiple questions designed to measure the satisfaction construct. These measures were then combined into a single value of CSI using factor analysis. Using an approach similar to that of Davis (1991), these three levels of customer satisfaction are also used later in this study:

- (1) High levels of customer satisfaction will occur when the length of waiting time is equal to or less than the customer's desired expectation and it will have a positive effect on future customer behavior. A parameter V_H is defined as the proportion of increased future repurchase or visit frequency of the customers.
- (2) Acceptable levels of customer satisfaction will occur when the length of waiting time is more than the customer's desired expectation, but less than the customer's predictive expectation. This level of customer satisfaction will have no effect on future customer behavior.
- (3) Customer dissatisfaction or low levels of customer satisfaction will occur when the length of waiting time is greater than both the customer's desired and predictive expectations, which will have a negative effect on future customer behavior. A parameter V_D is defined as the proportion of decreased repurchase or future visit frequency of the customers.

As our study draws heavily and uses many notations from the Davis model, the procedure of developing the total cost model in Davis (1991) is briefly discussed here for reference. In particular, $P_H(t)$, $P_A(t)$, and $P_D(t)$ are the percentages of customers associated with each level of satisfaction, namely,

high satisfaction, adequate satisfaction, and dissatisfaction, respectively. If D is the total customer demand in a given time period and V is the number of visits that a customer is projected to make within that time horizon, the total number of future visits made by these customers, as a function of waiting time of t , can then be defined as:

$$F(t) = DV(\sum(P_H(t)(1 + V_H) + P_A(t) + P_D(t)(1 - V_D))).$$

If the net profit contribution of each customer visit averages X dollars, the total profit contribution over the stated time horizon, as a function of waiting time of t , is:

$$N(t) = XF(t).$$

The cost of waiting can be calculated as the opportunity cost associated with the decrease in the net contribution as the waiting time increases, or:

$$\text{Cost of waiting} = W(t) = N(0) - N(t).$$

On the other hand, the cost of service is a function of number of servers, $K(t)$, required to provide an average waiting time of t , average hourly wage of a server (A), and the length of time horizon in hours (H):

$$\text{Cost of service} = S(t) = K(t)AH.$$

The total cost function, $T(t)$, is the sum of the cost of waiting and the cost of service, depending on the waiting time t :

$$T(t) = W(t) + S(t).$$

To apply this total cost function to a single stage process, Davis (1991) needed to define many model parameters by assumptions in addition to collecting on-site survey data on customer satisfaction and waiting time. Our study will attempt to improve the total cost model by conducting a more comprehensive survey to estimate the parameters in the model. Furthermore, we will develop a simulation model to examine the impact of service configurations on the total cost. Individual customers' waiting times will be recorded to derive the exact cost of waiting. Our approach will enable us to study the complexity of a two-stage, multi-channel queuing system and to determine the optimal number of servers at each facility to minimize the total cost function $T(t)$.

Measuring customer satisfaction

Customer satisfaction is often viewed in marketing literature as a major factor influencing future customer behavior (Kivela *et al.*, 1999). Our customer satisfaction data was obtained through a field study during the first four weeks of a semester, between noon and 2 p.m., in a university canteen in Hong Kong. A team of researchers followed students entering the canteen and timed their waiting times at different stages of services. After they finished all the waiting

and service activities and sat down to eat, the researcher would pass a questionnaire for the student to fill out. A total of 386 completed and useful survey questionnaires were collected over the course of four weeks. The operations of a university canteen could be considered as a simple two-stage process: customers went to the cashier counter to purchase meal tickets and then exchanged their tickets for food and beverage at several facilities inside the canteen (Figure 1).

In order to provide enough coverage for each customer being surveyed, we only targeted the two most popular food items for analysis. These two food items alone, barbecue (BBQ) dishes and daily specials (DS), already accounted for about 45 percent of all purchases in the canteen. Note that some customers might pick up their beverage before approaching the service counters for BBQ dishes or DS. Waiting time for each customer at the facilities for cashiers, BBQ dishes, and DS, was individually recorded without the customers knowing it to ensure that their opinions of satisfaction were free of any bias of actual waiting time.

The self-administered questionnaire (shown in the Appendix) contains questions about their level of satisfaction with the waiting in the two stages. In addition, questions were also included to identify the impact of the waiting

Figure 1.
Exiting the two-stage
service system

satisfaction on their future frequency of purchases. The survey questionnaire was similar to the one used by Davis (1991), which has four items to capture the feeling of satisfaction for the entire process. However, the number of questions was doubled in this study: four items (A1 to A4) for the first stage and the other four items (B1 to B4) for the second stage of the process. Respondents were asked to indicate the level of satisfaction along each of the four dimensions using a scale of 1 to 5 with 1 being “very dissatisfied” and 5 being “very satisfied”. Confirmed by factor analysis, these two sets of four items each provided a multi-item measure of customer satisfaction in stages 1 and 2 of the process. Two separate customer satisfaction indices (CSI) were computed with the normalized factor coefficients, representing a weighted average of the responses.

