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ESTIMATING OPTIMAL RESOURCE ALLOCATION IN THE INPATIENT DEPARTMENT USING SIMULATION AND DATA ENVELOPMENT ANALYSIS

(Menganggar Peruntukan Sumber yang Optimal di Jabatan Pesakit dalam Menggunakan Simulasi dan Analisis Pembangunan Data)

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ABSTRACT

The inpatient department is one of the important departments at Universiti Sains Malaysia Hospital (HUSM) which ensures that the patients will get their first checkup by the nurse within 15 minutes after getting bed. The inpatient department encounters problems as it wrestles with the long waiting time for patients getting first checkup, and the shortage of nurses and beds in the management of patients. This study demonstrate the application of hybrid method of Discrete Event Simulation (DES) and two types of Data Envelopment Analysis (DEA) specifically the Bi-Objective MCDEA BCC model and the Cross-Efficiency model to determine the most effective resource allocation in the inpatient department. The result of the simulation model has shown that the utilization of nurses per day exceeds 100% and the utilization of beds is relatively higher. Besides, the waiting times for patients to get their checkups are too long that exceeds 15 minutes in the inpatient department. The findings of the research show the number of nurses used in the inpatient department increased from 16 to 18, and the number of beds also increased from 36 to 38. The waiting time for patients to get their first checkup has been reduced to under 15 minutes. These additions and reductions can restore the problems faced by the inpatient department. Lastly, the optimum resource identified will enhance the quality of nurses, beds, and the flow of patients in the inpatient department to meet the Key Performance Indicators (KPI) of HUSM.

Keywords: inpatient department; discrete event simulation; data envelopment analysis

ABSTRAK

Jabatan pesakit dalam merupakan salah satu jabatan penting di Hospital Universiti Sains Malaysia (HUSM) yang memastikan pesakit mendapat pemeriksaan pertama oleh jururawat dalam tempoh 15 minit selepas mendapatkan katil. Jabatan pesait dalam menghadapi masalah kerena ia bergelut dengan masa menunggu yang lama oleh pesakit mendapat pemeriksaan pertama, dan kekurangan jururawat dan katil dalam pengurusan pesakit. Kajian ini menggunakan kaedah hibrid menggabungkan Simulasi Peristiwa Diskret (SPD) dan model Analisis Penyampulan Data (APD) seperti model Bi-Objektif MCDEA BCC dan model Kecekapan-Silang untuk menentukan peruntukan sumber yang paling berkesan untuk penambahbaikan semasa di jabatan pesakit dalam. Hasil daripada model simulasi telah menunjukkan bahawa penggunaan jururawat sehari melebihi 100% dan penggunaan katil secara relatifnya lebih tinggi. Selain itu, masa menunggu pesakit untuk mendapatkan permeriksaan adalah terlalu lama sehingga melebihi 15 minit di bahagian pesakit dalam. Penemuan penyelidikan menunjukkan bilangan jururawat yang digunakan di jabatan pesakit dalam meningkat daripada 16 kepada 18, dan bilangan katil juga meningkat daripada 36 kepada 38. Masa menunggu pesakit untuk mendapatkan pemeriksaan pertama telah dikurangkan kepada bawah 15 minit. Penambahan dan pengurangan ini dapat memulihkan masalah-masalah yang dihadapi oleh jabatan pesakit dalam. Akhir sekali, sumber optimum yang dikenal pasti akan meningkatkan kualiti jururawat, katil dan aliran pesakit di jabatan pesakit dalam untuk memenuhi Petunjuk Prestasi Utama (KPI) HUSM.

Kata kunci: jabatan pesakit dalam; simulasi peristiwa diskret; analisis penyampulan data

1. Introduction

An Inpatient Department (IPD) is a hospital ward designed for patients who require short-term admission and 24-hour care from healthcare professionals such as doctors and nurses. The IPD is fully equipped with medical resources and comfortable beds to provide the best possible care for patients. Occupying between 33% and 50% of the hospital's physical space, the IPD is responsible for managing a significant portion of patient care, medical education, training, and research activities (Aggarwal 2020; Neelesh 2020; Shaban 2021). The statistics from university hospitals, including Hospital Universiti Sains Malaysia (HUSM) and Hospital Canselor Tuanku Muhriz UKM (HCTM), indicate a consistent increase inpatient admissions to the wards each year. In recent years, the total number of inpatient admissions has increased significantly from 44,809 patients in 2019 to 59,142 in 2020 for HUSM (HCTM 2023; HUSM 2023). Additionally, Ministry of Health Malaysia (MoH) (2020) reports a nationwide rise by 8% until 10% in inpatient hospital admissions across all states in Malaysia over the years. Unfortunately, the IPD faces several challenges that greatly impact patient satisfaction with their treatment experiences in the ward. One of the most prevalent issues encountered in the IPD is the prolonged waiting time for a bed after the registration process. A recent study conducted by Zaidi in 2023 and reported by Berita Harian (BH) highlighted the issue of overcrowding in the IPD, leading to extensive wait times for patients in the emergency department. Consequently, these problems have contributed to a significant decrease in patients' overall satisfaction levels during their stay in the ward. In certain instances, patients in the ward are prematurely discharged to accommodate critical patients due to a shortage of beds (Devaraj 2019). Consequently, these patients end up occupying emergency wards, further exacerbating the issue (Malaysiakini 2021; Baharu 2021). Moreover, the hospital faces the problem of a shortage of nurses, leading to delays in patients receiving timely treatment within the IPD. The shortage of nursing staff often results in nurses feeling overwhelmed and experiencing burnout due to the heavy workload (Boyle *et al.* 2021; Sacadura-Leite *et al.* 2020; Said 2022).

