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Queue Management during Health Pandemics: A Queuing Theory Perspective

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Authors' contributions

This work was carried out in collaboration among all authors. Author YAWN designed the study, performed the data analysis and wrote the first draft of the manuscript. Authors AAAD and SI verified the data analysis, reorganized the draft and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The era of coronavirus has called for sustained social distancing measures to minimize the spread of the viral disease. Healthcare establishments are reducing the size of their working staff; while others are running their outfits base on shift work in other to ensure protocols for social distancing. Inherent in social distancing protocol is the potential for generating waiting lines at service delivery points. Healthcare centres in many countries are already inundated with loads of patient's attendance on daily basis for treatment off mild to severe ailments. COVID-19 has added a further burden on the already frail health systems. Whiles visits are increasing, social distancing measures are to be ensured. Quick service delivery which is an indispensable need of patients visiting hospitals for treatment is shortened. The occurrence of waiting line, an impediment to healthcare provision has become commonplace in most healthcare centres in Ghana in particular. In addition to loss of financial gains, delay and unsatisfactory healthcare could lead to loss of lives. Health

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units are dealing with the effective management of staff schedules to curtail the impact of COVID-19 and at the same time cover up capacity to meet the added health care delivery demands. Accordingly, efforts to reduce time spent in waiting to receive medical attention is crucial. In this paper we study the queue situation at a case Outpatient Department (OPD) by applying query theory and offer recommendations for queue management. The study was conducted in the month of May 2020. We present also, an approach to determine the optimal number of service windows required to reduce the time spent waiting for healthcare attention. Numerical analysis of the queuing situation at the case department is given also, drawing from relevant equations from queuing theory.

Keywords: COVID-19; pandemic; outpatient department; waiting line; queuing theory.

1. INTRODUCTION

The world is confronted with a huge public health condition in the wake of the coronavirus pandemic. The novel coronavirus christened, COVID-19, is a member of the family of viruses known as coronaviruses. It is a new strain of the Severe Acute Respiratory Syndrome (SARS) called the Severe Acute Respiratory Syndrome (SARS-CoV-2) [1,2]. The COVID-19 viral causes infection in the respiratory tract of humans and animals [2,3]. The pathogen broke out in late December of 2019 in Wuhan, China. After a long period of hesitancy, COVID-19 reached pandemic status in February, 2020 after a declaration by the World Health Organization (WHO) [4]. Its spread has reached most parts of the world including the entirety of the African continent. COVID-19 is transmitted when droplets from an infected person comes into physical contact sensitive parts of human – mouth, nose and eyes. The virus has infected well over 50,000,000 people across the globe and taken the lives of several others at the time of this write-up [2,4].

Health systems globally are under grave siege with the presence of the coronavirus pandemic. Hospitals and makeshift isolation centers are used as places of case management (CDC, 2020). Given the existence of many other ailments and the sheer number of patient visits to hospitals and other health centres, the COVID-19 presents yet another burden on public health system of countries across the globe especially developing countries like Ghana. In many countries, health systems have been completely exhausted. Mitigating measures such as the use of personal protective equipment (PPE) by health professional and especially by frontline workers has been recommended in various parts of the world. Within and outside of health facilities social distancing protocol is also recommended to be practiced [3].

Outpatient departments are the first point of contact when patients visit these health care facilities for support. While many outfits are shut, it is unlikely that any reasoning will call for shutting down of this outfits given its pivot nature to health care delivery [5]. Not even a lockdown or curfew situation will necessitate the incidence of closure of outpatient units. However, in seeing to it that these health centre are alive and rendering health services, no one want to see these points of patients contact become a source of transmission of SARS-CoV-2. Some fine adjustment to the normal chain of service delivery to guarantee the safety of workers and patients alike is needed. In addition to the application of social distancing measures and the insistence on the proper use of personal protective equipment (PPE), hospitals are rolling out shift systems for workers. Shift works demands that working hours are partitioned to allow only some workers at some periods of working hours. Consequentially, there is extra demand on already less sufficient health professionals and service delivery points coupled with the increase in visits occasioned by the number of patients needing treatment due to the corona virus and other known aliments.