- For stage 1: $CSI_1 = 0.2620(A1) + 0.2318(A2) + 0.2396(A3) + 0.2666(A4)$.
- For Stage 2: $CSI_2 = 0.2581(B1) + 0.2355(B2) + 0.2465(A3) + 0.2598(B4)$.

Using linear regression analysis, the length of waiting time was found to have a negative impact on customer satisfaction. Specifically, given a waiting time of t (in minutes),

- For stage 1: $CSI_1 = 3.764334 - 0.250016(t) \quad R^2 = 0.8131$.
- For stage 2: $CSI_2 = 3.990245 - 0.3225(t) \quad R^2 = 0.9084$.

The nature of the relationship between customer satisfaction and waiting time was reflected in the above two linear regression equations. As expected, customer satisfaction declined as waiting time lengthened. By examining CSI_1 and CSI_2 closely in Figure 2, we found that waiting time at food taking stage (stage 2) has a more significant impact on customer satisfaction. This result contradicts the finding by Davis and Maggard (1990) that the waiting time at

Figure 2.
CSI and waiting time

stage 2 in a fast food environment has a less significant impact on customer satisfaction. The reason for the differences in findings can be caused by the way that the customer will have to wait in stage 2. In Davis and Maggard's study, a customer's order in the form of duplicate receipt was passed to the food packer right after the customer paid the money and got the receipt in the first stage. Customers could wait at their table for the call from the food packer to pick up the food. Therefore, the waiting was more pleasant. In the case of our study, customers had to travel from the cash counter to the food picking counter; wait in line to hand in the receipt and wait again for the food server to fill the food order. Therefore the waiting was not as pleasant as in Davis and Maggard's study. The difference in findings between this and the previous study lends further support to previous research findings that how you wait may have a more significant impact on customer satisfaction than the length of the wait (Maister, 1985).

Model development

As a result of high customer interaction in the service delivery process, service operations face a trade-off between better customer service (as manifested by reduced waiting time) and increased labor utilization. That has led to the development of a total cost of waiting model consisting of two major components: the cost of providing the service and the cost of having the customer wait. The service manager must, as a consequence, decide the level of service to minimize the sum of these two cost components.

Prior research has established the correlation between customer satisfaction and waiting time. In Davis (1991), three levels of customer satisfaction were subjectively defined according to the CSI values on a scale of 1 to 5. In particular, high satisfaction had a CSI value of 4 and above; adequate satisfaction had a CSI between 2 and less than 4; dissatisfaction had a CSI less than 2. Using the standard error as a measure of the CSI variance around the regression line that related customer satisfaction to waiting time, the percentage of customers that fell within each designated CSI range, as a function of waiting time t , could be calculated. See Davis (1991) for details. Using the calculated percentages of highly satisfied ($P_H(t)$), adequately satisfied ($P_A(t)$), and highly dissatisfied ($P_D(t)$) customers and a set of assumed parameters in term of the increase or decrease in frequency of future visits, total number of future visits and average contribution per sale, relationship between the total cost of waiting and waiting time was derived. Using a steady state queuing model, the number of servers needed to have a specific average waiting time was also derived thus calculating the cost of services.

In this study, he assumed that the satisfaction index at different waiting time t is normally distributed around the mean. Furthermore, he calculated the cost of waiting and cost of services based on the average waiting time rather than the individual waiting time. Because of the random variations in the queuing process, individual customers' waiting time and the subsequent costs can be quite different from the averages; the model developed may not provide

the best solution for designing the service system. Furthermore, the model just considered a single channel and single stage waiting system.