The IPD caters to patients with serious health conditions requiring immediate medical attention and continuous supervision (Torres 2022). To ensure timely access to appropriate care, the Ministry of Health Malaysia (MoH) has established a maximum waiting time of 30 minutes for patients in the emergency department before admission to the inpatient department (Ibrahim *et al.* 2017). However, Sultan Sharafuddin Idris Shah highlighted that current waiting times exceed the recommended limit due to the high influx of patients in the emergency department (Arof 2023). Consequently, these prolonged waiting times not only cause delays in patient treatment but also exacerbate the issue of inadequate nurse-to-patient ratios and bed shortages within the inpatient department (Malaysiakini 2021; Nation 2022; Hamzah 2022; Manzor *et al.* 2023; Noor 2019). Nurses play a critical role in IPD, as they are responsible for monitoring and ensuring that each patient receives adequate treatment to prevent critical incidents (Bergman *et al.* 2020; Dabija *et al.* 2021). However, the shortage of nurses hampers the delivery of timely and efficient care to patients. Additionally, insufficient patient beds further contribute to treatment delays and hinder the overall flow of patients within the department.

The IPD serves as the next phase of care for patients after they have been assessed and treated in the emergency department. Within the IPD, patients receive specialized care under the supervision of doctors and nurses. The department caters to various categories of patients, including those requiring specific services such as neurology or cardiology, individuals in need of surgical procedures or childbirth-related care, as well as patients with unexpected emergencies or illnesses like heart attacks or severe accidents. The patient journey in the IPD typically begins with registration at the counter to secure a bed. Subsequently, patients undergo consultations with doctors and receive diverse treatments for several days until they are deemed fit for discharge (Shaban 2021; Wikipedia 2022). While numerous studies have explored resource allocation optimization within hospitals, most research has primarily focused on operations within the emergency department, with limited attention given to the inpatient department. In this study, particular emphasis will be placed on the Inpatient Department Hospital Universiti Sains Malaysia (IPDHUSM), as it represents the busiest ward within the department.

The challenges faced by the IPDHUSM are not unique to this hospital but are common issues encountered in other healthcare facilities as well. These challenges include high patient admissions, resource shortages, and long waiting times. HUSM, being a renowned teaching hospital in Malaysia with various specialties, attracts a large number of patients, leading to overcrowding and increased demand for services (Yusoff et al. 2019). This study specifically focuses on the IPDHUSM and the management of patients with various generalized illnesses, including kidney disease, diabetes, heart disease, and other conditions. During data collection and interviews with nurses, it was observed that IPD is divided into distinct zones, namely Green Zone 1 (GZ1), Green Zone 2 (GZ2), Yellow Zone (YZ), and Red Zone (RZ), based on the severity of patients' conditions or diseases. The GZ1 and GZ2 accommodate non-critical patients, while the YZ caters to semi-critical patients, and the RZ serves critical patients. The ward consists of a total of 36 beds, with 12 beds allocated to GZ1 and GZ2, and 6 beds each for the YZ and RZ. The number of nurses assigned to each zone during their respective shifts is predetermined. Currently, IPD has a daily assignment of 16 nurses, with 6 nurses for Shift 1 (7 am to 2 pm), 6 nurses for Shift 2 (2 pm to 9 pm), and 4 nurses for Shift 3 (9 pm to 7 am).

The Kelantan Health Department has observed that the utilization of beds in the IPD has exceeded its capacity, leading to patients waiting for as long as four hours before being admitted (Nation 2022). An audit review conducted in a Kelantan government hospital revealed an uneven distribution of nurses, which does not align with the recommended level of care ratios. As a result, nurses are forced to work overtime (Bernama 2023). Despite a slight increase in annual patient admissions to IPDHUSM, the number of beds has remained constant at 36 since 2017 (HUSM 2023). This imbalance between the number of beds and patient admissions is a significant factor contributing to prolonged waiting times in the emergency department (Luo *et al.* 2019). Consequently, the IPD faces challenges in meeting the Key Performance Indicators (KPIs) set by the Ministry of Health Malaysia (MoH). Addressing the resource shortage, particularly in terms of available beds in the ward, is crucial to reduce patient waiting times and enhance the overall efficiency of the IPD.

To address the challenges of patient waiting time, treatment quality, crowding issues, and KPIs achievement, it is essential to implement effective actions. These actions should include the rearrangement of the current work shift timetable and the augmentation of beds and nursing staff in IPD, considering the existing resource limitations (Malaysiakini 2021; Bergman *et al.* 2020). Consequently, the primary challenge faced by the management of IPD is the strategic determination of the required number of doctors, nurses, and beds for each zone within the ward.

