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Service System under Service Pressure by System Dynamics Model

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Abstract. The change of the service demand is hard to be controlled for an enterprise. The customers have to line up when the service capability has been fulfilled. Therefore, to increase the service rate in the quick service industry is the best way to keep the enterprise's competitiveness. To serve customers directly is the major job of the forefront attendants; whenever lots of customer waits for service, attendants' working pressure would be changed, and the pressure will influence the service rate of service from the attendants. The queuing system under pressure condition is always discussed with infinite queuing capacity as well as service rate, but it obviously conflicts with the truth. Based on the above-mentioned reason, this paper tries to construct a service function with upper limit of service rate, and then applying the "System Dynamic" model to conduct the simulation. In addition, the relationship between the changes of the 'Pressure coefficient' and the "working efficiency" would be discussed.

Keywords. Queuing Theory, System Dynamic, Pressure Coefficient, Enterprise's Competitiveness and Infinite queuing capacity, Conservation of resources and Salary Reward Policy.

1 Introduction

How to reduce loss of customer loyalty has become one of the most crucial issues in business administration [3]. Business turnover is the foundation of substantial management [1], and customer is an asset for creating business turnover [2]. As indicated in a report by Forrester Research, the cost of developing a new customer is five times higher than that of retaining an existing one. In other words, keeping an old customer brings more profits than winning many new ones [4, 5]. Providing adequate services and accomplishing a sales operation in an instant manner before customers run out of their patience and leave for other competitors is the only solution to win re-patronage of existing customers and ensure long-term development of the enterprise. Therefore, appropriate arrangement of the service team can be considered as a core competence of enterprises aiming to enhance their competitiveness.

It is very easy to see people waiting in line at cashiers, gas stations, box offices, bus stops, and highway toll stations [12]. Also, malfunctioning machines to be repaired, data to be processed by the CPU, and orders to be fulfilled in the production line are invisible but typical types of queues. The potential impact of pressure on work performance is one of the primary focuses of many managers [6, 7, 8]. Service pressure, before reaching to a certain extent, has positive effect on the increase of service provider's work performance [9]. The rapid changes in social structure and economy have posed even greater pressure on the general public, and very few consumers are willing to spend time on queuing [10]. As a result, issues associated with queuing have become more important [11].

Enterprises nowadays all attach much importance to increase of service quality and reduction of customer waiting time. Most of them increase service quality by setting up more service facilities. For instance, hypermarkets increase the number of POS counters, clerks, and cash registers, and factories set up more equipment to expand the production line. All these methods can indeed shorten customer waiting time, but they also drastically increase business cost and the difficulty of controlling time efficiency. Thus, appropriate work force arrangement, adequate intensity of service pressure, and proper reward policies are issues that the service industry expects to investigate first to enhance service quality and decrease queuing cost at the same time.

System dynamics was proposed in 1956 by a MIT research team led by Professor Jay W. Forrester et al. It is a pioneering science developed by applying the concept of "information feedback" to business administration. It is a methodology, an instrument, and also a concept [13]. In his book, 'Industrial Dynamics', [14, 15] argued that the universe is in fact a dynamic system that contains many interacting decision points. The status of a decision point can lead to motions in a certain form, which further brings changes to status quo and influences other decision points. In short, the system is comprised of factors that act as both the cause and the result.

For service providers who have direct contact with customers, the intensity of pressure fluctuates with the number of customers in queue, especially when there are a huge amount of customers waiting to be served by a small number of service providers. However, very few studies have touched upon the issue that some employees may perform better under reasonable pressure.

In addition, most studies have explored the influence of pressure with the assumption that capacity of the waiting area is unlimited, which is unrealistic and impractical.