In the present study, we collected individual data that matched customer satisfaction with waiting time so we could apply regression analysis to derive the relationships between the percentages of different levels of satisfaction and the waiting time. Statistical tools in SAS were used for data editing, coding, and analysis. Given a waiting time of t at Stage i , $P_{D_i}(t)$ is the percentage of dissatisfied customers; $P_{H_i}(t)$ is the percentage of highly satisfied customers; and $P_{A_i}(t)$ is the percentage of adequately satisfied customers. We used the same cut-off points for the three levels of satisfaction as used by Davis (1991). The following regression equations represented the best-fit estimates of the proportion of customer satisfaction as a function of waiting time:

- Stage 1:

$$P_{D1}(t) = 1.1(t)^2 \quad R^2 = 0.8199$$

$$P_{H1}(t) = 55.323 - 24.5933(t) + 3.759(t)^2 - 0.1929(t)^3 \quad R^2 = 0.8559$$

$$P_{A1}(t) = 100 - P_{D1}(t) - P_{H1}(t).$$

- Stage 2:

$$P_{D2}(t) = 0.1944(t)^3 \quad R^2 = 0.9166$$

$$P_{H2}(t) = 66.2941 - 31.9849(t) + 5.5129(t)^2 - 0.32166(t)^3 \quad R^2 = 0.9186$$

$$P_{A2}(t) = 100 - P_{D2}(t) - P_{H2}(t)$$

Using the two sets of functions, we were able to compute the individual cost of waiting for the customers based on their waiting times at both stages. Furthermore we also considered two channels of services in the second stage: one for BBQ dishes and the other one for DS. In doing so, this study not only expanded the previous study, but it also examined the effect of waiting time of different service products on customer satisfaction within the same process. Our analysis used primarily the notations and methodology first mentioned in Davis (1991) with the extended application of two stage services and two service channels in stage 2. In doing so, we, for example, need to define V_{ij} to be the immediate future visit index of customer j after experiencing waiting time t_i at stage i in the service system. The value of V_{ij} implies the increased revenue that can be generated because of a reduced customer waiting time. Management can use this value to decide for the trade-off of adding additional servers. The future visit index of customer j , as a function of his/her current satisfaction level given a waiting time t_i could be calculated separately as:

$$V_{ij} = P_{H_i}(t_i)(1 + V_{H_i}) + P_{A_i}(t_i) + P_{D_i}(t_i)(1 - V_{D_i}) \text{ for } i = 1, 2.$$

The waiting costs at each stage were then calculated with a net profit contribution of HK\$9.20 (or US\$1.18, an estimate provided by the canteen manager) per customer visit. Eventually, the total waiting cost, which was the sum of waiting cost and service cost, could be derived and minimized. The cost

of providing service was calculated based on HK\$25 per server per hour. In our business scenario, two major products were offered at stage 2 with significantly different waiting times. To accurately reflect the true waiting cost for BBQ and DS customers, individual computations were carried out for estimating the waiting and service cost at the cashier counter, BBQ counter, and DS counter in the following equations:

Total cost per customer ordering BBQ dishes = average waiting cost per BBQ customer + labor cost per customer at cashier + labor cost per customer at the BBQ counter.

Total cost per customer ordering daily special dishes = average waiting cost per DS customer + labor cost per customer at cashier + labor cost per customer at the DS counter.

Varying the number of servers at each counter and calculating the average cost per customer served would allow us to identify the least average cost configuration for the canteen service process.

Analysis and result

Standard queuing theory involves the mathematical study of waiting lines. The goal of most queuing problems is to achieve an economic balance between the cost of service and the cost associated with waiting. Since both the inter-arrival and service times are usually random variables in a real life service system, the problem can be quite complicated to solve mathematically. In particular, for a two-stage, multi-channel service system like the one in this study, there are dependency and interactions between the two stages, which makes it even harder to analyze with any existing mathematical models.

An alternative way of analyzing such complicated waiting problems is to employ computer simulation. We built a simulation model of the queuing system using ServiceModel (ProModel Corporation, n.d.). ServiceModel software is developed and marketed by ProModel, one of the most popular simulation software vendors in the world. ServiceModel is designed based on the success of ProModel and customized for simulating service systems. ServiceModel's rich animation capability makes it very easy for managers to visualize and validate different simulated scenarios.

The simulation design for this study consisted of 18 system configurations with three parameter choices for the number of cashiers and servers at the BBQ and DS facilities, representing scenarios of plus and minus one server of the current configuration. For each system configuration, we performed a total of ten simulation runs and computed the average cost for further analysis. For each simulation run, we recorded the actual waiting time of each customer in the two different stages. We computed the total cost per customer including the waiting cost and the service cost using the individual waiting time. Table I shows the average costs per customer under different combinations of numbers of servers in stage 1 and 2. Note that the results can only be generalized to other problems with similar model parameters and assumptions. However, since the

simulation methodology is so flexible, management can easily modify the model used in this study for their particular situation.