This article studies queue management in healthcare centres by employing the mathematical concept of queue theory. The main aim is to provide a mathematic perspective to studying and understanding waiting lines at health delivery centres in this era of coronavirus pandemic and to facilitate safety of visitors and to control the spread of the viral disease.

1.1 Background of Queuing Theory

Queuing theory is the study of waiting lines with application in mathematics and operations research. The queuing theory concept has its origin in the research of Agner Krarup Erlang who created models to describe the Copenhagen telephone exchange [6]. Erlang's documented ideas have since seen applications in areas including, traffic engineering, computing and in industrial engineering, in the design of factories, shops, offices and hospitals, as well as in project management. Queuing theory is hugely useful in studying problems such as queue behaviour, optimization and statistical inference [7,8]. It is also useful in evaluating efficiency of manufacturing processes, customer service line, health care and in computer system that executes software request [9,10,11].

1.1.1 Queuing system

A queuing system is typically characterized by one or more service points called servers that deliver service to arriving customers in some order. Customers who arrive at such delivery points are from a finite or infinite population [12]. Arrivals at the centre are generally in an unplanned random fashion. Queues into which these customers join have either limited or unlimited capacity. A typical queue system is depicted by the following parameters; (1) Arrival rate (λ) – the average rate at which customers arrive. (2) Service time (s) – the average time required to service one customer. (3) Number waiting (L_q) – the average number of customers waiting. (4) Number in the system (L_s) – the total number of customers in the system According to [13,12]. Graphically, a queue system is shown in Fig. 1.

1.1.2 Queue models

Kendall's provides a notation for specifying and representing a queuing system in the following form:

$$(a/b/c):(d/e) \quad (1)$$

Where

1. a is the distribution of the inter-arrival times
2. b is the distribution of the service times
3. c is the number of servers (channels or service stations)
4. d is the capacity of the system, the maximum number of customers in the system including the one being serviced
5. e is the service discipline

We shall use a simplified notation to (1) above denoted as $a/b/c$ to describe the queueing systems. Distribution types include General, Exponential and Deterministic commonly specified as G, M and D [14,15]. Queue models can be classified as; Probabilistic when both the arrival rate and service rates are random, or Deterministic when both arrival and service rate are fixed, or Mixed when either arrival rate or service rate is constant and the other variable.

Following from above, many models exist which are used to predict the performance of service systems when there is uncertainty in arrival and service times. Models often analysed include; (M/M/1): (K/FCFS), (M/M/S): (K/FCFS), (M/M/1): (∞/SIRO) and (M/G/1): (∞/GD), where FCFS, SIRO and GD denote a First-In-First-Out, Service-In-Random-Order and a General (GD) service disciplines respectively. We shall briefly summarize (M/M/1): (∞/FCFS) and (M/M/s): (∞/FCFS) below.