For all descriptions above, I hereby summarize the objectives of this study as below:

1. To use the Queuing Theory' and construct the Queuing Models' under pressure.

2. To deduce and prove the 6 formulas by considering the $M/M/s/k$ of Pressure Coefficient'.

3. With service pressure considered, apply system dynamics techniques to construct a service system mode.

2 Research assumptions and limitations

2.1 Case study research assumptions and limitations

Our case study on quick-service restaurant is based on the following conditions and limitations:

1. Many auxiliary decision variables manipulated in this study, such as service speed and scheduling of attendants, are all simulated under normal distribution. Exceptional circumstances are excluded.

2. Customer arrival rate complies with exponential distribution.

3. Service level is consistent among all attendants; neither individual differences nor variations in service proficiency are considered.

4. The capacity of the waiting system may vary with customers' willingness to queue up in different time intervals and is thus set as an operational exogenous variable.

5. Both the interval between customer arriving times and system service time are in exponential distribution.

6. When an arriving customer realizes the queue is unacceptably long, the customer will leave the system, causing loss to the enterprise.

7. "The number of arriving customers in context" is estimated by the restaurant and hence set as a known exogenous variable.

8. Focused on the domain of social science, this research does not touch upon the psychology and social interactions of attendants under different contexts and business strategies.

2.2 The research on service pressure

2.2.1 Notations

We hereby illustrate the symbols of our mathematics models from our graduate school as the following:
s - Maximum service person number
k - Allowed maximum person(s) of the system capacity
μ_n - Service rate when there is/are "n" person(s) in the system
n - Number of the customers in the system
α_i - Pressure Coefficient' with i' service persons, $\alpha_i = \alpha$, for constructing deduction
λ_n - Arrival Rate when n' person(s) in the system

2.2.2 Assumptions

I gave the research an essential hypothesis as the following:

1. There are "s" service persons here, only "k" customer(s) allowed in the system, and both the interval time of arrival and service time are subject to the allocation of coefficient.

2. When any customer arrives here and finds the queuing lines occupied completely, he/she will refuse to enter into the system and withdraws.

3. For the limited system capacity, the average rate of arrival is

$$\lambda_n = \begin{cases} \lambda, & n = 0, 1, \ldots, k-1 \\ 0, & n \geq k \end{cases}$$

   when there is/are "n" customer(s) in the system.

4. There are "s" service persons in the system, so only "s" customers as a maximum can enjoy the service simultaneously; when customer numbers "n" are under "s", only "n" customers are allowed to be served and the other $(s - n)$ service person(s) will be in an idle state'.

In this case, the average service Rate is

$$\mu_n = \begin{cases} n\mu, & n = 0, 1, \dots, s \\ [\frac{n(s+1)}{s(n+1)}]^\alpha \, s\mu, & n = s+1, \dots, k \end{cases}$$

when there is/are "n" customer(s) in the system. α' means Pressure Coefficient'.

The reason why we are considering using the function is that it may meet the following 3 essential conditions:

1. Whenever the number "n" of customer(s) is increasing limitlessly, the maximum value of the system service rate μ_n' is a limited value
$$(s+1)^\alpha s^{1+\alpha}\mu, \text{ i.e., } \lim_{n\to\infty} [\frac{n(s+1)}{s(n+1)}]^\alpha s\mu = (s+1)^\alpha \mu$$
2. Whenever the number "n" of customer(s) is equal to the number "s" of service persons, the system service rate μ_n' is the same as '$s\mu$'.
3. Whenever α' of the Pressure Coefficient' is 0' (zero), the average service rate is
$$\mu_n = \begin{cases} n\mu, & n = 0, 1, \dots, s \\ s\mu, & n = s+1, \dots, k \end{cases}$$
when there is/are "n" customer(s) in the system.

In other words, Pressure Coefficient' is not considered for the average service rate μ_n'.