Numerous previous researchers have conducted studies in hospitals to estimate optimal resource allocations, employing either single or hybrid methods (Deng *et al.* 2023; Keshtkar *et al.* 2020; Ordu *et al.* 2021; Stuart *et al.* 2023; Yusoff *et al.* 2021; Wang & Gao 2017). Notably, Keshtkar *et al.* (2020), Ordu *et al.* (2021), and Yusoff *et al.* (2021) have opted for hybrid methods due to their comprehensive nature, which surpasses the limitations of single methods. Hybrid approaches offer systematic guidance in understanding and managing workflow interruptions (Rodgers 2022). Conversely, other researchers such as Jung *et al.* (2023), Kohl *et al.* (2019), Wang & Gao (2017), and Zakowska & Cwirko (2020) have relied on a single method, specifically Data Envelopment Analysis (DEA), to estimate efficiency in hospitals. However, it is widely agreed among researchers that a single method alone cannot provide optimal findings due to the complexity of the healthcare operating system (Keshtkar *et al.* 2020; Kovalchuk *et al.* 2018; Luo *et al.* 2019; Ordu *et al.* 2021; Yusoff *et al.* 2021). Additionally, there is a lack of comprehensive studies focusing on resource allocations in IPD. Notably, Keshtkar *et al*. (2020) and Yusoff *et al.* (2021) have conducted research in the emergency department using hybrid methods.

This study aims to propose the optimal allocation of resources, including doctors, nurses, and beds, in IPD. To achieve this objective, the study utilizes the DES (Discrete Event Simulation) and DEA (Data Envelopment Analysis) methods. Specifically, the Bi-Objective MCDEA BCC model and Cross-Efficiency model are employed. The study also focuses on detailed modeling based on four zones: GZ1, GZ2, YZ, and RZ within IPDHUSM. The results of this study aim to achieve several outcomes. First, it aims to reduce the utilization of nurses, beds, and waiting time for checkups by nurses in each zone of IPDHUSM. Additionally, the study aims to enhance the quality of services provided by each zone.

2. Research Methodology

This study focuses on the combination of DES (Discrete Event Simulation) and DEA (Data Envelopment Analysis) methods to determine the most effective resource allocation and improve the performance of IPDHUSM. The integration of DES and DEA methods offers a comprehensive approach to understanding the complexities of the system, leveraging the advantages of each method in solving intricate problems (Jung *et al.* 2023; Keshtkar *et al.* 2020; Kohl *et al.* 2019; Vázquez-Serrano *et al.* 2021; Yusoff *et al.* 2021; Zakowska & Cwirko 2020). By utilizing the combined model, hospital administrators can accurately evaluate various scenarios and make necessary adjustments to optimize the hospital's operations. The model serves as a reliable reproduction tool, aiding in decision-making, policy implementation, and the development of long-term plans for the inpatient department. Overall, this study provides valuable assistance and guidance to the administration of the inpatient department, facilitating effective decision-making and the implementation of strategies to enhance performance in IPD.

2.1. *Discrete event simulation (DES)*

The research initially employed DES models, which are highly suitable for addressing complex problems in the healthcare sector. DES focuses on representing systems at an operational level, where factors such as transactions, procedures, and the flow of individual entities play a crucial role. DES's capability to model events over discrete time intervals allows for a more comprehensive analysis (Vázquez-Serrano *et al.* 2021). The development of the DES model begins by identifying the problems under investigation through data collection in IPDHUSM. Subsequently, the observations made during the data collection process help in understanding the patient flow within IPD. Additionally, interviews with Sister Fithriyaani, the head nurse of IPDHUSM, and other nurses help uncover other potential issues within the ward. These steps contribute to a deeper understanding of the overall system, the procedures involved, and the necessary details for creating the model of the IPDHUSM.

The data collection process was conducted manually over one month, spanning 24 hours each day at IPDHUSM. The focus of data collection encompassed inter-arrival time, service time, bed count, doctor count, nurse count, and all patient-related processes, starting from their arrival in IPD until their discharge. To ensure comprehensive results, a dedicated team of data collectors worked on shifts according to their schedules. IPD operates three shifts: 7 a.m. to 2 p.m., 2 p.m. to 9 p.m., and 9 p.m. to 7 a.m. During each shift, two data collectors were assigned. Throughout the month, a total of 143 patients were admitted to IPD, averaging approximately 4 to 5 patients per day. During the observation period, it was noted that 55 non-critical patients were transferred to GZ1, while 46 non-critical patients were admitted to GZ2. Additionally, YZ treated 22 patients under the semi-critical category per month, while RZ attended to 20 patients under the critical category. The average length of stay in IPD ranged from 3 to 7 days, depending on the patient's recovery progress. However, critical cases admitted to RZ had an extended stay of up to 30 days due to ongoing treatment requirements from medical professionals.

Patients are required to register at the registration counter if they are coming from home before they can be assigned a bed in the ward. On the other hand, patients from the emergency department are directly assigned beds in the IPD. However, if there are no available beds, patients have to wait in their current location. In certain cases, such as when a patient's condition improves from critical to semi-critical, they may be moved from an RZ bed to a YZ bed. Similarly, patients in YZ beds may be transferred to GZ1 or GZ2 beds depending on bed availability. Once patients are settled in their beds, they need to wait for their initial checkup by a nurse, which includes monitoring blood pressure, conducting glucometer tests, and other necessary assessments before their consultation sessions with doctors. The waiting time for nurse checkups has been a challenge in IPD due to a shortage of nurses. During the consultation, the doctor will evaluate the patient's condition and determine the appropriate treatment or schedule surgery if needed, based on the results of the nurse's checkup. Subsequently, patients will undergo various treatments and continue their consultations with the doctor, which can take several days until the doctor decides they are ready for discharge. As patients are discharged from the ward, the patient flow in IPD comes to an end.

