Applied Mathematics and Computational Intelligence
Volume 13, No. 2, 2024 [11-24]

Estimation of New Resource Allocation in Hospital's (or Medical Care) Inpatient Department using Discrete Event Simulation

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Received: 26 July 2023
Revised: 1 March 2024
Accepted: 12 March 2024

ABSTRACT

This study presents a computer simulation model for the inpatient department of a public hospital located in Kelantan by using the Discrete Event Simulation approach. Overcrowding, long wait times, and shortages of nurses and beds have been identified as significant issues in the department, which requires a reliable tool for analyzing current operations and optimizing resource allocation to improve service quality. By applying Discrete Event Simulation, the study models the system of the inpatient department and identifies bottlenecks in the process. Arena software was utilized to determine the optimal number of resources needed to meet the demands. The improvement model was developed based on the optimization results, and its conclusive findings demonstrate that the enhanced model significantly improves the performance of the inpatient department in terms of patient waiting time and the utilization rate of nurses and beds. In addition, a new mathematical equation has been developed to generate alternative resource allocation options based on the hospital budget. The implementation of the new configuration of inpatient department resources, as constructed in this study, effectively improves system bottlenecks. The findings of this study can be used to inform decision-making and enhance the efficiency and effectiveness of the inpatient department.

Keywords: inpatient department; discrete event simulation; optimal resource; bottlenecks; mathematical equation

1 INTRODUCTION

The inpatient department (IPD), also referred to as the inpatient unit or hospital ward, is a specifically designated section within a hospital where patients are admitted for medical treatment that necessitates an overnight stay or an extended period of care. Its primary purpose is to deliver comprehensive medical care and assistance to patients who need intensive monitoring, specialized treatments, or surgical interventions [1]. According to the latest demographic statistics released by the Department of Statistics Malaysia (DOSM), Malaysia's population is estimated to have reached 33 million people in the fourth quarter of 2022, reflecting a 1.3 percent increase compared to the 32.6 million recorded during the same period in 2021 [2]. As a consequence of this population growth, the rate of inpatient admissions to hospitals has also risen in 2021 (2,258,022) compared to 2020 (2,336,400) [3]. With a continuous increase in the human population, the demand for medical treatment has likewise increased, leading to a higher number of patients being admitted to hospitals which will cause overcrowding and long waiting time issues. The issue of overcrowding in government hospitals, as highlighted by Oscar Ling Chai Yew, Member of Parliament (MP) for Sibu district has become a growing concern due to the prolonged waiting times for patients in need of medical services [4]. The situation may lead to patient dissatisfaction.

There are problems also faced by IPD. Dr. N Ganabaskaran, President of the Malaysian Medical Association (MMA), highlights that shortages of healthcare professionals, including doctors and nurses, stem from the rapid expansion of the medical sector, leading to the establishment of new hospitals [5]. Consequently, the existing medical staff is burdened with excessive workloads, necessitating doctors to put in extra hours and nurses to undertake double shifts within their designated working hours. Furthermore, Sultan Sharafuddin Idris Shah, Sultan of Selangor voiced concerns regarding the extended waiting period endured by patients in the emergency department before their admission to the IPD [6]. The patients face significant waiting periods of several months for necessary treatments and surgeries. These prolonged delays can be attributed to the shortage of doctors and nurses in the IPD, resulting in inadequate capacity to effectively manage the patient load [7]. Tan Sri Dr. Noor Hisham Abdullah, Director General of Health Ministry of Health, Malaysia highlighted the pressing issue of numerous critically ill patients remaining in the emergency department, unable to be transferred to the IPD due to severe overcrowding and insufficient bed availability [8, 9]. Patients often face a waiting period of up to four days before being admitted to the IPD and receiving a bed. Moreover, the daily utilization rate of patient beds in IPD occasionally exceeds 80 percent [10].