2.2.3 Construction of Queuing Model

We are discussing the limited queuing space here, i.e., the number of the customers is controlled under some maximum (hereinafter called k') and the capacity of queuing line is $(k-s)$. When any customer arrives here and finds the queuing lines occupied completely, he/she will refuse to enter into the system and withdraws. By the point of Birth-and-death process', the average rate of arrival is

$$\lambda_n = \begin{cases} \lambda, & n = 0, 1, \dots, k-1 \\ 0, & n \geq k \end{cases}$$

when there is/are "n" customer(s) in the system; the average service rate is

$$\mu_n = \begin{cases} n\mu & n = 0, 1, \dots, s \\ [\frac{n(s+1)}{s(n+1)}]^\infty s\mu, & n = s+1, \dots, k \end{cases}$$

when there is/are "n" customer(s) in the system; α' means Pressure Coefficient'; to simplify the symbols

$$C_n = \frac{\lambda_{n-1}\cdots\lambda_0}{\mu_n\cdots\mu_1}, \quad n = 0, 1, 2, \ldots, k.$$

And we may get that

$$C_n = \frac{\lambda_{n-1}\cdots\lambda_0}{\mu_n\cdots\mu_1},$$

$$\begin{aligned} C_n &= \frac{\lambda^n}{\{[\frac{n(s+1)}{s(n+1)}]^\alpha s\mu\}\{[\frac{(n-1)(s+1)}{sn}]^\alpha s\mu\}\cdots\{[\frac{(s+1)(s+1)}{s(n+2)}]^\alpha s\mu\}\cdot s\mu\cdot(s-1)\mu\cdots 2\mu} \\ &= \frac{\lambda^n}{s^{n-s}s!\mu^n[\frac{(s+1)}{s}]^{\alpha(n-s)}\{\frac{n}{n+1}\frac{n-1}{n}\cdots\frac{s+1}{s+2}\}^\alpha} \\ &= \frac{\rho^n s^{\alpha(n-s)}(n+1)^\alpha}{s^{(n-s)}s!(s+1)^{\alpha(n-s+1)}}. \end{aligned}$$

When we set $n = 0$, $\rho = (\lambda/\mu)$ the symbol "n" brings a steady probability as $P_n = C_nP_0$

$$= \begin{cases} \frac{\rho^n}{n!}P_0, & n = 0, 1, \ldots, s \\ \frac{\rho^n(n+1)^\alpha}{s^{(1-\alpha)(n-s)}s!(s+1)^{\alpha(n-s+1)}}p_0, & n = s+1, \ldots, k \end{cases}$$

Here

$$P_0 = \frac{1}{\sum_{n=0}^{s}\frac{\rho^n}{n!} + \sum_{n=s+1}^{k}\frac{\rho^n(n+1)^\alpha}{s^{(1-\alpha)(n-s)}s!(s+1)^{\alpha(n-s+1)}}}$$

We will acquire the steady probability P_n' and the expected length of Queuing persons for being served in the system as L_q;

$$\begin{aligned} L_q &= \sum_{n=s+1}^{k}(n-s)P_n \\ &= \sum_{n=s+1}^{k}(n-s)\frac{\rho^n(n+1)^\alpha}{s^{(1-\alpha)(n-s)}s!(s+1)^{\alpha(n-s+1)}}P_0 \\ &= \frac{\rho^sP_0}{s!(s+1)^\alpha}\{\sum_{n=s+1}^{k}(n-s)\frac{\rho^{(n-s)}[(n-s)+(s+1)]^\alpha}{s^{(1-\alpha)(n-s)}(s+1)^{\alpha(n-s)}}\} \\ &= \frac{\rho^sP_0}{s!(s+1)^\alpha}\{\sum_{i=1}^{k-s}i\frac{\rho^i(i+s+1)^\alpha}{s^{(1-\alpha)^i}(s+i)^{\alpha i}}\}, \quad \text{let } i = n-s \\ &= \frac{\rho^sP_0}{s!(s+1)^\alpha}\sum_{i=1}^{k-s}i(i+s+1)^\alpha[\frac{\rho}{s^{(1-\alpha)^i}(s+i)^\alpha}]^i, \\ &= \frac{\rho^sP_0}{s!(s+1)^\alpha}\sum_{n=S+1}^{k-s}[(n-s)+(k+1)]^\alpha[\frac{\rho}{s^{(1-\alpha)}(s+i)^\alpha}]^{(n-s)} \end{aligned}$$