The simulation model of IPDHUSM was developed using Arena 14 to accurately represent and visualize the daily operations of each zone. The model categorizes the zones into GZ1, GZ2, YZ, and RZ. The simulation results include metrics such as nurse utilization by the shift in each zone, bed utilization in each zone, and waiting time for nurse checkups. These outputs and inputs from the simulation serve as the foundation for the DEA method employed in the second phase of the study. The DES models of IPDHUSM have undergone thorough validation and verification in this study. Model verification involves ensuring the accuracy of the simulation model and producing an animation based on precise data. The generated model must faithfully represent the system and process flow of IPD, as validated by Bhosekar *et al.* (2023). Furthermore, the management of the IPDHUSM has reviewed and approved the validity of these models. Subsequently, a validation test is conducted to assess the simulation results, an essential step in ensuring that the models behave similarly to the actual system, as emphasized by Vázquez-Serrano *et al.* (2021). The simulation models are executed 30 times within 24 hours. The results obtained from the simulation model are then compared to the actual results, with a threshold of less than 10% difference required for the comparison to be deemed valid (Vázquez-Serrano *et al.* 2021).

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

Eq. (1) serves a fundamental purpose in this study, which is to ascertain the validity of the simulation model's results. This equation plays a crucial role in assessing the accuracy and reliability of the outcomes produced by the simulation model.

2.2. *Bi-Objective MCDEA BCC model (Bi-O MCDEA BCC)*

The DEA technique is a linear programming method used to evaluate the relative effectiveness of a homogeneous decision-making unit (DMU). In conjunction with other quantitative models that generate alternative schemes, DEA assesses the effectiveness of each scheme by calculating a relative efficiency score for them (Barat *et al.* 2019). The MCDEA model was initially developed by Li and Reeves in 1999, and Ghasemi *et al.* (2014) further improved it by introducing a new model called the Bi-O MCDEA CCR model. This model aimed to address any limitations in DEA and offer an alternative solution. Aminuddin *et al.* (2018) proposed another enhancement known as the Bi-O MCDEA BCC model, which aimed to improve upon the Bi-O MCDEA model. According to the study, only the Bi-O MCDEA BCC model has successfully optimized all three MCDEA goals within a single model, providing improved weighted values for both inputs and outputs. This consolidation of the model has streamlined the calculation process, reducing the occurrence of errors in calculating efficiency values. Consequently, the model's effectiveness lies in its ability to narrow down the options, making it easier and more efficient to choose the best alternative for research purposes. In summary, an effective IPD should strive to achieve the department's key performance indicators, reduce patient waiting times for similar procedures, and optimize resource utilization. The Bi-O MCDEA BCC model (Aminuddin *et al.* 2018) is provided below as an example:

$$\min, h = \left(w_2 M + w_3 \textstyle\sum_j d_j\right) \tag{2}$$

$$\textstyle\sum_{i=1}^{m} v_i \, x_{i0} = 1, \tag{3}$$

$$\textstyle\sum_{r=1}^{s} u_r \, y_{rj} - \sum_{i=1}^{m} v_i \, x_{ij} + d_j + c_0 = 0, j = 1, \dots, n, \tag{4}$$

$$M - d_j \geq 0, j = 1, \dots, n, \tag{5}$$

$$u_r \geq \varepsilon, r = 1, \dots, s, \tag{6}$$

$$v_i \geq \varepsilon, i = 1, \dots, m, \tag{7}$$

$$d_j \geq \varepsilon, j = 1, \dots, n, \tag{8}$$

where h is the efficiency score for inefficient DMU, w_θ is the weights $(\theta > 0)$, M is the maximum quantity for all variable $d_j(j = 1, \dots, n)$, v_i and u_r are the weightage for i input and r output d_0 and d_j are the variable deviation for DMU_0 and DMU_j, the values of input i and output r from DMU_j are x_{ij} and y_{rj}. The number of DMU_s is n, the number of inputs is m, the number of outputs is s and the free sign is c_0. DMU is deemed efficient when its efficiency score equals 1.00, whereas a score less than 1.00 indicates inefficiency. Unlike other models, Bi-O MCDEA BCC needs to be calculated $h = 1 - d_j$ to determine the value of 1.00. Since the Bi-O MCDEA BCC model cannot rank the efficient DMU_s by itself, the Cross-Efficiency DEA model will be utilized to rank the most efficient DMU_s that have an efficiency of more than 1.