Likewise, a public hospital situated in Kelantan, Malaysia, recognized for its highest inpatient admissions every year, is currently grappling with the same predicament [11]. That hospital is Hospital Universiti Sains Malaysia (HUSM), situated strategically in Kota Bharu, attracting a significant number of people seeking medical treatment. HUSM faces challenges related to patient overcrowding in IPD due to its prominent role as the primary hospital on the East Coast for cancer treatment, attracting numerous medical specialists [12, 13]. Consequently, the high patient load in the IPD leads to extended waiting times in the emergency department for admission to IPD. Insufficient bed capacity and shortages of nurses are the issues at HUSM [14]. The main objective of IPD management is to identify and allocate the necessary resources effectively, ensuring that the increasing number of inpatient admissions does not result in overcrowding while maintaining minimal waiting times for patients.

Computer simulation refers to the use of computer programs to model real-life scenarios or products, enabling the testing of numerous possible outcomes [15]. It has become a valuable tool in mathematical modeling across various disciplines such as natural systems, physics, mechanics, chemistry, biology, economic systems, psychology, and social sciences. By employing computer simulation, researchers can effectively examine intricate processes and product flows within these fields [16]. Computer simulation has gained significant popularity in the healthcare industry due to its ability to enhance understanding and improve healthcare operations [17]. It offers researchers valuable flexibility in dealing with variability and uncertainty, particularly when modeling complex systems like hospitals. Utilizing simulation to model hospital processes proves highly beneficial in determining parameters such as efficiency, utilization, service time, and overall throughput of the hospital. This enables researchers to identify areas for improvement and optimize healthcare delivery [18]. Furthermore, simulation models can aid management in identifying unforeseen bottlenecks, preventing resource overutilization or underutilization, and optimizing system performance [19]. By evaluating both the existing system and proposed alternative scenarios, simulation allows for thorough testing without disrupting the actual system.

Discrete-event simulation (DES) is a highly effective stochastic modeling approach commonly employed to tackle dynamic and intricate systems, particularly in the healthcare field. DES provides a powerful tool for analyzing and understanding complex processes by simulating events as they occur over time [20]. In a healthcare environment involving DES, the system revolves around patients: sick or injured individuals enter, wait in designated areas, transform processes like surgeries, radiological exams, or treatment courses, and eventually, healthy patients leave the system [21]. Recent advancements in DES have expanded its scope to encompass long-term population health outcomes, evaluating the effects of different treatments, therapies, or medications. One common focus of the study is the economic implications in terms of quality-adjusted life years (QALY) [22]. DES systems have proven to be invaluable in optimizing resource allocation within hospitals, particularly when it comes to determining the appropriate number of nurses or beds in the IPD [23].

The objective of this study is to develop a DES model that accurately represents the functioning of IPD. By analyzing the results obtained from the simulation model, the study aims to determine the optimal allocation of resources based on demand. Additionally, the study aims to develop a new mathematical equation to enhance the precision and effectiveness of resource planning in the IPD.

2 MATERIAL AND METHODS

The primary focus of this study is to enhance resource allocation within the IPD and optimize the utilization of its resources to improve overall efficiency. To achieve these objectives, the study will employ a systematic methodology outlined in the following steps:

Step 1: Data collecting.
Step 2: Modelling the IPD system by using the DES method.
Step 3: Identify the IPD bottlenecks and generate resource allocation alternatives.

The first step involves the data collection process at the IPD. Initially, we obtained approval from the hospital's Research Ethics Committee to conduct this study. With permission in hand, we embarked on a month-long data collection process in the IPD, meticulously visiting every shift and interviewing the nurses. This approach allowed us to gain a deep understanding of the operational system and the processes involved, as well as identify the necessary data required for developing the IPD model. Following these visits and interviews, we conducted a comprehensive survey to gather data on the patient flow within the IPD. This survey covered various stages, starting from the patient's arrival, through the treatment process, and concluding with their discharge from the IPD. To facilitate the collection of this information, we developed a specialized form that was used by our dedicated data collection team.

