Model, analysis and application of employee assignment for quick service restaurant

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Abstract
This paper not only applies queuing theory with finite servers and queuing capacity to the mathematical model called optimal employee assignment (OEA) model, but also introduces the customer reneging function into its objective to search the cost minimization with the consideration of the customer arrival rate. Additionally, different employee experience in related job presents different service time and wage payment in this study. Moreover, a step-by-step algorithm to achieve the optimal employee assignment for open counters of the quick service restaurant is also provided. Furthermore, a computerized tool written by Visual Basic 6.0 to reach the minimum total system cost as well as perform the simulated analysis is completely proposed. The application of OEA model in constructing a decision support table for a case restaurant is also followed. This study definitely contributes a practical computerized tool for decision makers in employee management.

Keywords: Queuing capacity, customer reneging function, computerized decision tool, employee management.

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1. Introduction

The waiting line model has been applied in a lot of researches to resolve the problems in the scope of manufacturing and management [7]. In both daily-life and industrial field, queuing theory not only has a wider potentiality to solve a variety of practical problems but also opens for fundamental researches. Practically, some factors such as available/capacitated resources, human behaviors, etc should be considered in discussing decision-making problems of management.

At first, the available resources are discussed. Lee et al. [6] proposed a concept that server unavailability increases the mean queue size and the mean waiting time, which can be often observed in daily-life, manufacturing industry and many other fields. Recently, the decision through queuing theory under available servers for a waiting system has been widely applied [10]. Since the whole available servers are operating, the mean queue size and the mean waiting time will simultaneously increase with respect to large arrivals [6]. The other application of available resource is also focused to develop a maintenance system as a finite birth and death process (M/M/S/F queue) [11].

Another important factor is capacity. The topic of capacity is focused by lots of works, such as the investigations for the effective allocating policies of network resources and the capacitated concerns in a high speed network [3], the determinations for the queuing capacities of the upstream and the downstream bottlenecks in the production system [5], the discussion of a single-server queue for finite buffer space in a discrete-time environment [2]. Hence, this work is concentrated on considering the constraint of finite queuing space (capacity), etc.

Then human behavior, the third factor, is discussed in this study. Stank et al. [8], conducted a study to investigate how the service performance effects on customers’ loyalty, and then concluded a positive relationship between the service performance and the customer’s loyalty. Conventionally, the probability of customer leaving will decrease if a customer has high loyalty. Chebat et al. [1] stated that the particular attribution of the cause for waiting involves both emotions and cognition. Therefore, customer behaviors such as balking and reneging [9] have arrested more attention recently. In fact, a customer who finds all channels busy must decide to either join the queue or leave. Why customers won’t intend to get in the service system? The reason is a large queue size of the system. If a customer decides to leave the system
before joining a queue, this is balking behavior. In addition, the other important human behavior, reneging, means that a customer gives up waiting and leaves the system after spending some time in wait. This article considers the behaviors of customer balking and reneging at the quick service restaurant. The M/M/C/N queuing model [9] is applied to represent the customer balking behavior, and a customer reneging function is provided to describe the behavior of customer reneging in this paper.

Additionally, how many counters should operate under the consideration of available servers to minimize the system cost [4] has always encountered by a manager of the quick service restaurant. Thus, determining the number of servers (operating counters) and employees with different experiences to minimize the system cost is considered. Therefore, a mathematical model with the considerations of available servers, queue capacity (balking condition), different experiences with different service rates, and the customer reneging function (reneging condition) is presented to determine the optimal number of servers and experiential levels of employees for minimizing the system cost. Besides, a step-by-step algorithm, a computerized tool and a decision support table are developed and described in this study.

2. Notations and assumptions

Before formulating the problem, several notations and assumptions are described as follows.

2.1 Notations

\( n \) : the maximum number of service counters in the restaurant.

\( k \) : the number of counters for service; where \( 1 \leq k \leq n \).

\( J \) : \( J = \{ j | j = 0, 1, 2, \ldots, M \} \); \( J \) is a set of the employee experience; where \( j \) means the employee experience (number of years) in the related job \( j = 0 \) means an employee with no experience and \( M \) presents the largest available experience of employees.

\( Y_k \) : \( Y_k, Y_k = (y_1, y_2, \ldots, y_k) \) and \( Y_k \in J^k \) is a vector presenting the experience of \( k \) employees assigned in the \( k \) operating counters in order; where \( y_i \) means the employee experience \( \forall y_i \in J \) assigned in the \( i \)-th counter.