2.3. *Cross-Efficiency model (CE)*

The concept of cross-evaluation was introduced by Sexton *et al.* (1986). In this method, each decision-making unit (DMU) selects a set of weights, resulting in multiple efficiency values. The average of these values represents the overall performance of the DMU. The Cross Efficiency (CE) model offers several advantages, including the ability to generate a comprehensive rating of DMUs and the elimination of unrealistic weight schemes without the need for input from domain experts (Soltanifar & Sharafi 2022). To proceed with the utilization of the Cross Efficiency model, it is necessary to collect new input and output data for each efficient DMU. This data collection process involves gathering the inputs and outputs of every efficient DMU, which can be obtained from the values generated by the Bi-O MCDEA BCC model in Lingo Software. To obtain the efficiency value in the CE model, the efficient DMU from the previous Bi-O MCDEA BCC model is utilized. The DMU with the highest efficiency rating is considered the most efficient, while the DMU with the lowest efficiency rating is deemed the least efficient. The Cross Efficiency model is as follows, as proposed by Charnes *et al.* (1978):

$$E_{0j} = \frac{\sum_{r=1}^{s} u_{r0}\, y_{rj}}{\sum_{i=1}^{m} v_{i0}\, x_{ij}} \quad j \neq 0 \tag{9}$$

where,

E_{0j} = the efficiency score for DMU_j

x_{ij0} = the total of input *i* of j_0 unit

y_{rj0} = the total of output *r* of j_0 unit

u_{r0} = description given to output r_0

v_{i0} = description given to input i_0

Eq. (9) is to find the efficiency score for DMU_j. Solving this equation will get the E_{0j}value of each DMU. These E_{0j} values are then used to create the CE matrix, as shown in Table 1.

Table 1: Cross efficiency matrix

	1	2	3	…	j
1	E_{11}	E_{12}	E_{13}	…	E_{1j}
2	E_{21}	E_{22}	E_{23}	…	E_{2j}
3	E_{31}	E_{32}	E_{33}	…	E_{3j}
…	…	…	….	…	….
j	E_{j1}	E_{j2}	E_{j3}	…	E_{jj}
	e_1	e_2	e_3	…	e_n

This CE matrix is used to determine the mean CE, e_j. Meanwhile the following equation is used to calculate the average of all E_{0j}.

$$e_j = \frac{1}{n} \sum_{d=1}^{n} E_{dj} \tag{10}$$

The highest e_j value of a DMU represents its efficiency score. In this study, the Bi-O MCDEA BCC model will be used to evaluate the effectiveness of each alternative, and then the most efficient alternative will be chosen by the CE model.

3. Results and Discussion

The DES model developed for IPDHUSM successfully identified deficiencies in each zone during the first phase of the study, as shown in Table 2. A comparison was made between the simulation results and real data using Eq. (1) to calculate the percentage differences. It was determined that for the model to be considered accurate, the percentage differences should not exceed 10%. Furthermore, all the different values were found to be within the acceptable range, confirming the validity of the IPDHUSM model. During the interview session with Nurse Fithriyaani, it was revealed that the KPIs for the waiting time for check-ups by the nurse in Ward 7 Utara HUSM is a maximum of 15 minutes for each zone (Rahim 2022). Table 2 presents the waiting time results for YZ, RZ, GZ1, and GZ2, indicating that the waiting time for check-ups in YZ and RZ met the KPIs with durations of 6.79 minutes and 9.64 minutes, respectively. However, the average waiting time for GZ1 and GZ2 in IPD exceeded the KPIs, with waiting periods of 21.17 minutes and 21.57 minutes, respectively. These findings highlight a significant weakness in IPD, particularly concerning the care of non-critical patients. Prolonged waiting times for non-critical patients in GZ1 and GZ2 may lead to adverse outcomes if their conditions worsen or if other unfavorable consequences arise (Yusoff *et al.* 2019).

Table 2: Simulation result of waiting time for a checkup by the nurse in IPDHUSM

Types of zone	Simulation output average waiting time (minutes)	Actual data average waiting time (minutes)	Differences (%)
Green Zone 1	21.17	22.25	4.9
Green Zone 2	21.57	22.79	5.4
Yellow Zone	6.79	6.32	7.4
Red Zone	9.64	9.35	3.1

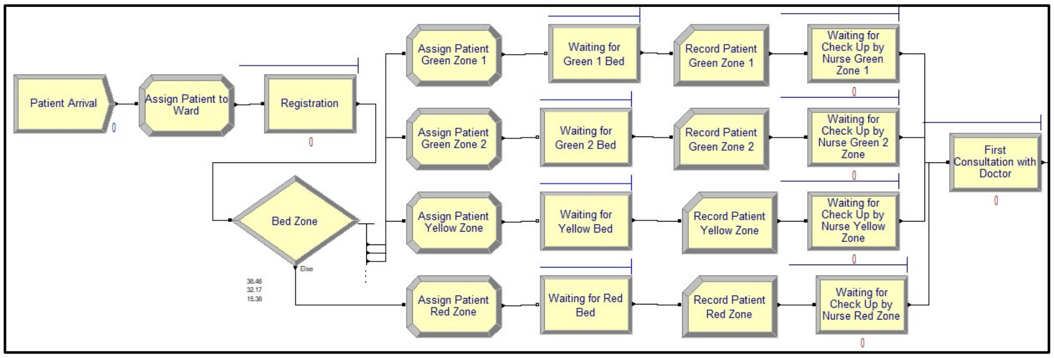

Figure 1: The beginning phase of the DES model

Figure 1 show that overview of the beginning phase of DES model. In this phase, the simulation models are executed over a continuous 24-hour period, and this process is repeated for a total of 30 replicated runs. Furthermore, an animation of the model was created to facilitate verification checks during the subsequent steps. As shown in Table 3, there are simulation results for percentage resource utilization at the IPDHUSM.

