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DES-Based Optimization of Hospital Consultation and Treatment Process under the COVID-19

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Abstract

To solve the problem of hospital queues during the COVID-19, this project takes The Second Hospital, University of South China as an example, clarifies the hospital outpatient process under the epidemic through on-site research and data analysis, collects the waiting time and service time of patients at each stage, builds its simulation model based on Discrete Event System (DES) theory, and discovers through simulation experiments, bottlenecks limiting the efficiency of the process were identified, and a service improvement plan was proposed through process optimization.

Keywords

DES Theory, Outpatient Flow, Process Optimization, Simulation

1. Introduction

At the end of 2019, there was an outbreak of COVID-19 and China was able to contain the outbreak with a national effort. In the early stages of an infectious disease outbreak, the process of diagnosing and treating the outbreak in a medical facility is an important part of the prevention and control of the outbreak. The hospital's contingency plan (coordination, treatment protocols, screening and isolation, etc.) is key to preventing the emergence of nosocomial cross-infection and is crucial to the control and ultimate direction of the outbreak. Patients infected with the novel coronavirus require focused isolation treatment and the need for consultation and treatment of other patients is increasing. In normal times, hospitals have problems with long waiting times and short diagnosis times for registration, payment, waiting and medication collection, etc. During an epidemic, restrictions on the number of people and the setting of safe distances lead to longer waiting times, which can even lead to delays, missing the best time for treatment, and causing irreparable loss of life and property. Therefore, it is imperative that the usual hospital procedures during an epidemic are adapted to the characteristics of COVID-19 infection and the need for prevention and control.

In this paper, we conducted an on-site study of The Second Hospital, University of South China to understand the outpatient flow of the hospital, recording the time between patient arrivals and the service time at each step. Based on the actual workflow and data, a simulation and analysis model of the outpatient service of The Second Hospital, University of South China was developed based on DES theory and studied in depth. The process redesign resulted in a service improvement solution, which was simulated and quantitatively evaluated to obtain an optimised outpatient process that resulted in a significant reduction in the average waiting time for outpatients.

2. Current Status of Domestic and International Research

A hospital is an institution that treats and cares for patients, and its first responsibility is to save patients so that they can continue to live healthy lives. The survival and development of hospitals must therefore be patient-centered, with the aim of improving the efficiency of services and promoting people (Rechel et al., 2009). At present, a common problem experienced by patients is the long waiting time in the queue. Therefore, the authors realize that changing the outpatient process and reducing consultation times is an urgent issue to be addressed. Reducing patient waiting times through optimization of hospital processes.

Overseas, there has been a boom in the application of business process reengineering theory to hospitals since the 1990s. Hillingdon Hospital in the UK used BPR theory to optimize the patient examination process by performing some examinations in the examination room on the ward, which was adapted to reduce the full patient flow time by almost 24 hours (Xu, 2019). Stockholm Hospital in Sweden uses industrial enterprise management techniques to reorganize its outpatient operating system around patient flow, solving bottlenecks encountered in the operating theatre (Cassandras & Lafortune, 2010). In addition to this, queuing theory has also been used abroad to optimize hospital outpatient clinics. Maister (1985) believes that free time feels longer than busy time and that hospitals can improve patient satisfaction by creating a comfortable queuing and waiting environment, which relieves patient anxiety to a certain extent (Toshihiko et al., 2010).

In China, public hospitals have become a common first choice due to their strong reputation, level of care, and protection, which has generally led to long waiting times and uneven allocation of resources for patients in public hospitals, and an urgent need to optimize hospital processes. It can be said that the concept of business process optimization in domestic hospital outpatient clinics arose in parallel with the need for hospital modernization (Huang, 2015), the concept of BPR and BPM was first introduced into hospital management by Ma Xiemin and others from Beijing Medical University in 1999 (Sun, 2015). In 2005, Chen Xingfeng applied the process re-engineering theory and incorporated the "patient-centred" service concept, using a combination of information technology and process re-engineering theory to optimise and integrate the process (Xu, 2019). At the same time, the popularity of computers and the development of technology, China also began to use computer simulation to simulate the hospital's diagnosis and treatment process. Xue & Xue (2002) used GPSS/H to simulate the hospital outpatient service system and made several specific suggestions to improve the system structure and operational performance. Su et al. (2006) have developed a simulation model for hospital outpatient clinics on MedMoel to identify the problem and optimize the process, reducing the average waiting time for patients from 17.24 minutes to 3.15 minutes through research and analysis in a public hospital in Shanghai.