Step 2 focuses on developing the IPD model using the DES method. During this stage, it is crucial to conduct verification and validation tests on the model to ensure its accuracy and its ability to faithfully represent the actual IPD operation system. These tests help in verifying the validity of the model and its capability to mimic real-world scenarios. Following the modeling process, Step 3 involves analyzing the results obtained from the DES simulations to identify any bottlenecks within the system. This analysis allows us to pinpoint areas where the IPD operation may face constraints or inefficiencies. To address these bottlenecks, a new mathematical equation will be developed to generate resource allocation alternatives. By formulating these alternatives, we can recommend improvements that will enhance the identified bottlenecks and optimize the overall performance of the IPD system.

2.1 Discrete Event Simulation

2.1.1 System description

Based on observations made during the data collection phase, the IPD can be categorized into four distinct zones: Green Zone 1 (GZ1), Green Zone 2 (GZ2), Yellow Zone (YZ), and Red Zone (RZ). GZ1 and GZ2 are designated for the treatment of non-critical patients, while YZ is responsible for treating semi-critical patients. On the other hand, RZ is specifically dedicated to the care and treatment of critical patients. The operation of the IPD is currently structured around three distinct working shifts: the morning shift, evening shift, and night shift. The morning shift commences at 7 a.m. and concludes at 2 p.m., followed by the evening shift from 2 p.m. to 9 p.m., and finally the night shift from 9 p.m. to 7 a.m. The allocation of nurses across these shifts is as follows: six nurses are assigned to both the morning (nurse shift 1) and evening shifts (nurse shift 2), while the night shift (nurse shift 3) is staffed by four nurses. For a detailed breakdown of the nurse allocation per zone and shift, please refer to Table 1. Moreover, the IPD consists of a total of 36 beds, with 12 beds assigned to both GZ1 and GZ2 and 6 beds each designated for YZ and RZ. These figures are highlighted in Table 1 below.

Table 1: The number of nurses and beds in each of the zones in IPD.

Number of nurses shift 1 (NNS1)	**Number of nurses shift 2 (NNS2)**	**Number of nurses shift 3 (NNS3)**	**Number of beds**
$6(1^{GZ1}, 1^{GZ2}, 2^{YZ}, 2^{RZ})$	$6(1^{GZ1}, 1^{GZ2}, 2^{YZ}, 2^{RZ})$	$4(1^{GZ1}, 1^{GZ2}, 1^{YZ}, 1^{RZ})$	$36(12^{GZ1}, 12^{GZ2}, 6^{YZ}, 6^{RZ})$

Various types of patient admissions occur in the IPD, involving individuals from both the emergency department in need of immediate admission and patients from home seeking treatment from doctors

[24]. Once the administration process is completed, these patients proceed to register at the IPD to secure their designated bed in the appropriate zone. After arrival, patients are directed to their assigned beds where they await their initial checkup by a nurse. The waiting time for each patient varies depending on the availability of the nurses. Following the nurse's assessment, patients receive a consultation with a doctor. During this consultation, the doctor informs the patient about any necessary tests, such as X-rays, CT scans, urine tests, or others. The investigation test results are then reviewed by the doctor, who makes decisions regarding further tests and consultations. Patients continue undergoing tests and consulting with doctors until they are satisfied with their test results. In certain cases, critically ill patients may require consultations with specialist doctors. Finally, patients are either discharged or admitted to the ICU. Unfortunately, in rare instances, some patients may pass away while in IPD due to severe conditions. Figure 1 shows the general flow of patient (from they are discharged or admitted) and the process involved in IPD.