Table 3: Simulation result for utilization of resources in IPDHUSM

Resource	Utilization (%)
Nurse Green Zone 1	106.22
Nurse Green Zone 2	106.26
Nurse Yellow Zone	69.52
Nurse Red Zone	69.51
Bed Green Zone 1	69.03
Bed Green Zone 2	64.36
Bed Yellow Zone	46.57
Bed Red Zone	38.54

Based on the data presented in Table 3, it is evident that the utilization of nurses in GZ1 and GZ2 is quite high, exceeding 100% at 106.22% and 106.26%, respectively. Similarly, the utilization of beds in GZ1 and GZ2 is also relatively high at 69.03% and 64.36%, respectively. Such high utilization rates can lead to overcrowding and may result in patient dissatisfaction. Ideally, in a well-functioning service sector, the average nurse utilization rate should fall within the range of 70% to 80% to ensure optimal efficiency (Zulkifli *et al.* 2016). However, the current utilization rates in GZ1 and GZ2 exceed this acceptable range, indicating a potential strain on resources and staffing in these zones. It is crucial to address these high utilization rates to mitigate overcrowding and improve the overall patient experience.

Table 4 presents the results of the DES model for resource allocation in IPDHUSM, where a total of 255 DMUs were recommended. Each DMU represents a specific combination schedule, with DMU 0 representing the current schedule and DMUs 1 to 255 representing the recommended schedules for nurses and beds. The inputs considered in the model were the number of beds, the number of nurses, and the average waiting time for a check-up by the nurse. These inputs are typically preferred to have smaller values. On the other hand, the outputs considered were the average utilization of beds and the average utilization of nurses, which are desirable to have higher values. The DES model results were used to determine the waiting time for a check-up by a nurse, as well as the utilization of beds and nurses. These factors are crucial in evaluating the efficiency and effectiveness of resource allocation in IPDHUSM, and they provide valuable insights for optimizing the allocation of resources and improving overall performance (Bhosekar *et al.* 2023; Vázquez-Serrano *et al.* 2021).

Table 4: Efficiency scores of actual DMU and proposed DMU for IPDHUSM

	Input								Output									Result	
DMUs	NNS1	NNS2	NNS3	NB	CNG1	CNG2	CNY	CNR	UNG1	UNG2	UNY	UNR	UBG1	UBG2	UBY	UBR	PT	d_i	$1-d_i$
0	$6(1^{G1},1^{G2},2^{Y},2^{R})$	$6(1^{G1},1^{G2},2^{Y},2^{R})$	$4(1^{G1},1^{G2},1^{Y},1^{R})$	$36(12^{G1},12^{G2},6^{Y},6^{R})$	21.17	21.57	6.79	9.64	106.22	106.26	69.52	69.51	69.03	64.36	46.57	38.54	102	0.169	0.831
1	**6(1,1,2,2)**	**6(1,1,2,2)**	**4(1,1,1,1)**	**37(12,13,6,6)**	**21.17**	**21.13**	**6.41**	**9.07**	**106.22**	**106.31**	**69.56**	**69.54**	**69.03**	**59.41**	**57.91**	**48.83**	**102**	**0**	**1**
2	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	38(12,14,6,6)	21.17	21.13	6.41	9.07	106.22	106.31	69.56	69.54	69.03	55.17	57.91	43.83	102	0.185	0.815
3	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	39(12,15,6,6)	21.17	21.13	6.41	9.07	106.22	106.31	69.56	69.54	69.03	51.49	57.91	43.83	102	0.280	0.720
4	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	37(13,12,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	35.77	33.45	27.08	24.89	143	0.132	0.868
5	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	38(13,13,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	35.77	30.88	27.08	24.89	143	0.139	0.861
6	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	39(13,14,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	35.77	28.68	27.08	24.89	143	0.145	0.855
7	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	40(13,15,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	35.77	26.76	27.08	24.89	143	0.150	0.850
8	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	38(14,12,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	33.22	30.88	27.08	24.89	143	0.141	0.859
9	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	39(14,13,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	33.22	33.45	27.08	24.89	143	0.136	0.864
10	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	40(14,14,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	33.22	28.68	27.08	24.89	143	0.148	0.852
11	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	41(14,15,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	33.22	26.76	27.08	24.89	143	0.154	0.846