The expected number of customer(s) in the queuing system is

$$\begin{aligned}
L &= \sum_{n=0}^{k} nP_n \\
&= \sum_{n=0}^{s} nP_n + \sum_{n=s+1}^{k} nP_n \\
&= \sum_{n=0}^{s} nP_n + \sum_{n=s+1}^{k} (n-s)P_n + \sum_{n=s+1}^{k} sP_n \\
&= \sum_{n=0}^{s} nP_n + L_q + s(1 - \sum_{n=0}^{s} P_n) \\
&= L_q + \sum_{n=0}^{s} n\frac{\rho^n}{n!}P_0 + s(1 - \sum_{n=0}^{s} \frac{\rho^n}{n!}P_0) \\
&= L_q + P_0 \sum_{n=1}^{s} \frac{\rho^n}{(n-1)!} + s - sP_0 \sum_{n=0}^{s} \frac{\rho^n}{n!} \\
&= L_q + P_0\rho \sum_{n=0}^{s-1} \frac{\rho^n}{n!} + s - sP_0 \sum_{n=0}^{s} \frac{\rho^n}{n!} \\
&= L_q + P_0\rho(\sum_{n=0}^{s} \frac{\rho^n}{n!} - \frac{\rho^s}{s!}) + s - sP_0 \sum_{n=0}^{s} \frac{\rho^n}{n!} \\
&= L_q + s + P_0(\rho - s) \sum_{n=0}^{s} \frac{\rho^n}{n!} - P_0\frac{\rho^{s+1}}{s!}
\end{aligned}$$

Based on a steady queuing process and the following Little's formula'

$$L = \lambda W \tag{2.1}$$

$$L_q = \lambda W_q \tag{2.2}$$

We may acquire the time of each customer in the queuing lines of the system by entering the values of L' (2.1) and L_q' (2.2) to the formulas.

$$W = \frac{L}{\lambda}$$

$$W_q = \frac{L_q}{\lambda}$$

3 Construction of a system dynamics simulation model for service system under service pressure

System simulation with a limited service speed function under customer pressure

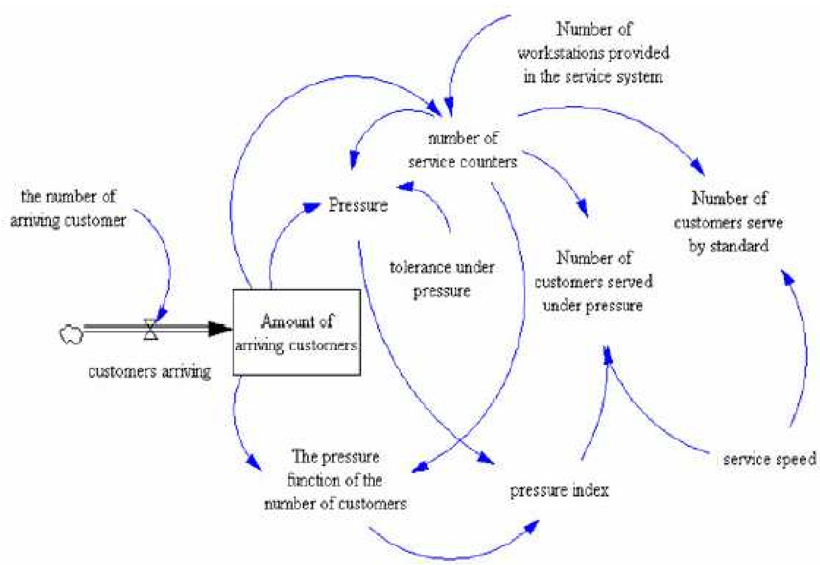

Figure 1: The system dynamics simulation model is a service system with customer pressure