From Table I, the highest average costs per customer ordering BBQ and DS dishes are HK\$4.15 and HK\$2.11 respectively, which corresponds to a system configuration of seven cashiers and one server each at the BBQ and DS counters. This result is as expected since such a configuration represents the minimum staffing requirement and the maximum waiting time for customers. The lowest average cost per customer ordering BBQ dishes is only HK\$0.93, which corresponds to a system configuration of nine cashiers and two servers at the BBQ counter. On the other hand, the lowest average cost per customer ordering DS dishes is \$0.60, which corresponds to a system configuration of nine cashiers and two servers at the DS counter.

Adding more servers at the BBQ or DS counters did not always produce a lower average cost per customer. For example, if we added an extra server at the BBQ or DS counter to the optimal system configuration (i.e. from two to three servers), the average cost would rather increase slightly. The utilization of the second stage facility depended largely on the performance of cashiers at the first stage, which controlled the arrival rate for BBQ and DS counters.

The effects of varying the number of servers at all of these facilities can be investigated through a standard matched sample *t*-test. The results of the matched sample *t* tests for different numbers of servers are presented in Table II. The average cost per customer decreased dramatically when the number of servers was increased from one to two for both BBQ and DS counters. However, the average cost began to rise slightly when the number of

Number of cashiers	Number of BBQ servers			Number of DS servers		
	1	2	3	1	2	3
7	4.15	1.72	1.82	2.11	1.41	1.55
8	3.73	1.01	1.12	1.61	0.83	0.85
9	3.39	0.93	1.04	1.47	0.60	0.65

Table I.
Summary of average
cost per BBQ and DS
customer

Facility in which customers are served	Original number of servers –1	Original number of servers	Original number of servers + 1	Test statistic	d.f.	<i>p</i> -value
	(\$)	(\$)	(\$)	<i>t</i>		
Cashier	2.13	1.52	–	–14.1165	179	< 0.0001
Cashier	–	1.52	1.35	–7.0737	179	< 0.0001
BBQ counter	3.75	1.22	–	–63.9326	89	< 0.0001
BBQ counter	–	1.22	1.33	6.6197	89	< 0.0001
DS counter	1.73	0.95	–	–11.5482	89	< 0.0001
DS counter	–	0.95	1.02	1.8456	89	0.0341

Table II.
Pair-wise comparison
of average cost per
customer for various
system configurations

servers was increased from two to three. Increasing the number of servers at the BBQ and DS counters was only beneficial as long as the cost of waiting outweighed the cost of service. Although the dollar value savings might seem to be small, the increase of the average costs per customer served were statistically significant for the BBQ counter ($p < 0.0001$) and for the DS counter ($p = 0.0341$) when the number of servers was increased from two to three.

Increasing the number of cashiers was proved to be beneficial in all cases investigated in this study. While the average cost might change, the server cost portion (as opposed to the customer waiting cost portion) of it did not change much. This is because the cost for hiring an additional cashier is relatively low in Hong Kong. Given such a large number of customers served each day, any change of the average server cost per customer was insignificant to alter the model results. Given a minimum of seven cashiers in the service system, any increase of the number of cashiers would have a more significant impact ($p < 0.0001$) of reducing the average cost per customer for any combination of BBQ and DS servers. When nine servers were used at the cashier, the total cost per customer was the lowest for both the BBQ and DS customers. It seems that a further increase in cashiers might decrease the cost per customer further. However, we did not examine the cost under such situations because it is physically impossible to have more than nine servers at the cash counter. Therefore, we concluded that nine servers at the cashier counter were optimal given the physical constraint.

The average cost per customer did not appear to go down when the number of servers at BBQ and DS was increased from two to three even when the number of servers at the cashier is nine. This is because the waiting line problem for the stage 1 facility (i.e. the cashiers) would no longer be a serious one after the number of cashiers reached nine. When an extra server was added to the BBQ or DS counters, the utilization of these facilities would also go down further. As a result, the average cost per customer began to increase when the cost of providing service exceeded the cost of waiting, as in the case of three BBQ or DS servers.

Managerial implications

Determining how long a customer should wait has long been a major decision for service managers who face a trade-off between minimizing the cost of customer waiting and the cost of providing speedy services. As modern economies progressively turn into service economies, managing customer waiting is becoming an important marketing problem to many service companies. Long waits are likely to affect negatively the performance evaluation of service companies. By learning how to effectively deal with waiting lines, service companies can improve customer satisfaction and their corporate images.