\( N \) : the queuing capacity indicating the maximum admissible number of customers (both in service and waiting) in the system.
\( G(t) \) : the customer reneging function indicating the probability of a customer leaving under spending \( t \) time in wait; where \( t \) is evaluated as the mean waiting time of a customer in the system.

\( L_s^{Y_k} \) : the mean number of customers in the system without considering customer reneging under \( k \) employees with \( Y_k \) experiential vector assigned.

\( L_q^{Y_k} \) : the mean number of customer in the waiting line without considering the customer reneging under \( k \) employees with \( Y_k \) experiential vector assigned.

\( W_q^{Y_k} \) : the mean waiting time of a customer spending in the system under \( k \) employees with \( Y_k \) experiential vector assigned.

\( w(y_i) \) : the wage payment per unit time for an employee with \( y_i \) experience.

\( c_{Y_k} \) : the mean cost per operating counter per unit time under \( k \) employees with \( Y_k \) experiential vector assigned.

\[
\sum_{i=1}^{k} w(y_i) \\
\]

Here, \( c_{Y_k} = \frac{1}{k} \).

\( c_w \) : the mean waiting cost of a customer per unit time.

\( a \) : the mean cost of losing unit customer per unit time.

\( \lambda \) : the mean number of arrivals per unit time.

\( \mu_{Y_k} \) : the mean employee service rate under \( k \) employees with \( Y_k \) experiential vector assigned.

\[
\sum_{i=1}^{k} S(y_i) \\
\]

Here, \( \mu_{Y_k} = \frac{1}{k} \); where \( S(y_i) \) means the service rate of an employee with \( y_i \) experience.

\( Z(Y_k) \) : the estimated number of customers leaving the system with considering customer reneging function, \( G(t) \), under \( k \) employees with \( Y_k \) experiential vector assigned. Since \( W_q^{Y_k} \) presents the mean waiting time of a customer in the system, \( G(W_q^{Y_k}) \) means the estimated probability for a customer leaving the system. Thus, the estimated number of customers leaving the system, \( Z(Y_k) \), is estimated to be \( L_q^{Y_k} G(W_q^{Y_k}) \).

\( N(Y_k) \) : the estimated number of customers staying in the system with considering the customer reneging function, \( G(t) \), under \( k \) employees with \( Y_k \) experiential vector assigned; where, \( N(Y_k) = L_s^{Y_k} - Z(Y_k) \).
$H$ : the mean fixed cost of a restaurant per unit time (not including the employee cost).

2.2 Assumptions

1. The restaurant is operated based on FCFS (First Come First Serve) to serve the customers and there is one employee assigned at each counter.
2. An employee with higher experience performs better efficiency in serving customers than those with lower experience; i.e. as $\frac{\partial S}{\partial y} \geq 0$.
3. There are no balking customers if the queuing capacity is not full. On the other hand, while the queuing capacity is full, the incoming customers won’t enter the system. The waiting area of a restaurant is regarded as the queuing capacity in this study.
4. The customer reneging function, $G(t)$, is assumed to be an increasing function of the mean waiting time $t$ for a customer.
5. The service time per customer at each counter is assumed to be exponential probability distribution, and the customer arrival rate is assumed to follow Poisson process.

3. Model formulation

After explicating the notations and assumptions, the mathematical model to achieve the minimum cost under constrained servers and queuing capacity for a quick service restaurant is constructed. In this study, $kc_{Y_k}$ describes the service cost of all open counters per unit time. $c_wN(Y_k)$ presents the waiting cost for this system per unit time. Also, $aZ(Y_k)$ and $H$ denote the cost of losing customers and the fixed cost of the restaurant per unit time respectively.