Figure 1 illustrates a system dynamics simulation model for a service system in which service providers are confronted with customer pressure. The increase in the number of arriving customers adds pressure to service providers, who may respond to this situation by acting more quickly to finish serving all the customers as soon as possible. The result is enhanced service speed, which can directly increase turnover and profit. However, when waiting customers exceed the amount that attendants can handle (tolerance under pressure), attendants may become less motivated, maintaining at normal service speed or even slowing down. In this case, the enterprise will suffer loss of reputation and profit.

In Figure 1, number of service counters, tolerance under pressure, service speed, and the number of arriving customer are all exogenous variables.

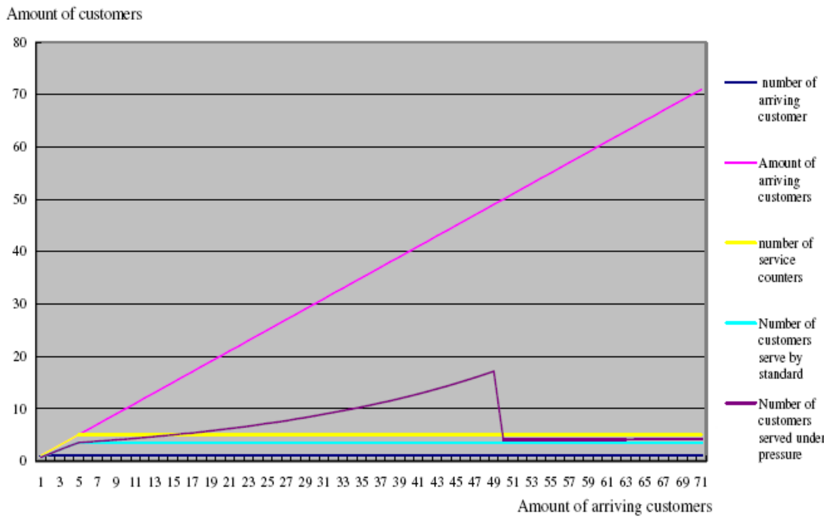

Figure 2: System simulation with a limited service speed function under customer pressure

4 Simulation results and implications for business administration

Our case study is focused on the service system of quick-service restaurant. Quick-service restaurant requirement for service speed is that, with service quality maintained, a customer should spend only 1 minute standing in front of the counter and 2 minutes waiting in the queue. In total, the entire service procedure should not exceed 3 minutes.

Thus, it is presumed in our simulation that the number of service counters in the restaurant is 5 ($S = 5$), each operating time interval lasts 60 minutes (min/period). The enterprise's standard service speed is 0.7 customer/minute.

Data used in the system simulation accord with actual practices of the restaurant. Findings and implications obtained are discussed below:

Explanation of system simulation with a limited service speed function under customer pressure.

As can be understood from the simulation results in Figure 2 and Table 1, the system incorporates 5 service counters. The number of customer is on linear increase. The service speed gradually increases from 0.7 (customer/minute) to 3.5 (customer/minute) and maintains at 3.5 (customer/minute). In practice, when confronted with customer pressure, service providers at front service desk tend to unconsciously increase their service speed from 0.7 (customer/ minute) 17.1 (customer/minute), which is the upper limit of their pressure tolerance. However, when the number of arriving customers exceeds the service provider's pressure tolerance, the service speed will drastically drop to 4.1

Table 1: Date for system simulation with a limited service speed function under customer pressure