This study has presented one way to optimize the configuration of a service system by alternating the number of servers with the least average customer cost approach. The existing configuration consists of eight cashiers and two

servers each at the BBQ and DS counters. Through computer simulations and subsequent calculations of total cost, we examined the total cost per customer for alternative system designs with a plus and minus one server at each of these three counters. Our simulation analysis suggested that the current configuration (i.e. eight cashiers, two BBQ servers, and two DS servers) implemented by management has been providing adequate service for the customer with an average cost of HK\$1.01 per BBQ customer and HK\$0.83 per DS customer. However, our simulation results also suggested that adding one more cashier, while keeping two servers each at the BBQ and DS counters, could further reduce the average cost to HK\$0.93 per BBQ customer and HK\$0.60 per DS customer. While the savings in dollar value seemed small, the difference of the average cost per customer was statistically significant. Given a total of about 3,000 customers a day for the canteen, the savings would have been between HK\$7,200 and HK\$20,700 a month. However, the savings described were not measurable from an accounting standpoint, and would not show up in the financial statements of the canteen right way. The savings will be realized in the future in terms of improved revenue or reduced costs.

Other than approaching this waiting line problem through operational improvement, service managers could approach the same problem through perception management. Extensive research has indicated that the perception of waiting time, instead of actual waiting time, is the determining factor for customer satisfaction. If customers think that their wait is short enough, it does not really matter how long it actually is. A major benefit of perception management is that it is often very inexpensive to implement (Katz *et al.*, 1991). Customers who are unoccupied tend to perceive longer waiting times than customers who are occupied during their wait (Davis and Heineke, 1994). To occupy the customer's time in a waiting line, management may consider options such as interesting displays or music in the waiting lobby of the canteen.

Conclusions

In this study, a total cost model was built to incorporate both operational cost of providing services and the marketing cost of losing future sales as a result of waiting for services. Survey data from the field studies of a university canteen allowed a more accurate and realistic estimation of the parameters of the total cost model. Furthermore, we built a computer simulation model that allowed us to collect the individual waiting times under different service configurations. The combined use of the simulation model and the cost model enabled us to determine the optimal number of servers at each facility in the two-stage service system.

Our simulation model and the subsequent statistical analyses have revealed that the optimal configuration is to have one extra cashier at stage 1 while maintaining the same number of servers at BBQ and DS counters at stage 2 (i.e. a service system of nine cashiers, two BBQ servers, and two DS servers). However, since the cost savings are relatively small, management may also

consider keeping the current system configuration of eight cashiers, two BBQ servers and two DS servers if they can improve the waiting perception of the customers. Even better system configurations are possible and can be investigated through computer simulation if management is willing to make significant changes in the operations sequence or the layout of the facilities.

The interpretation of the findings in this study requires knowing the various assumptions and parameters used as this study suffered many limitations commonly found in other simulation studies. Sensitivity analyses were carried out for certain system parameters. For example, we found our recommendation still valid for a wide range of cost per DS server per hour values after increasing the BBQ server cost value four-fold (from HK\$25 to \$100). Only beyond that level of server cost, the optimal system configuration will change to eight cashiers (i.e. one fewer cashier) and two BBQ servers as the cost of service begin to outweigh the cost of waiting for the BBQ customers. Likewise, the DS server cost needs to exceed HK\$250 per hour (ten times the current level) before the recommended configuration will change.

This paper contributes to the academic literature by extending the cost model proposed by Davis (1991) from a single stage service system to a two-stage service system and by empirically estimating the parameter for the cost model. Furthermore, this study demonstrates how a computer simulation model can be used to optimize the performance of service operation system utilizing a total cost function. The total cost function includes both the service cost and the waiting cost in term of the impact of waiting on customer satisfaction and future purchase. This paper presents a new approach that can be used to make operational improvements taking into consideration of customer satisfaction and its impact on future revenue.

Like other simulation-based studies, the results of this study must be interpreted with caution after considering the model parameters and assumptions. However, the approach presented in this paper can be used to make operational improvements in many service settings. Therefore, this study has both significant managerial implication as well as academic contributions.

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Appendix. Survey questionnaire

Part A: waiting experience for purchasing a meal ticket (1 = very dissatisfied, 5 = very satisfied):

- A1. Your opinion of the speed of service.
- A2. Waiting time compared to your prior waiting expectation.
- A3. Waiting time compared to other fast food restaurants.
- A4. Your overall satisfaction of waiting experience.

Part B: waiting experience for getting the food (1 = very dissatisfied, 5 = very satisfied):

- B1. Your opinion of the speed of service.
- B2. Waiting time compared to your prior waiting expectation.
- B3. Waiting time compared to other fast food restaurants.
- B4. Your overall satisfaction of waiting experience.

Part C: future visit plan:

- C1. How would your waiting experience for purchasing a meal ticket today affect your future visit plan? (Increase/decrease future visit by percentage).
- C2. How would your waiting experience for getting the food today affect your future visit plan? (Increase/decrease future visit by percentage).