12	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	39(15,12,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	31.00	33.45	27.08	24.89	143	0.138	0.862
13	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	40(15,13,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	31.00	30.88	27.08	24.89	143	0.145	0.855
14	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	41(15,14,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	31.00	28.68	27.08	24.89	143	0.151	0.849
15	6(1,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	42(15,15,6,6)	22.68	28.70	12.29	9.07	114.19	113.93	72.33	72.30	31.00	26.76	27.08	24.89	143	0.157	0.843
16	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	36(12,12,6,6)	7.63	3.59	0	13.49	57.85	48.02	36.75	36.93	80.64	72.89	60.20	71.29	46	0.414	0.586
17	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	37(12,13,6,6)	7.63	3.48	0	13.49	57.85	48.08	36.75	36.93	80.64	70.95	61.52	71.29	46	0.452	0.548
18	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	38(12,14,6,6)	7.63	3.36	0	13.49	57.85	48.16	36.75	36.93	80.64	69.15	61.34	71.59	46	0.497	0.503
19	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	39(12,15,6,6)	38.24	23.82	7.97	16.92	117.25	90.01	75.82	75.81	36.58	28.64	30.57	30.50	143	0.548	0.452
20	**6(1,1,2,2)**	**7(1,2,2,2)**	**4(1,1,1,1)**	**37(13,12,6,6)**	**12.43**	**12.15**	**7.99**	**11.45**	**135.04**	**107.64**	**89.05**	**89.23**	**37.40**	**28.86**	**26.83**	**27.01**	**143**	**0**	**1**
21	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	38(13,13,6,6)	12.43	12.15	7.99	11.45	135.04	107.64	89.05	89.23	37.40	26.64	26.83	27.01	143	0.616	0.384
22	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	39(13,14,6,6)	12.43	12.15	7.99	11.45	135.04	107.64	89.05	89.23	37.40	24.74	26.83	27.01	143	0.116	0.884
23	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	40(13,15,6,6)	12.43	12.15	7.99	11.45	135.04	107.64	89.05	89.23	37.40	23.09	26.83	27.01	143	0.164	0.836
24	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	38(14,12,6,6)	8.81	3.48	0	13.49	59.65	49.90	38.43	38.69	78.37	73.64	64.38	59.02	47	0.551	0.449
25	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	39(14,13,6,6)	8.81	3.36	0	13.49	59.65	49.94	38.41	38.59	78.37	71.85	64.20	58.56	47	0.605	0.395
26	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	40(14,14,6,6)	23.49	9.32	2.28	13.54	37.24	31.13	24.14	24.14	86.10	80.93	79.66	81.79	25	0.715	0.285
27	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	41(14,15,6,6)	8.81	3.16	0	13.49	59.65	50.09	38.40	38.57	78.37	68.25	63.24	57.32	47	0.731	0.269
28	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	39(15,12,6,6)	11.70	3.48	0	20.85	59.32	49.38	38.02	38.24	77.42	71.99	63.30	66.37	47	0.722	0.278
29	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	40(15,13,6,6)	24.39	9.69	2.28	13.54	37.24	30.96	24.04	24.04	85.56	80.96	81.33	80.17	25	0.764	0.236
30	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	41(15,14,6,6)	11.70	3.36	0	20.85	59.32	49.47	38.02	38.24	77.42	68.03	63.97	65.96	47	0.833	0.167
31	6(1,1,2,2)	7(1,2,2,2)	4(1,1,1,1)	42(15,15,6,6)	11.70	3.16	0	20.85	59.32	49.54	38.02	38.24	77.42	66.36	63.97	66.42	47	0.865	0.135
32	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	36(12,12,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	47.75	46.37	49.41	62.66	115	0.531	0.469
33	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	37(12,13,6,6)	30.42	30.16	7.25	6.53	107.21	124.29	77.51	77.75	47.75	42.80	49.41	62.66	115	0.624	0.376
34	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	38(12,14,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	47.75	39.74	49.41	62.66	115	0.705	0.295
35	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	39(12,15,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	47.75	37.09	49.41	62.66	115	0.776	0.224
36	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	37(13,12,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	44.08	46.37	49.41	62.66	115	0.577	0.423
37	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	38(13,13,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	44.08	42.80	49.41	62.66	115	0.670	0.330
38	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	39(13,14,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	44.08	39.74	49.41	62.66	115	0.751	0.249