Number of arriving customer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Amount of arriving customers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of service counters	1	2	3	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Number of customers serve by standard	0.7	1.4	2.1	2.8	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Number of customers served under pressure	0.7	1.4	2.1	2.8	3.5	3.6	3.7	3.9	4.0	4.2	4.3	4.5	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.7	6.9
Number of arriving customer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Amount of arriving customers	25	26	27	28	29	30	31	32	33	34	35	36	36	37	38	39	40	41	42	43	44	45	46	47
Number of service counters	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Number of customers serve by standard	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Number of customers served under pressure	7.2	7.4	7.7	8.0	8.3	8.6	8.9	9.2	9.6	9.9	10.3	10.7	10.7	11.1	11.5	11.9	12.4	12.8	13.3	13.8	14.3	14.8	15.4	15.9
Number of arriving customer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Amount of arriving customers	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Number of service counters	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Number of customers serve by standard	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Number of customers served under pressure	16.5	17.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1

(customer/minute).

5 Conclusion

Pressure is considered in the model for average service speed constructed by Mr. Hiller. Hiller argues that the increase in pressure can lead to higher service speed $n\mu$. However, this assumption is not reasonably grounded. Increased number of arriving customers can trigger higher service speed $n\mu$, but the increase is definitely limited. Hence, we proposed a reasonable model that recognized the existence of an upper limit. Deduction and reasoning were performed to obtain a set of more logical formulae that considered the impact of pressure. Based on these formulae, a system dynamics simulation model for restaurant service system was developed.

This research report gives you a logical model with existed maximum value. utilize the Birth-and-death process' to prove 6 characterized formulas from the Queuing Model' as $M/M/s/k$. After all I have got the following conclusions through deduction and research of $M/M/s/k$ under service pressure

1. Probability of no people in the system is

$$P_0 = 1 \Big/ \left[\sum_{n=0}^{s} \frac{\rho^n}{n!} + \sum_{n=s+1}^{k} \frac{\rho^n (n+1)^\alpha}{s^{(1-\alpha)(n-s)} s! \, (s+1)^{\alpha(n-s+1)}} \right]$$

2. Probability with n -n-1-customer(s) in the system is

$$p_n = \begin{cases} \frac{\rho^n}{n!} P_0, & n = 1, \ldots, s \\ \frac{\rho^n (n+1)^\alpha}{s^{(1-\alpha)(n-s)} s! (s+1)^{\alpha(n-s+1)}} p_0 & n = s+1, \ldots, k \end{cases}$$

3. Number of average person(s) in the queuing line is

$$L_q = \frac{\rho^s p_0}{s!(s+1)^\alpha} \sum_{i=1}^{k-s} i(i+s+1)^\alpha \left[\frac{\rho}{s^{(1-\alpha)}(s+1)^\alpha} \right]^i$$

4. Number of average person(s) in the system (including served person(s)) is

$$L = L_q + s + P_0(\rho - s) \sum_{n=0}^{s} \frac{\rho^n}{n!} - P_0 \frac{\rho^{s+1}}{s!}$$

5. Expected queuing time of each customer in the system is

$$W = \frac{L}{\lambda} = \frac{1}{\lambda} (L_q + s + P_0(\rho - s) \sum_{n=0}^{s} \frac{\rho^n}{n!} - P_0 \frac{\rho^{s+1}}{s!})$$

6. Expected queuing time of each customer in the queuing line is

$$W_q = \frac{L_q}{\lambda} = \frac{1}{\lambda} \{ \frac{\rho^s p_0}{s!(s+1)^\alpha} \sum_{i=1}^{k-s} i(i+s+1)^\alpha [\frac{\rho}{s^{(1-\alpha)}(s+1)^\alpha}]^i \}$$

"Putting the right man in the right place at the right time" is one of the key principles in human resource arrangement. We proposed a system dynamics model for service systems under customer pressure to address how customer pressure could motivate service providers to enhance service speed and consequently improve the enterprise's turnover and revenue.

It could help optimize task scheduling of employees to avoid customer loss due to unsatisfactory service efficiency. In short, the proposed model was constructed with regard to the actual practices in the service system.

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