From the above studies, it can be seen that hospitals at home and abroad have achieved certain research results in the optimization of the regular hospital consultation process by combining enterprise reengineering theory and different simulation software. However, little research has been done on the optimization of hospital care processes in non-conventional settings, especially in the context of Covid-19. It would make more practical sense to optimise the hospital consultation process in the context of the extraordinary situation of the epidemic, taking into account the actual needs of patients.

3. Basic Concepts and Related Theories

3.1. Discrete Event System

A discrete-event system is a model for modelling physical systems that are simultaneously discrete and continuous. This class of physical systems usually remains relatively stationary for a certain period of time, while at discrete points in time there are actions that change the stationary state (Cassandras & Lafortune, 2010), its earliest research dates back to the study of queuing phenomena and queuing networks. Discrete-event systems are dynamic systems driven by events and whose system state changes in leaps and bounds only at indeterminate and discrete points in time. Describe the basic concepts of discrete-event systems including entities, attributes, states, events, activities and processes (Wei, 2016; Xie et al., 2019). Specifically the discrete event system has the following characteristics:

1) The state of DES can only jump at discrete event points. In DES, state evolution is event-driven, i.e. the state can only jump at the instant of the driving event and remains constant at other times. It is an inherently discontinuous property.

2) Asynchronous and concurrent DES state changes. In DES, due to the inhe-

rent discrete nature of the system, the evolutionary process exhibits asynchrony in the moments of state leap, and the moments of state leap are arranged asynchronously on the time axis. In addition, the occurrence of a discrete event may cause a concurrent state change, i.e. a jump in some or even all of the state variables at the same time.

3) Actual DES state changes often exhibit uncertainty. In DES, discrete events are subject to both internal and external factors of the system, which strictly speaking always contain some uncertainty, resulting in uncertainty in the change of the system state.

4) Since DES obeys artificial rules of logic rather than the laws of physics and their derivatives, this dictates that DES cannot usually be described using traditional differential or difference equations.

In summary, discrete-event systems are a class of models that can describe both dynamic and static properties, mapping concrete physical systems to logical systems through abstraction and definition (Wang, 2014).

3.2. Process Optimization Theory

The whole process of sorting out, refining and improving existing processes is called process optimisation (Ye, 2016). In the process of implementation and design, the process should be continuously improved to achieve the best results, mainly by reducing time, reducing or simplifying operational steps and making the best use of available personnel, funds and materials (Zhang, 2019; Xie et al., 2020; Huang et al., 2021). Currently, in order to cope with the problems faced in the new environment and the traditional intelligent management model, business process optimisation has become an inevitable choice in order to gain a foothold in the fierce market competition of the future (Xie et al., 2016). Whether optimizing part of the process or the whole process, the optimization process is oriented to customer needs, effectively reorganizing or redesigning existing business processes, increasing the effective linkage of business (Zhang, 2019; Wei et al., 2022), achieving improved process efficiency, improving the quality of the whole work, reducing operating costs and improving customer satisfaction (Wu, 2014).

4. Data Collection and Model Building

4.1. Hospital Process Description

In this paper, the current outpatient flow of the hospital is shown in **Figure 1**. According to hospital regulations, patients are required to check their health code and trip code before entering the hospital, have their temperature taken, and if they are found to have a trip code with *, they are asked to register their personal identification information before entering the hospital; Patients enter the hospital and have to go through registration, outpatient tests, payment and medication, each part with a certain queue. All or part of the process is: patient arrival, waiting in line, service, departure.

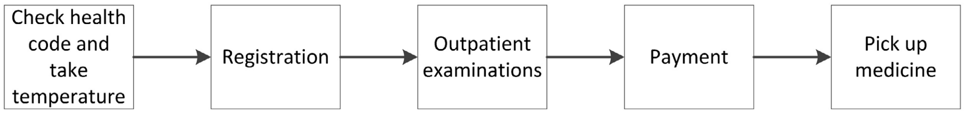

Figure 1. Hospital outpatient flow.