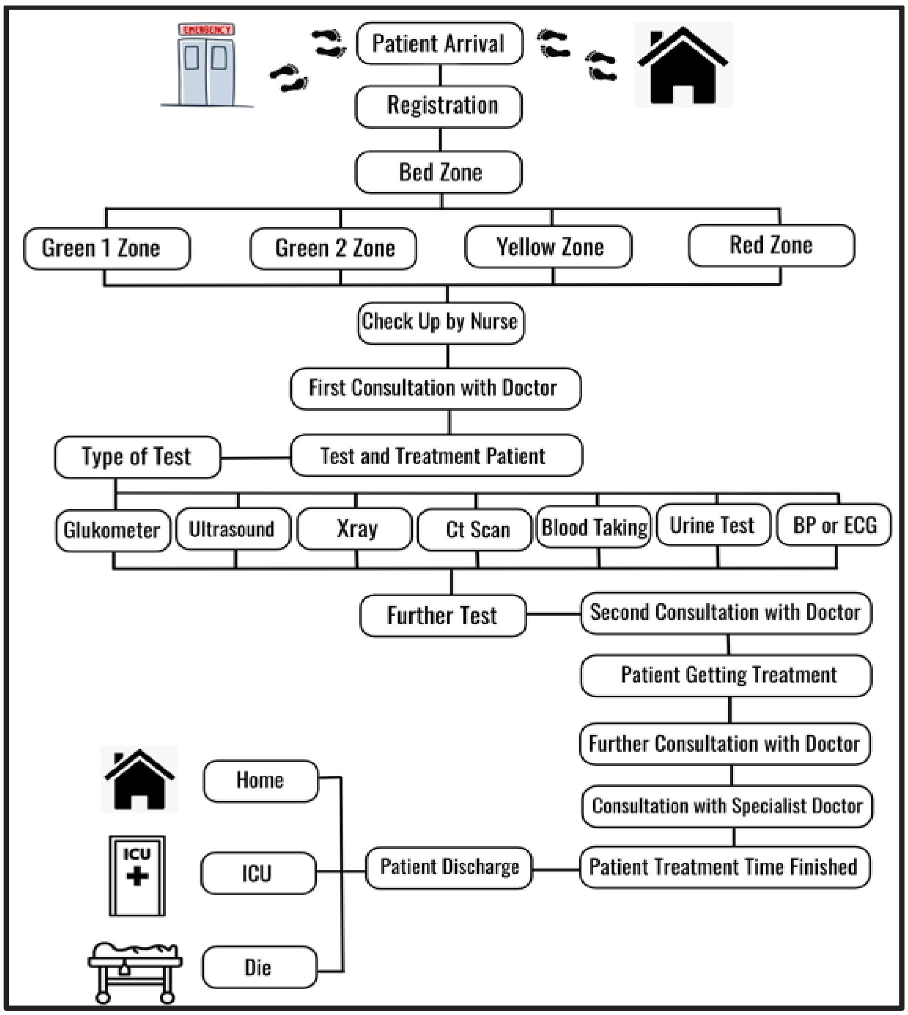

Figure 1: The general flow of patients at IPD.

2.1.2 Model design

The flowchart in Figure 1 illustrates the development of the simulation model utilized in this study. To model the overall process of the IPD, a DES software called ARENA was employed. Following the completion of the data collection process, the ARENA Input Analyzer was utilized to determine the appropriate distribution that best fits the collected data. Table 2 presents the service time distribution for each activity within the IPD. To illustrate, the registration process follows a triangular distribution with an average time of 15 minutes, ranging from a minimum of 10 minutes to a maximum of 30 minutes. These distributions were incorporated into modules within the ARENA simulation software. The modules were interconnected and executed through three to five replications to ensure reliable and precise results [25]. In ARENA version 16.1, a new feature has been introduced, enabling the distribution of individual replications across the logical processors of our computers. Although the runtime of each replication may exceed our desired timeframe, running them in parallel instead of sequentially can significantly reduce the overall time required to complete all the replications necessary for achieving statistical validity [26]. The simulation models are run for 24 hours for 30 replicated times. Additionally, an animation of the model was created to facilitate verification checks during the subsequent steps.