In addition, Eq. (2) means that the number of open counters, $k$, should satisfy the constraint $1 \leq k \leq n$. This constraint limits $k$ to be greater than or equal to one and less than or equal to the maximum number of counters $n$. Moreover, Eq. (3), $Z(Y_k) = L_{W_k}g(Y_k)$, presents the estimated number of customers leaving the system, and Eq. (4), $N(Y_k) = L_{Y_k} - Z(Y_k)$, means the estimated number of customers staying in the system. Hence, the optimal employee assignment (OEA) Model is constructed below.
\[
\begin{align*}
\text{min} & \{kc_{Y_k} + c_wN(Y_k) + aZ(Y_k) + H\} \\
\text{s.t.} & \ 1 \leq k \leq n; \text{ where } k \text{ is an integer.}
\end{align*}
\]

\[\begin{align*}
Z(Y_k) &= L_q^Y G(W_q^{Y_k}) \\
N(Y_k) &= L_q^Y - Z(Y_k).
\end{align*}\]

Here, \(c_w, n, \lambda, N, a, \text{ and } H\) are given parameters; \(w(y_i), S(y_i), G(t)\) and \(J\) are given functions and set; \(k\) and \(Y_k\) are the decision variables of the OEA Model. Thus, a step-by-step algorithm for achieving the optimal solution is developed and shown in the following section.

4. Step-by-step Algorithm

After introducing the objective function and its associated constraints, a step-by-step algorithm for reaching optimal solution is proposed as follows. Initialize integer \(k \forall k \in [1, n]\), then let \(k = 1\) and go to following steps.

**Step 1.** List and order all possible \(Y_k\) and assign each possible \(Y_k\) a number \(\alpha\) in sequence. A feasible \(Y_k\) is denoted as \(Y_k^{\alpha} = (y_{\alpha 1}^{0}, y_{\alpha 2}^{0}, \ldots, y_{\alpha k}^{0})\). Then, search all possible values of \(\alpha\) and let the maximum one as \(m_k\). i.e. \(\{\alpha\} = \{1, 2, 3, \ldots, m_k\}\).

Set \(\alpha = 1\) and go to next step.

**Step 2.** Calculate \(c_{Y_k^{\alpha}} = \frac{1}{k} \sum_{i=1}^{k} w(y_{\alpha i}^{0})\) and \(\mu_{Y_k^{\alpha}} = \frac{1}{k} \sum_{i=1}^{k} S(y_{\alpha i}^{0})\).

Then compute \(\rho = \frac{\lambda}{\mu_{Y_k^{\alpha}}}\)

\[
\begin{align*}
Y_0^{Y_k^{\alpha}} = & \left\{ \begin{array}{ll}
\frac{1}{\rho} \left( \frac{\prod_{\bar{n}=0}^{k-1} (\rho)^n}{n!} + \sum_{\bar{n}=0}^{k} (\rho)^{\bar{n}} \left[ 1 - \left( \frac{\rho}{\bar{n}} \right)^{N-k+1} \right] \frac{k!}{k} \right) & \rho \neq 1, \\
\frac{1}{\rho} \left( \frac{\prod_{\bar{n}=0}^{k-1} (\rho)^n}{n!} + \sum_{\bar{n}=0}^{k} (\rho)^{\bar{n}} \left[ 1 - \left( \frac{\rho}{\bar{n}} \right)^{N-k+1} \right] \frac{k!}{k} \right) & \rho = 1.
\end{array} \right.
\end{align*}
\]
If \( k \mu Y^k Y^\alpha - \lambda_{\text{eff}} < 0 \), set \( TC_{Y^k Y^\alpha} = \infty \) and go to Step 3.

Otherwise compute

\[
L_{q_k}^{Y^\alpha} = \begin{cases} 
(\rho)^{k+1} \frac{1}{(k-1)!} (1-\rho) N^{-k} N_k \sum_{i=1}^{N} \left( \frac{\rho}{k} \right)^{N-k} \left( 1-\frac{\rho}{k} \right) \quad \rho \neq 1 \\
-\rho^{-k} (N-k) \frac{\rho^{-N+k+1}}{k!} N_k \sum_{i=1}^{N} \left( \frac{\rho}{k} \right)^{N-k} \left( 1-\frac{\rho}{k} \right) \quad \rho = 1
\end{cases} [9]
\]

\[
L_{s_k}^{Y^\alpha} = L_{q_k}^{Y^\alpha} + \frac{\lambda_{\text{eff}}}{\mu Y^k Y^\alpha},
\]

\[
W_{q_k}^{Y^\alpha} = \frac{L_{q_k}^{Y^\alpha}}{\lambda_{\text{eff}}},
\]

\[
Z(Y^k Y^\alpha) = L_{q_k}^{Y^\alpha} G(W_{q_k}^{Y^\alpha}),
\]

\[
N(Y^k Y^\alpha) = L_{s_k}^{Y^\alpha} - Z(Y^k Y^\alpha),
\]

\[
TC_{Y^k Y^\alpha} = k c Y^k + c_w N(Y^k Y^\alpha) + a Z(Y^k Y^\alpha) + H.
\]

Save \( \alpha, k, Y_k^\alpha, TC_{Y_k^\alpha} \) and then go to Step 3.