4.2. Data Collection

To build the simulation model and quantify the data, process distributions such as patient arrival time distribution, registration time distribution, outpatient time distribution, payment time distribution and medicine collection time distribution are required. Due to constraints, it was not possible to collect data (Table 1) from all hospital outpatient clinics, and the field research team only recorded the service hours of dermatology and Ophthalmology from 9:00-12:00 on 21 September 2021 to obtain the required distribution of process times.

4.3. Simulation of Existing Process Validation

This paper focuses on modeling dermatology and Ophthalmology, where the arrival time of the patient can be expressed as exponential (0, 25.36, 0), setting the processing time for each entity based on the data given in Table 1. The analysis of the results is shown in Table 2. In the actual hospital system, given the need for diagnosis and treatment, patients may make repeated round trips to different departments, resulting in some reasonable errors in the collected and simulated data.

The model defines a virtual time of 7200 seconds to control the variation of the parameters, records the patient's activity data during this time and exports it in an EXCEL sheet. After calculations, this simulation was compared with the collected data, the statistical results of the collected and simulated data were very close, and the feasibility and validity of the simulation model were determined.

5. Simulation and Optimisation

5.1. Analysis of Simulation Results

Two simulations were conducted and we found that as time increased, patients were mostly most congested in the session (Table 3) where they presented their trip code and took their temperature, followed by the waiting clinic and finally the Drug-taking window. At the same time, the simulation results show that the utilization rate of the registration 2 window is only 26.52%, while the utilization rate of the registration 1 window is 68.86%, which is very uneven; Both payment windows were underutilized at 26.94% and 5.81% respectively. It is clear that some parts of the hospital departments are not fully utilized to their optimum configuration.

5.2. Cause Analysis

According to the on-site research study, the following reasons exist:

1) No advance guidance on showing the trip code and taking temperature

Table 1. Parameters for each link.

Session	Average service time/second	Average service time distribution
Check health code and take the temperature	62.12	Negative exponential distribution
Registration	57.36	Negative exponential distribution
Dermatology	584.00	Negative exponential distribution
Ophthalmology	183.00	Negative exponential distribution
Payment	65.63	Negative exponential distribution
Drug-taking window	839.00	Negative exponential distribution

Table 2. Analysis of real system simulation results.

Session	Simulation results/second	Realistic data/second
Check health code and take the temperature	57.11	62.12
Registration 1	56.95	57.36
Registration 2	45.66	
Dermatology	566.20	584.00
Ophthalmology	193.99	183.00
Payment 1	70.85	65.63
Payment 2	56.74	
Drug-taking window 1	791.29	839.00
Drug-taking window 2	958.54	
Total waiting time	2797.33	

Table 3. Utilization rate by the department before optimization.

Session	Utilization rate
Check the health code and take the temperature	99.48%
Registration 1	68.86%
Registration 2	26.52%
Dermatology	95.42%
Ophthalmology	74.88%
Payment 1	5.81%

Continued

Payment 2	26.94%
Drug-taking window 1	92.86%
Drug-taking window 2	79.01%

The hospital did not place signs in advance on the road where the patients were coming from, but only placed guide signs and two security guards in front of the hospital. This resulted in patients not knowing the hospital's requirements in advance, but only knowing that they needed a trip code and a temperature measurement at the door before they followed the guide to open the trip code, and some patients were unfamiliar or had poor mobile phone networks, which led to many patients blocking the door.

2) Uneven intensity of service across service windows

When the service windows are busy, patients need to choose a queuing sequence, and as service times generally obey an exponential distribution, this leads to differences in the efficiency of different service windows within a short period of time, resulting in an uneven intensity of service and thus to a certain extent a waste of hospital resources.

3) Unmanaged order at the Drug-taking window

As there was no one to manage the order, this led to a number of patients appearing to not follow the route of the arrows on the floor, which led to a number of patients not leaving the queue and waiting for their number to be called after being given a Drug-taking slip, but standing in front of the window waiting to pick up their medication, so much so that it blocked the patients behind them and increased their queuing time; secondly, there was queue jumping, which further increased the waiting time.

5.3. Optimised Solutions

5.3.1. Optimisation of Queuing Methods

Generally, there are two types of queuing methods, one is multi-queue-multi-service desk, where there are multiple queues corresponding to multiple service desks at the same time. If all the service counters are busy, the customer chooses the "shortest" queue to receive the service, for example, the hospital outpatient registration window and the pharmacy pick-up window, the queuing flow chart is shown in **Figure 2**.