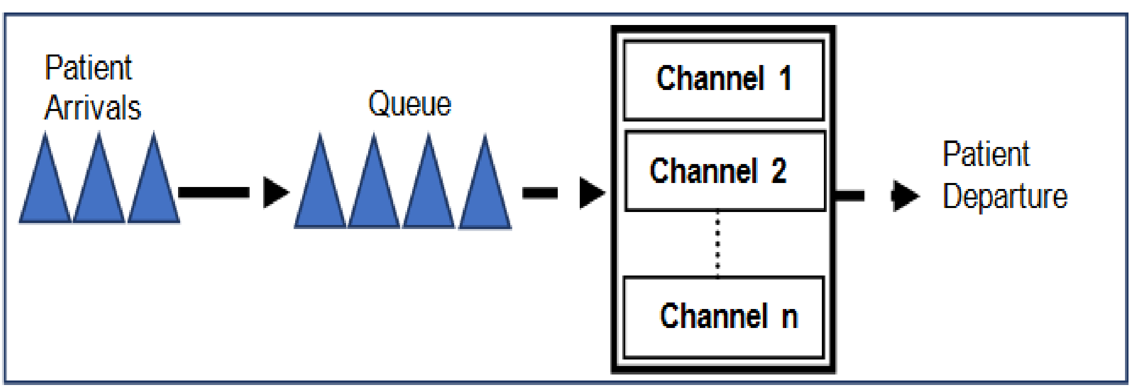

Fig. 1. A FIFO queue system

1.1.3 The M/M/1: (∞/FCFS) queue: Model for single server queues

The $M/M/1$ model is one of the most used queuing models used to analyse queuing problems involving a single server. This model specifically represents a system with Poisson arrivals at a rate λ, exponentially distributed service times µ and a single server serving customers in a first-come first-serve fashion. When a customer enters an empty system, service is started immediately. If, however the system is non-empty, the customer joins the queue. When service is completed, a customer from the queue, if any, enters the service window to get served [16]. Performance Measures of interest in the M/M/1 Queue Model are as follows [7,12].

Utilization factor (ρ) = $\frac{\lambda}{\mu}$ (2)

Probability of an idle system (P_0) = $1-\rho$ (3)

Probability of n customers in the system $(P_n) = P_0\rho^n = (1-\rho)\rho^n$ (4)

Number of customers in the system (L_s) = $\frac{\rho}{(1-\rho)} = \frac{\lambda}{(\mu-\lambda)}$ (5)

Number of customers in the queue $(L_q) = L_s \times \rho = \frac{\rho^2}{1-\rho} = \frac{\rho\lambda}{\mu-\lambda}$ (6)

Waiting time for a customer in the queue (W_q) = $\frac{\rho}{\mu-\lambda}$ (7)

Waiting time for a customer in the system (W_s) = $\frac{1}{\mu-\lambda}$ (8)

2. METHODOLOGY

The study of waiting lines requires first-hand collection of customer queue characteristics including length of time spent in the queue. In order to put emphasis on the research situation, the case study design is advised. The case study approach offers opportunity for relevant aspects of queuing problem to be studied in some depth within a limited time scale. Moreover, it allows coverage of contextual and non-queue conditions relevant to activities and processes of health delivery point.

2.1 Data Collection

Each patient arriving at a health care point is associated with the following time measurements;

1. The arrival times
2. The service start time
3. The service completion time
4. The wait times
5. The service times
6. The wait time of in system

Time measurements as in above were computed daily for a one-week period. Averages for the inter-arrival times and service times each day are taken. The daily averages are then further averaged to give a picture of the queue behaviour over the study duration.

An important determination required to model a case delivery point as a queue system is to determine the appropriate distribution for the arrival and inter-arrival times. Goodness of fit test is a fitting procedure performed on the measured inter-arrival and service times. The Chi square test at 0.05 significant level was applied to both the inter-arrival times and service times at the case study points. The conclusion is that the distributions of both arrival times and service times are exponential in nature. Authors in [17] affirm that the specification of interarrival times as exponential is accurate for many service systems.

2.2 Performance Characteristics

This paper uses mathematical models because of their advantages over simulation in regard of finding optimal solution [18]. Following below we determine the indices as contained in equation (2) to (8) using example time measurements.

2.3 Computing Arrival Rate (λ) and Service Rate (μ)

First, we compute the basic parameters; patients arrival rate λ and the service rate μ. Parameter λ represents the average number of patients who arrive at the outpatient department during a period. If this is not available an arithmetic mean representing the average interval between two consecutive patients' arrivals (t_{int}) is computed. The value of t_{int} is the inverse of patient arrival rate λ give as;

$$\lambda = 1/t_{\text{int}} \quad (9)$$

Using the same matching as in (9), we can compute the service rate represented as μ. The service rate is the average number of patients that can be serviced in a time unit at the outpatient department.