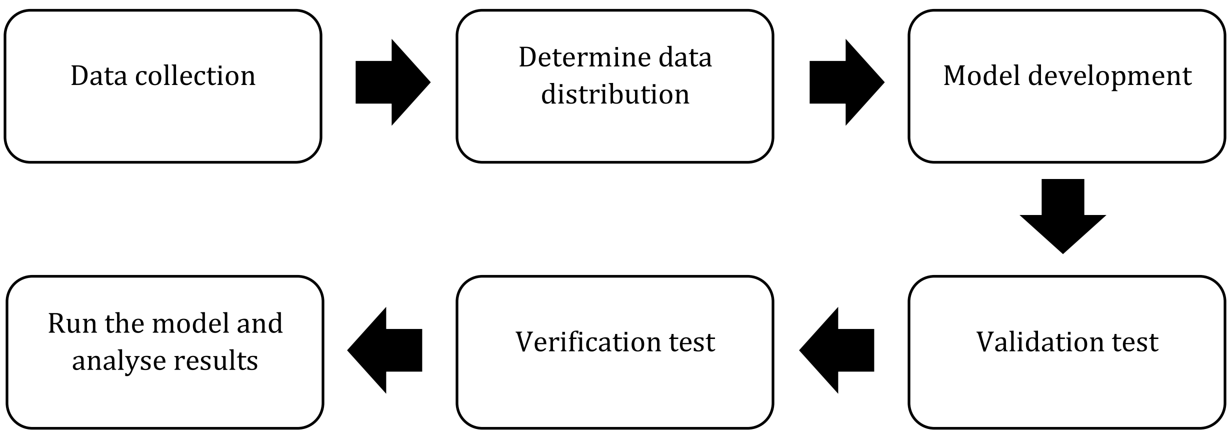

Figure 2: Steps to develop a simulation model.

Table 2: Distribution of service time at each activity.

Activity	Distribution
Patient Arrival	$-0.001 + EXPO(210)$
Registration	$TRIA(10,15,30)$
Checkup by Nurse	$TRIA(5,10,15)$
First Consultation with Doctor	$TRIA(10,20,30)$
Test and Treatment Patient	$TRIA(10,20,30)$
Second Consultation with Doctor	$TRIA(10,20,30)$
Patient Getting Treatment	$TRIA(1440,2880,4320)$
Further Consultation with Doctor	$TRIA(10,20,30)$
Consultation with Specialist Doctor	$TRIA(15,30,45)$

2.1.3 Model verification and validation

After the development of the IPD simulation model, verification tests and validation procedures were conducted to ensure its accuracy and reliability. The model is executed and thoroughly reviewed by IPD management to identify any errors. Upon completion of the verification process, the validation test is conducted. The purpose of this test is to ensure that the simulation results align with expectations and accurately represent the real system [27]. Subsequently, the obtained results are presented to the IPD management, who assess the model's validity based on their extensive knowledge and experience. Moreover, a validation test is conducted, employing the following mathematical formula for further verification [28]:

$$Difference(\%) = \frac{|Simulation\ output - Actual\ data|}{Actual\ data} \times 100\% \tag{1}$$

The results obtained from the simulation model are compared with the actual collected data, and to be deemed valid and achieve the desired level of accuracy, the resulting difference must be less than 10% [22]. To determine the optimal number of resources based on the number of patients, Arena software as the optimization tool.

3 RESULTS AND DISCUSSION

In this validation test, we compare the total number of patients in the IPD and the total number of patients in each zone of the simulation model with the actual monthly data collected previously, as presented in Table 3. This comparison is performed using the mathematical formula outlined in the preceding section. Based on the data presented in Table 3, it can be observed that all the conducted comparisons yielded results below the threshold of 10% [22]. As a result, we can confidently affirm the validity of the proposed IPD model, ensuring that all generated outcomes are applicable and suitable for this study.

Table 3: Differences between simulated and actual data.

Phase	Simulation output	Actual data	Difference (%)
Total number of patients	134	143	6.3
Number of patients in Green Zone 1	51	55	7.3
Number of patients in Green Zone 2	43	46	6.5
Number of patients in Yellow Zone	21	22	4.6
Number of patients in Red Zone	19	20	5.0

Once the developed model was deemed valid, it was executed, and the outputs generated by the DES

Table 4: IPD simulation model's results.