Another queuing method is single queue-multiple service desks, where there is only one queue but corresponding to multiple service desks, which receive services in turn according to the rules of FCFS. For example, the queuing flow of a bank's call system is shown in **Figure 3**.

This paper compares the magnitude of the main metrics of the two queuing models by comparing theoretical metrics and simulations for both queuing approaches.

The queuing system is first standardized with the following assumptions:

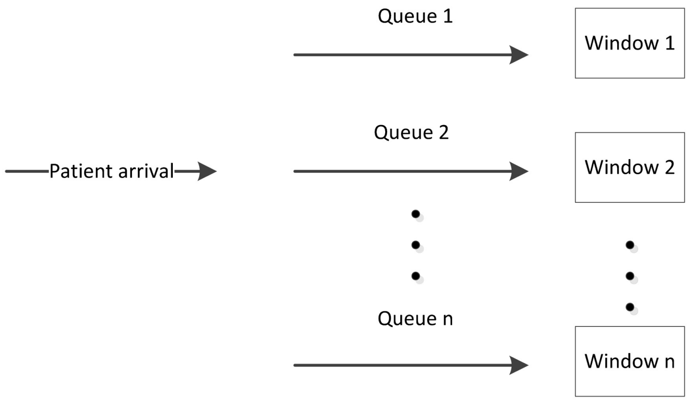

Figure 2. Multiple queue-multiple service desk queuing mode.

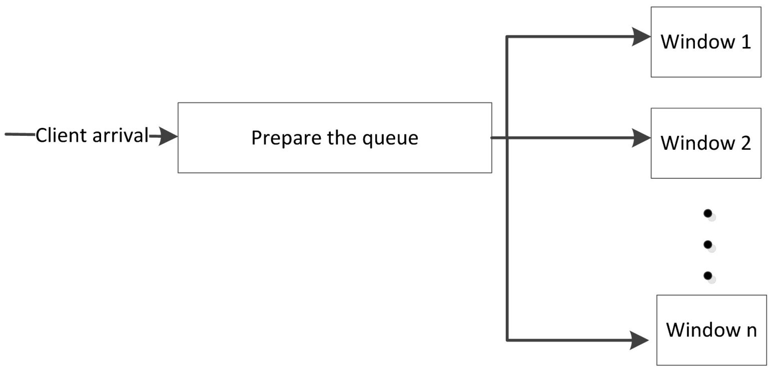

Figure 3. Single queue-multiple service desk queuing mode.

1) The customer arrival pattern follows a Poisson distribution, and the time interval between every two customers arriving at the system follows an exponential distribution with a mean value of $1/\lambda$.

2) Each customer's service time is independent and the distribution of service times follows an exponential distribution with a mean of $1/\mu$.

3) The number of customers that a customer source and system can accommodate is unlimited.

4) The service rule is FCFS, i.e. first come first served, and once a customer selects a queue he/she will wait in this queue until the service window is free, with no customers leaving in the middle.

5) The system is in a steady state: the characteristic indicators in the system do not increase or decrease with the simulation time.

- **Registration system process optimization**

The following optimizations have been made to the registration process at this hospital (Figure 4): Firstly, the original multi to multi-queue has been changed to single to multi-queue, with a ready queue where most patients can sit in the waiting area and wait. At the same time, a certain number of patients will be called to the ready queue next to the registration window to wait for their registration. The registrar who has completed the previous registration will receive the first patient in the preparation queue. As a patient in the preparation queue

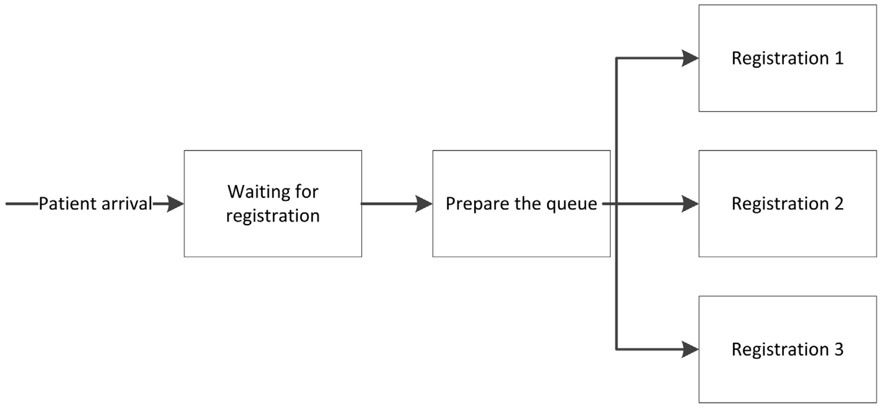

Figure 4. Improved registration process.

walks to the registration window to be served, the first patient waiting in the seating area will be called to the preparation queue. This cycle continues until all patients have been registered.