As is the case for the arrival rate, if only the duration of service time per patient is known, then the arithmetic mean represents the average service time per patient (t_s) and this time is the inverse value of the service rate given as;

$$\mu = 1/t_s \qquad (10)$$

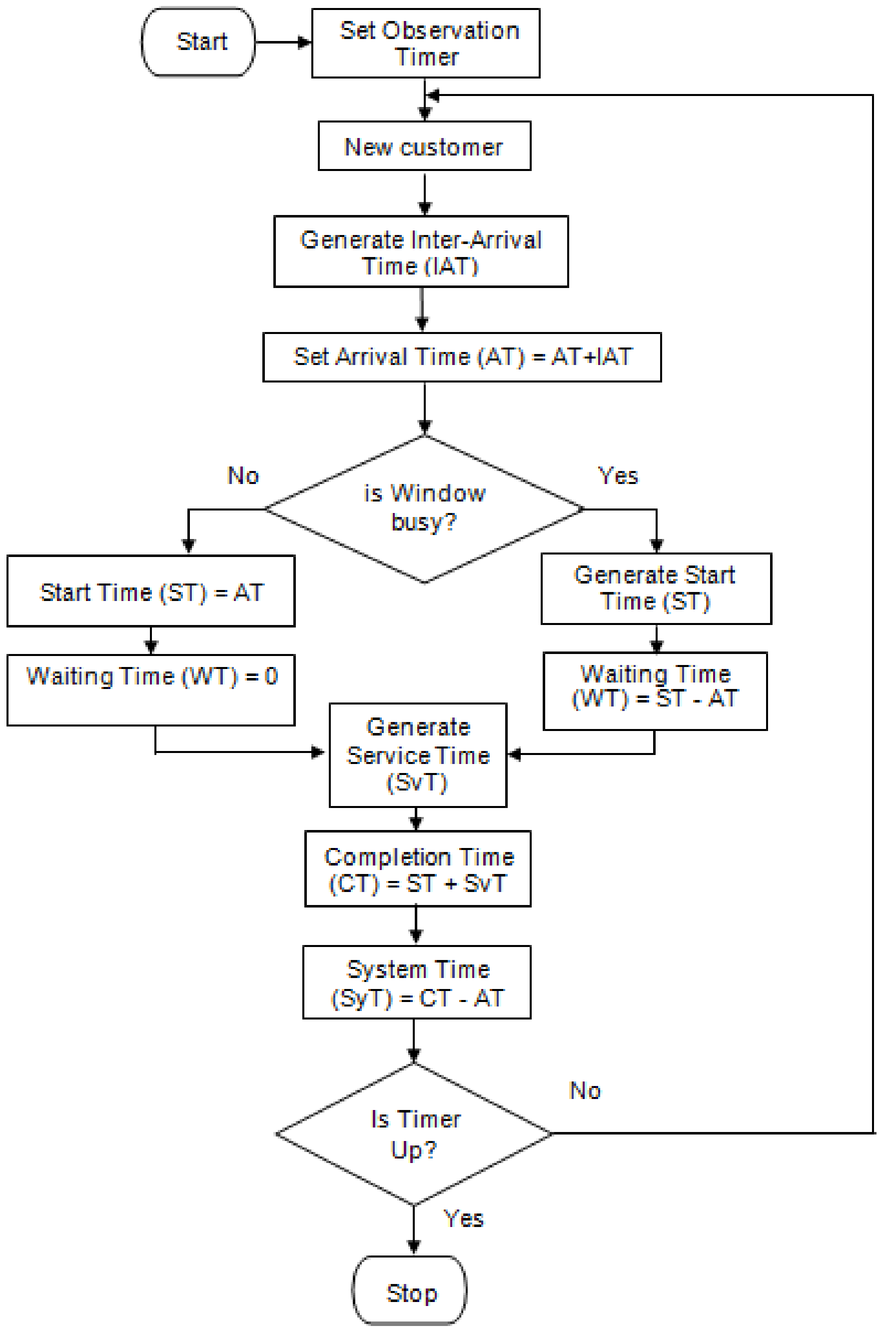

Fig. 2. Proposed data collection approach

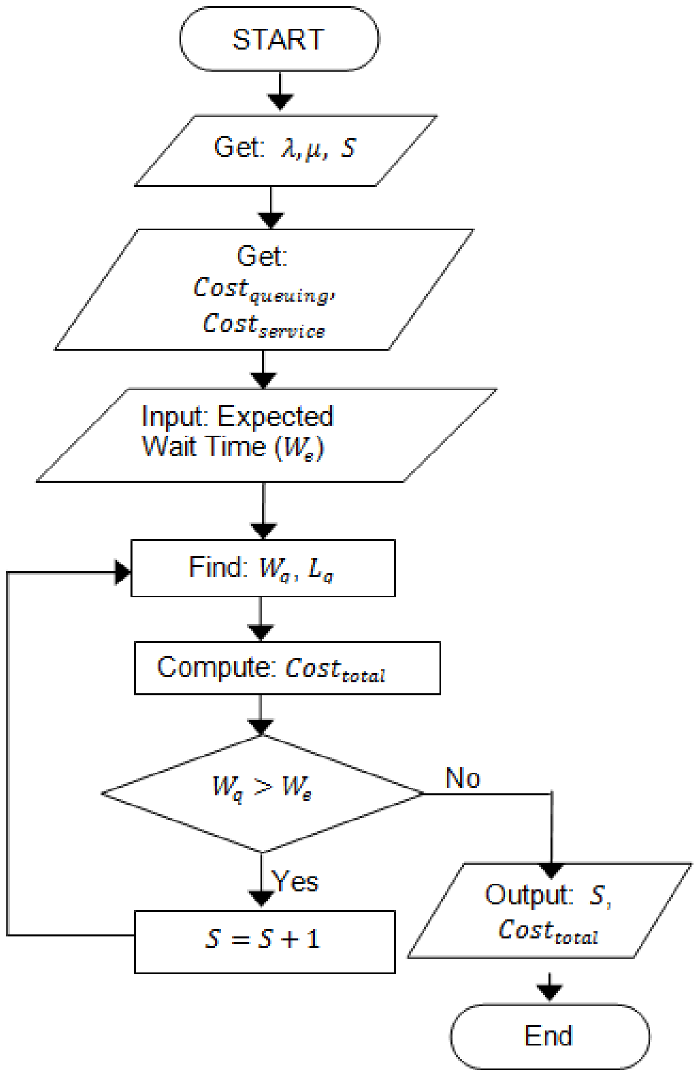

Fig. 3. Finding optimal number of service window

2.4 Optimal Service Window

Queuing models can also be used for optimization. In this paper we propose an approach to health care providers realize how many service channels should be availed to minimize time spent in queues and the service cost. In other words, the approach here is useful for finding the optimum number of service channels for which total cost of patients waiting time and costs of unoccupied service channel are minimum. In this regard, the total queuing costs ***C*** include both the patients queuing costs C_w and service channel costs C_s.

Total queuing cost and cost of unoccupied service channel is computed as follows:

Patients queuing cost

$$Cost_{queing} = c_w \times L_q \tag{11}$$

Service window cost

$$Cost_{service} = c_s \times S \tag{12}$$

Total cost ($Cost_{queing} + Cost_{service}$) is given as;

$$Cost_{total} = (c_w \times L_q) + (c_s \times S) \tag{13}$$

where:

$Cost_{queing}$ is total cost of queuing;

$Cost_{service}$ is the amount of costs caused by waiting of patients;

C_s is the cost arising from unoccupied service channel;

W_q is the average wating time of patients in the queue;

L_q is the average number of patients in the queue;

S is the number of service channels and

W_e is Customer's expectation of how long he/she will wait in queue.

Fig. 3 presents the proposed approach to determine the optimal service window.

3. NUMERICAL RESULTS AND DISCUSSION

The following computations illustrate the usefulness of queueing theory to study waiting lines at outpatient units. Inter arrival time and service times where obtain through observation of the operations of a case Outpatient department of the Tamale Teaching Hospital (TTH) in the Northern Region of Ghana. Inter-arrival times and service times of patients were measured in the month of May, 2020 - with the aid of an observation form and by following the flow logic in Fig. 2.

Based on the (M/M/1): FCFS/ ∞ / ∞) queuing model and on equation (2), (7) and (8), we compute the patient waiting time in the system, waiting time in queue and utilization of the service window.