**Step 3.** If \( \alpha + 1 \leq m_k \), set \( \alpha = \alpha + 1 \) and go to Step 2.

Otherwise, go to next step.

**Step 4.** If \( k + 1 \leq n \), set \( k = k + 1 \), go to Step 1.

Otherwise, go to next step.

**Step 5.** Find the minimum total system cost \( TC^* = \min_{k, \alpha} \{ TC_{Y_k Y^\alpha} \} \).

Let its associated \( k \) be \( k^* \)

\[
Y_k^{\alpha^*} = (y_1^{\alpha^*}, y_2^{\alpha^*}, \ldots, y_k^{\alpha^*}) \text{ be } Y_k^{\alpha^*}.
\]

5. **A case example**

A MacDonald restaurant located at ShinSheng S. Rd. Taipei Taiwan is selected to be the case restaurant in this study, and its maximum number of counters is six \( (n = 6) \). The experiential set of employees for this case restaurant is \( J = \{0,1,2,3,4\} \), and the time interval is ten minutes. We try to make the optimal employee arrangement in the night shift (6:00 pm ~10:00 pm) of weekend for this case. At the
night time of weekend, the mean number of customers arrived per ten minutes is estimated to be 12 customers ($\lambda = 12$), the employee service rate function and wage payment function are evaluated as $S(y_i) = 2 + 0.8055 \log_5(100y_i + 1)$ customers/(employee-ten mins) and $w(y_i) = 0.3333 + 0.2241 \log_{10}(100y_i + 1)$ dollars/(employee-ten mins). The diagrams for these two functions are shown in Figure 1. The queuing capacity is 25 customers ($N = 25$) and the waiting cost per customer per unit time is evaluated as 0.4 dollars ($c_w = 0.4$). Moreover, the cost of losing unit customer and the fixed restaurant cost per ten minutes are estimated as 1.6 dollars ($\alpha = 1.6$) and 3.5 dollars ($H = 3.5$).

![Figure 1](image1.png)

**Figure 1**

The diagram of $S$ and $w$ functions

Set customer reneging function be $G(t) = 1 - e^{-rt}$, and the parameter $r$ is assumed to be 0.8 in this case example. With the information above, the step-by-step algorithm is then applied. Then start the whole algorithm proposed in the previous section to find out the optimal solution. In addition, a computerized decision tool for seeking the optimal solution is written by VB 6.0 program. The window of this computerized decision tool is shown in Figure 2 and the optimal solution of night shift for the proposed case restaurant derived from the computerized decision tool is listed as follows.

1. Four is the optimal number of counters to be opened; i.e. $k^* = 4$.
2. The optimal employee assignment is to assign three employees with one-year experience and one employee with three-year experience; i.e. $Y_k^* = \{1, 1, 1, 3\}$. 
3. Based on above allocation, the optimal total system cost is 8.190 dollars per ten minutes; i.e. $TC^* = TC_Y^* = 8.190$ dollars per ten minutes.

![Figure 2](image)

**Figure 2**
The window for the computerized decision tool (Note: the optimal solution of case restaurant is also shown in this window)

6. Simulated analysis

In this section, the simulated analyses for changing key parameters are completely conducted through the simulated analysis program (written by VB 6.0 program). A larger customer arrival rate (from 2 to 25) leads to higher total system cost (Figure 3(i)). In addition, a larger customer arrival rate goes to more counters opened and higher service rate as shown in Figure 3(ii) and (iv). It is because that the increase of the customer arrival rate requires enough service rate to prevent the case restaurant from the full of the queuing capacity.
The changes of (i) total system cost, (ii) assignment, (iii) number of customer staying in the system, and (iv) service rate with increasing $\lambda$.

Figure 4 presents that a larger queuing capacity (from 5 to 35 customers) has a minor impact on both total system cost and service rate (Figure 4(i) and (iv)). Through the simulation of varied queuing capacity, the number of customers leaving the system will reduce and become stable if the queuing capacity is over 12 (Figure 4(iii)). Such phenomenon provides an interesting finding that the waiting size (area) of the proposed case restaurant can be considered to rearrange to be smaller (from 25 to 12) and the spared space can be rebuilt to be an extra dinning area.