- **Optimisation of the drug-taking process**

The following improvements have been made to the process of collecting medication from hospital pharmacies (Figure 5): Firstly, the multi queue-multi service desk has been changed to a single queue-multi-service desk. Patients no longer choose to wait in one of the multiple queues but enter the only queue after the staff has checked the tickets and medication lists, wait for the system to call the number and arrange for a designated window, and the customer whose number is called goes directly to the window arranged by the system to pick up the medication.

5.3.2. Optimisation of Body Temperature Measurement Flow

The following optimisation is made for the preparation before entering the hospital: signage is set up 15 meters in advance on the two roads before entering the hospital to guide patients to turn on their trip codes in advance so that patients with slow mobile phone networks, mobile phone lag, and other problems have time to prepare and avoid queue blockages. This has been proven in the field to reduce the time to enter the hospital from an average of 62.12 s to less than 40 s.

5.3.3. Simulation and Analysis

Simulation is carried out according to the above-optimized process (Table 4): firstly, the processing time of the trip code presentation and temperature taking process is changed to exponential (0, 40, 0), then the queuing process for registration and medicine collection is changed to single queue-multi desk queuing mode, and the rest of the parameters remain unchanged.

After process optimization, the waiting time for patients in the queue was reduced from 2799.33 s to 2179.37 s, a reduction of 22.15% from the original time, improving the operational efficiency of the hospital. The utilization rate of the registration window and the payment window has been improved compared to the pre-optimization period.

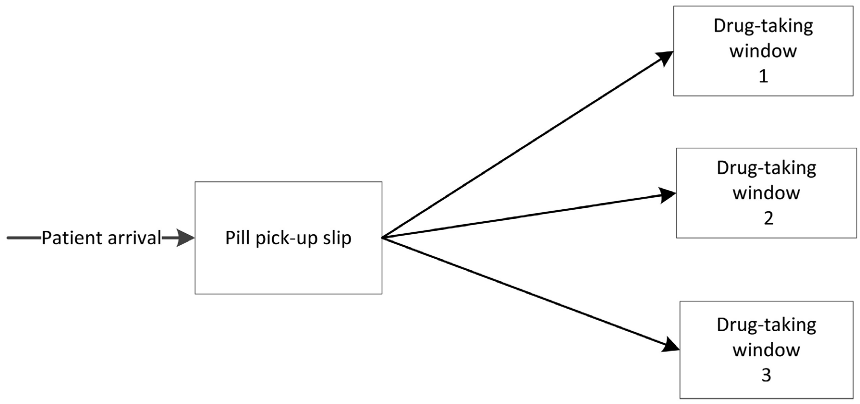

Figure 5. Improved drug-taking process.

Table 4. Optimized waiting times and utilization rates by the department.

Session	Average service time/second	Utilization rate
Check health code and take temperature	36.3	97.88%
Registration 1	60.59	83.16%
Registration 2	48.15	52.36%
Dermatology	548.44	93.80%
Ophthalmology	176.26	94.13%
Payment 1	94.15	32.02%
Payment 2	66.00	8.71%
Drug-taking window 1	543.54	91.90%
Drug-taking window 2	605.94	93.26%
Total average waiting time in queue	2179.37	

6. Summary

In hospitals, patients' time is precious. In this paper, taking The Second Hospital, University of South China as an example, in order to solve the problem of long queuing time for patients under the extraordinary situation of the new crown epidemic, based on the actual system data, the data was analyzed in SPSS software, a conceptual model was established through the knowledge of DES theory and queuing, then a simulation model was established in the simulation software, physical parameters were imported, the simulation model was run and the analysis. The results revealed the problem, changing the original multi-queue-multi-service desk queuing model at the registration window and medicine collection window into a single queue-multi-service desk model and optimizing the process of the temperature-taking link to achieve optimization of the treatment process and server, resulting in a 22.15% reduction in patient queuing time and greatly improving patient satisfaction.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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