The first point of contact of patients is at the Folder collection unit of the hospital. Patients who arrive at the main OPD of the hospital form a FIFO queue and wait till they are at the head of the queue where they get the opportunity to get their visitors folder retrieved for them upon verifying required health IDs. For first-time visitors' new folders are opened for them. The routine arrangement for patients afterwards is to take their vital signs such as temperature and blood pressure level. From there they then queue in front of consulting rooms in wait for attention by special and general medical practitioners. The pharmacy is the next area where most patient will interface to collect prescribed drugs. Patients treated on cash and carry basis must make payment at designated cash payment points where minimal queues do build up during some periods.

The analysis here is based only on the queuing situation at the folder collection counter. We did not study the queue behaviour in front of consulting room; at pharmacies; and at cash points in this research. It will be interesting to know the additional time patients have to wait before getting medical attention. That is, the overall time it takes a patient to register attendance at the folder collection point, to meeting a health consultant to receiving drugs at the pharmacy and making payment at cash points.

On average arrive at the OPD at a rate of 1 patient in 5.89 minute. The time it takes to locate a patient's folders and record attendance averages 4.2 minutes per patients. The length of time in queue varies from as short as 3 minutes to 34 minutes. Arrival times and service times are lower during weekend than on working days. The OPD enjoys near 87% utilization during weekdays. The OPD is relatively lowly patronized during the weekends.

Table 1. Queue characteristics at the OPD with a single server

Day	Mean arrival rate (λ)	Mean service rate (μ)	Utilization (ρ)	W_q	W_s
Monday	0.20	0.23	85.05%	24.27	28.54
Tuesday	0.20	0.23	87.88%	31.54	35.89
Wednesday	0.21	0.24	89.29%	34.72	38.89
Thursday	0.21	0.24	88.24%	31.88	36.13
Friday	0.21	0.24	84.88%	23.11	27.23
Saturday	0.12	0.26	47.75%	3.55	7.43
Sunday	0.11	0.25	46.12%	3.48	7.55

Customers as they arrive at the unit, expect to wait not more than 15 minutes in the queue from the point of entry till they exit. This means that they stay more twice as much the time in the system (about 34 minutes) as they expect which could increase the level of frustration and dissatisfaction. It is obviously seen that with an additional counter to serve patients at the folder collection unit, the queue performance of the unit will improve in terms of reduction in patient waiting time.

4. CONCLUSION

Health systems globally are under grave siege with the continues rage of the coronavirus pandemic. Outpatient departments are common contact and service points at most health centres. The appearance of COVID-19 has added more burden to outpatient departments and many other essential care units. Queues of waiting patients are growing and common so much so that quick and quality health care delivery is hampered. To facilitate operational efficiency at outpatient departments and speed up service delivery during epidemics such as the corona virus, there is need to determine the optimal number of service windows to reduce patient waiting time and enjoy the attendant health delivery benefits.

In this paper we demonstrated the applicability of queuing theory in managing patient queuing at outpatient departments.

The case outpatient department is modelled as a M/M/1 queuing system. Patient's arrival rate and service rate were measured in a one-week period. Relying on formulas from queuing theory, the performance of the case outpatient department was measured computationally; in areas such as utilization of the system, the expected number of patients in the queue, waiting time of patients in queue and more.

Based on personal observation at the case study, the following recommendations are given:

1. Computerized folder tracking system should be implemented since it was observed that much of the time spent serving customers is due to difficulty in locating patient folders which was done manually.
2. Waiting space for patient was found to be less spacious making social distancing difficult to adhere. The research recommends a relocation to a more spacious service point if funds allow.
3. Non-critical visits to the OPD should be avoided or deferred to less busy periods.
4. Priority queuing should be implemented at the OPD to allow patients exhibiting symptom of COVID-19 attended to separately from other patients with non-COVID-19 like symptoms.
5. To avoid long queues at OPDs of the class of the case OPD, those of non-tertiary care facilities should be earmarked for patients suffering from chronic diseases and minor complaints.

The research does not consider the cost implications of additional service windows on waiting cost and customer satisfaction. It will be interesting to investigate such analysis in future research. A simulation analysis will be considered in future studies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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