Item	**Simulation Results**
Waiting for Check Up by Nurse GZ1 (minutes)	21.17
Waiting for Check Up by Nurse GZ2 (minutes)	21.57
Waiting for Check Up by Nurse YZ (minutes)	6.79
Waiting for Check Up by Nurse RZ (minutes)	9.64
Utilization of Nurse GZ1 (%)	106.22
Utilization of Nurse GZ2 (%)	106.26
Utilization of Nurse YZ (%)	69.52
Utilization of Nurse RZ (%)	69.51
Utilization of Bed GZ1 (%)	69.03
Utilization of Bed GZ2 (%)	64.36
Utilization of Bed YZ (%)	46.57
Utilization of Bed RZ (%)	38.54

were analyzed to identify system bottlenecks. The identified bottlenecks were the long waiting time for nurse check-ups among patients and the inappropriate allocation of resources within the inpatient department (IPD). Three performance measures were monitored in this model: the total average waiting time for patient check-ups, the utilization rate of beds, and the utilization rate of nurses. The results, presented in Table 4, reveal that the average utilization rate for nurses falls within an acceptable range for a service sector, which is typically between 70% to 80% as stated in [29]. However, the utilization of beds is significantly higher, particularly in GZ1 and GZ2, where it exceeds 100%. Additionally, the total average waiting time for patient check-ups exceeds the 15-minute threshold set by IPD, especially in GZ1 and GZ2 [30]. These problems contribute to the overcrowded situation and may lead to patient dissatisfaction.

Several alternative approaches were developed to address the bottlenecks and enhance resource allocation in the IPD. These alternatives involved implementing new resource configurations, such as strategically adding resources where needed, reallocating existing resources, and adjusting the nurse timetable to optimize scheduling. These measures were taken to optimize the allocation of IPD resources and improve overall efficiency.

The role of nurses in ensuring patient safety and providing direct care is of paramount importance. The workload of each nurse in the IPD varies based on factors such as the number of patients they handle and the severity of their conditions. Nurses dealing with a high volume of patients daily face a heavier workload [31], [32]. Furthermore, there has been a significant rise in nurse workloads due to the increased number of patients with higher acuity levels in the IPD, as opposed to those with less severe conditions. These observations highlight the need to consider each nurse in different triage zones as a separate control variable, as their utilization rates differ. The control variables examined in this study include GZ1 Nurse, GZ2 Nurse, YZ Nurse, RZ Nurse, GZ1 Bed, GZ2 Bed, YZ Bed, and RZ Bed. The design of alternative approaches in this study takes into account these control variables. By considering the aforementioned control variables, this study makes a valuable contribution to the field of IPD research.

Changes will be introduced to the nurse staffing levels for each zone in the IPD during different shifts, especially in Green Zones. However, no modifications will be made to the nurses on shift 3 (night shift) due to a lower number of patients in the IPD during that time. Additionally, adjustments will be made to the total number of beds available in each zone. The nurses working in the IPD are actively seeking an economical approach to enhance efficiency. They aim to identify a new resource configuration for the IPD that fulfills these objectives while staying within their budget limitations. Following discussions and interviews, a consensus was reached to implement a range of changes for each variable, as outlined in Table 5.

Table 5: Range of changes for developing a significant results and contribution to the problem setting based on hospital budget.

Variable	**Current number**	**The possible range of change**	
		Minimum	**Maximum**
Nurse GZ1 Shift 1	1	1	2
Nurse GZ1 Shift 2	1	1	2
Nurse GZ1 Shift 3	1	1	1
Nurse GZ2 Shift 1	1	1	2
Nurse GZ2 Shift 2	1	1	2
Nurse GZ2 Shift 3	1	1	1
Nurse YZ Shift 1	2	2	2
Nurse YZ Shift 2	2	2	2
Nurse YZ Shift 3	1	1	1
Nurse RZ Shift 1	2	2	2
Nurse RZ Shift 2	2	2	2
Nurse RZ Shift 3	1	1	1
Bed GZ1	12	12	15
Bed GZ2	12	12	15
Bed YZ	6	6	6
Bed RZ	6	6	6
TOTAL	52	52	62