Figure 5(i) shows that a higher cost of losing customer (from 1.5 to 4 dollars) only leads to a minor increase of the total system cost. Conven-
tionally, a higher cost of losing customer should gain a significant high total system cost. This conception is contradicted in Figure 5(i). In fact, while a higher cost of losing customer happens, the optimal service rate is adjusted to be larger and makes the mean number of customers leaving the system decrease (shown in Figure 5(iv) and (iii). The combination of the increasing service cost and the decreasing number of leaving customer balances the total system cost, thus there is no significant vibration on the total system cost. In addition, a higher experience needed of the employee is also shown in Figure 5 (ii).

A higher waiting cost per customer per unit time (from 0.3 to 3) leads to more total system cost and service rate (shown in Figure 6(i) and (iv)).
It is that a higher waiting cost per customer raises the total system cost while the number of the customers staying in the system remains constant. Through the simulation of increasing waiting cost, it reveals that the mean number of customers staying in the system tends to be smaller (Figure 6(iii)) in order to balance the increasing costs of waiting and servicing.

Last, a higher value of $r$ (the parameter of customer reneging function) presents higher probability for a customer to leave. Figure 7(i) shows that a higher $r$ (from 0 to 50) leads to a minor increasing total system cost. Since the probability of losing customer increases, the optimal service rate then tends to lift (Figure 7(iv)) for reducing the number of customers staying in the system (Figure 7(iii)). Due to the combination
of the decreasing number of customers staying in the system and the increasing service rate, a significant vibration of the total system will not happen. Figure 7(ii) reveals while the number of counters opened remains unchanged, the experiential levels of the assigned employees are tending to be larger with increasing $r$.

![Figure 6](image)

The changes of (i) total system cost, (ii) assignment, (iii) the number of customer staying in the system, and (iv) service rate with increasing $c_w$.

7. Decision support table

This section provides one aspect of applications for OEA model, the construction of decision support table for the case restaurant called DST_{for Mac}. This DST_{for Mac} can be developed by Figure 3(ii), and
the thorough descriptions of $\text{DST}_{\text{for Mac}}$ are listed in Table 1. The case, MacDonald, restaurant opens from 6:00 am to 10:00 pm on weekend and has four shifts to be changed. These four shifts are: the first shift is from 6:00 am to 10:00 am, the second shift is from 10:00 am to 2:00 pm, the third shift is from 2:00 pm to 6:00 pm, and the last shift is from 6:00 pm to 10:00 pm. The mean customer arrival rate of each shift is estimate as 6, 10, 8, 12 customers per ten minutes in order.

Applying $\text{DST}_{\text{for Mac}}$, two employees with four-year experience are recommended to be assigned for the first shift, three employees with four-year experience are assigned in the second shift, three employees with one-
year experience are assigned in the third shift, three one-year experiential employees and one three-year experiential employee are assigned in the last shift. This result indeed presents the optimal solution and functions as a reference of employee arrangement on weekend for the manager of the case restaurant.

8. Conclusions

This study applies the multi-station queuing theory by considering customer arrival rate, balking and reneging behaviors to achieve

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the optimal number of open counters and the optimal experiential level of the employee for each counter to minimize the total system cost. In addition, the number of customers staying in the system, finite servers, queuing capacity, different service rate and wage payment for employees
with different experiential levels and the related costs are considered simultaneously into the mathematical model, OEA model, for minimizing the total system cost. Although this study covers a hard and complicated issue, this issue becomes easily solvable through the OEA model and the proposed step-by-step algorithm.

The main contributions of this study are as follows: Firstly, the decision support table of the case restaurant, DST_{Mac}, with respect to different customer arrival rates is founded. Based on DST_{Mac}, the case restaurant can quickly determine how many counters should operate and which employees would assign for an evaluated customer arrival rate. Secondly, a computerized employee assignment tool is well developed to solve the complicated and time-consuming computation for optimization. Whenever the optimal experience of the employee for each open counter to achieve the minimum total system cost for an evaluated customer arrival rate is obtained, this result can be applied to be the references in the head hunting (recruitment) of the case restaurant. Thirdly, the values of employee cost, the fixed cost of the restaurant, the waiting cost and the cost of losing customers are absolutely useful in performing cost analyses. In sum, this study definitely provides a prototype model in assigning employees to optimize the total system cost under a given customer arrival rate with the considerations of the customer balking and reneging for the modern quick service restaurant.

References


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