To simplify the generation of all potential resource allocation alternatives, a novel mathematical equation was devised. This equation not only facilitates the calculation of the total number of resource allocation alternatives but also ensures that no alternatives are inadvertently overlooked during the manual generation process employed by previous researchers. The equation formula is provided below:

$$X\{g_{s,}^1\ g_s^2, y_s, r_s\}_{s=1}^{s=3} \leq N \qquad (2)$$

subject to (st),

$n_{min} \leq g_{s_n}^1 \leq n_{max}$ where $s = 1,2$

$g_{s_n}^1 = 1$ where $s = 3$

$n_{min} \leq g_{s_n}^2 \leq n_{max}$ where $s = 1,2$

$g_{s_n}^2 = 1$ where $s = 3$

$y_{s_n=2}$ where $s = 1,2$

$y_{s_n} = 1$ where $s = 3$

$r_{s_n} = 2$ where $s = 1,2$

$n_{min} \leq r_{s_n} \leq n_{max}$ where $s = 3$

$b_{min} \leq g_{s_b}^1 \leq b_{max}$ where $s = 1,2,3$

$b_{min} \leq g_{s_b}^2 \leq b_{max}$ where $s = 1,2,3$

$y_{s_b} = 6$ where $s = 1,2,3$

$r_{s_b} = 6$ where $s = 1,2,3$

s is the number of shifts in the IPD, g_s^1 is the index for Green Zone 1, g_s^2 is the index for Green Zone 2, y_s is the index for Yellow Zone, r_s is the index for Red Zone, n is the number of nurses, n_{min} is the minimum number of nurses with $n_{min} = 1$, n_{max} is the maximum number of nurses with $n_{max} = 2$, b is the number of beds, b_{min} is the minimum number of beds with $b_{min} = 12$, b_{max} is the maximum number of beds with $b_{max} = 15$, $g_{s_n}^1$ is the number of Nurse Green Zone 1, $g_{s_n}^2$ is the number of Nurse Green Zone 2, $y_{s_n}$is the number of Nurse Yellow Zone, r_{s_n} is the number of Nurse Red Zone, $g_{b_n}^1$ is the number of Bed Green Zone 1, $g_{b_n}^2$ is the number of Bed Green Zone 2, y_{b_n} is the number of Bed Yellow Zone, r_{b_n} is the number of Bed Red Zone and N is the maximum number of changes ranges.

4 CONCLUSION

This research introduces a computer simulation model for the IPD that aims to enhance the understanding of the system and assist in performance analysis. By adopting a DES approach, the model provides valuable insights into IPD management. The findings from the DES model revealed improvements in nurse and bed utilization, as well as a reduction in waiting time for nurse check-ups. To address existing bottlenecks, this study successfully allocated IPD resources by devising a new mathematical equation formula based on the agreed budget set by the hospital management. This allocation ensures adequate staffing of nurses and availability of beds to deliver efficient and high-quality care to patients, particularly during peak hours. Consequently, patient waiting time for nurse check-ups is reduced, and IPD nurses are not overwhelmed with excessive workloads. As a result, the IPD functions smoothly and offers exceptional healthcare services to all patients.

Besides, by employing the simulation model and implementing the newly allocated resources configuration, the IPD management gains valuable insights into the issues within their current system. This knowledge allows them to conduct "what-if" analyses, exploring potential improvements and aiding in decision-making without directly impacting the actual system. Such solutions offer a practical approach to address concerns and optimize operations in the IPD.

Although the results obtained are considered satisfactory and beneficial for IPD management, it is critical to recognize the many limitations and constraints that should be considered in future efforts. Some data were not incorporated into the simulation model due to a lack of information. Consequently, for future work, it is essential to thoroughly study and examine these constraints and unavailable data before integrating them into the model. This approach will ensure a more comprehensive and accurate representation of the IPD system in future simulations.

ACKNOWLEDGEMENT

The authors wish to thank Universiti Teknologi MARA (UiTM) for giving us a grant to conduct this study. This study was supported by the Geran Penyelidikan MyRA [600-RMC/ GPM LPHD 5/3 (062/2021)]. Last but not least, the authors also express sincere gratitude to the management and staff of the inpatient department at Hospital Universiti Sains Malaysia (HUSM) for granting permission to conduct this study. Their cooperation and support were vital in collecting the necessary data and making this research possible.

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