Table 4 (Continued)

39	6(1,1,2,2)	7(2,1,2,2)	4(1,1,1,1)	40(13,15,6,6)	30.42	30.16	7.25	6.53	107.24	124.29	77.51	77.75	44.08	37.09	49.41	62.66	115	0.823	0.177
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	36(12,12,6,6)	10.27	17.01	18.50	13.75	73.75	73.47	57.67	57.78	75.46	65.12	61.57	62.44	88	0.188	0.812
49	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	37(12,13,6,6)	8.82	6.19	19.30	31.95	55.19	55.05	42.35	42.45	78.32	72.37	74.54	77.71	61	0.303	0.697
50	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	38(12,14,6,6)	8.82	6.03	19.30	31.95	55.19	55.11	42.35	42.45	78.32	70.62	74.54	77.71	61	0.413	0.587
51	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	39(12,15,6,6)	8.82	5.87	19.30	31.95	55.19	55.15	42.28	42.45	78.32	68.89	74.54	77.71	61	0.510	0.490
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	40(13,15,6,6)	12.32	17.93	5.89	16.57	55.70	55.51	41.38	41.50	80.26	72.74	76.24	75.53	54	0.696	0.304
56	**6(1,1,2,2)**	**8(2,2,2,2)**	**4(1,1,1,1)**	**38(13,13,6,6)**	**14.10**	**14.76**	**2.08**	**7.08**	**73.66**	**75.85**	**64.90**	**64.93**	**71.06**	**72.78**	**58.44**	**47.99**	**143**	**0**	**1**
57	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	39(14,13,6,6)	17.28	31.10	1.08	11.42	112.65	112.80	98.20	98.33	29.36	32.85	29.48	30.48	143	0.576	0.424
58	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	40(14,14,6,6)	18.85	39.42	1.68	16.33	99.64	45.33	71.46	71.51	30.47	29.50	30.02	32.45	143	0.230	0.770
59	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	41(14,15,6,6)	18.85	39.42	1.68	16.33	99.64	99.55	71.46	71.51	30.47	27.53	30.02	32.45	143	0.182	0.818
60	6(1,1,2,2)	8(2,2,2,2)	4(1,1,1,1)	39(15,12,6,6)	13.82	33.39	2.08	14.11	83.55	83.19	64.90	64.93	65.02	72.78	68.44	70.99	90	0.180	0.820
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
128	7(2,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	36(12,12,6,6)	10.53	25.00	15.91	6.32	48.75	59.69	38.33	38.59	82.33	79.52	63.50	77.08	52	0.791	0.209
129	**7(2,1,2,2)**	**6(1,1,2,2)**	**4(1,1,1,1)**	**37(12,13,6,6)**	**20.93**	**22.57**	**11.74**	**5.51**	**89.87**	**108.26**	**71.56**	**71.90**	**66.51**	**50.93**	**57.25**	**69.50**	**109**	**0**	**1**
130	7(2,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	38(12,14,6,6)	22.82	18.80	28.66	6.91	76.23	92.65	62.18	62.62	73.98	56.44	51.73	53.03	91	0.936	0.064
131	7(2,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	39(12,15,6,6)	22.82	18.80	28.66	6.91	76.23	92.65	62.18	62.62	73.98	52.68	51.73	53.03	91	0.103	0.897
132	7(2,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	37(13,12,6,6)	29.77	39.11	52.93	25.73	91.07	112.31	74.46	74.68	36.24	34.73	25.93	35.30	143	0.250	0.750
133	7(2,1,2,2)	6(1,1,2,2)	4(1,1,1,1)	38(13,13,6,6)	29.77	39.11	52.93	25.73	91.07	112.31	74.46	74.68	36.24	32.06	25.93	35.30	143	0.257	0.743
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
223	8(2,2,2,2)	7(1,2,2,2)	4(1,1,1,1)	42(15,15,6,6)	24.05	2.70	8.40	1.79	44.94	36.53	35.52	35.62	80.83	79.60	86.21	82.13	47	0.817	0.183
224	**8(2,2,2,2)**	**7(2,1,2,2)**	**4(1,1,1,1)**	**36(12,12,6,6)**	**8.60**	**10.58**	**9.26**	**10.20**	**66.86**	**82.45**	**65.36**	**65.17**	**71.40**	**51.20**	**53.62**	**58.99**	**103**	**0**	**1**
225	8(2,2,2,2)	7(2,1,2,2)	4(1,1,1,1)	37(12,13,6,6)	8.60	10.58	9.26	10.20	66.86	82.45	65.36	65.17	71.40	47.26	53.62	58.99	103	0.102	0.898
226	8(2,2,2,2)	7(2,1,2,2)	4(1,1,1,1)	38(12,14,6,6)	8.60	10.58	9.26	10.20	66.86	82.45	65.36	65.17	71.40	43.89	53.62	58.99	103	0.190	0.810
227	8(2,2,2,2)	7(2,1,2,2)	4(1,1,1,1)	39(12,15,6,6)	8.60	10.58	9.26	10.20	66.86	82.45	65.36	65.17	71.40	40.96	53.62	58.99	103	0.268	0.732
228	8(2,2,2,2)	7(2,1,2,2)	4(1,1,1,1)	37(13,12,6,6)	13.57	11.35	10.11	10.80	68.51	83.88	66.94	66.72	69.01	41.85	58.92	46.64	104	0.563	0.437
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
251	8(2,2,2,2)	8(2,2,2,2)	4(1,1,1,1)	41(14,15,6,6)	11.20	10.15	5.30	4.57	89.59	89.32	87.94	87.88	31.21	25.87	33.61	32.22	143	0.514	0.486
252	8(2,2,2,2)	8(2,2,2,2)	4(1,1,1,1)	39(15,12,6,6)	11.20	10.15	5.30	4.57	89.59	89.32	87.94	87.88	29.13	32.33	33.61	32.22	143	0.365	0.635
253	8(2,2,2,2)	8(2,2,2,2)	4(1,1,1,1)	40(15,13,6,6)	11.20	10.15	5.30	4.57	89.59	89.32	87.97	87.88	29.13	29.85	33.61	32.22	143	0.433	0.567
254	8(2,2,2,2)	8(2,2,2,2)	4(1,1,1,1)	41(15,14,6,6)	11.20	10.15	5.30	4.57	89.59	89.32	87.94	87.88	29.13	27.71	33.61	32.22	143	0.492	0.508
255	8(2,2,2,2)	8(2,2,2,2)	4(1,1,1,1)	42(15,15,6,6)	11.20	10.15	5.30	4.57	89.59	89.32	87.94	87.88	29.13	25.87	33.61	32.22	143	0.545	0.455

**Note: DMU-Decision Making Unit/ G1- Green Zone 1/ GZ2- Green Zone 2/ YZ-Yellow Zone/ RZ- Red Zone/ NNS1-Number of Nurse Shift 1/ NNS2-Number of Nurse Shift 2/ NNS3-Number of Shift 3/ NB-Number of Beds/ CNG1-Waiting Time for Checkup by Nurse Green Zone 1/ CNG2-Waiting Time for Checkup by Nurse Green Zone 2/ CNY-Waiting Time for Checkup by Nurse Yellow Zone/ CNR-Waiting Time for Checkup by Nurse Red Zone/ UNG1-Utilization of Nurse Green Zone 1/ UNG2-Utilization of Nurse Green Zone 2/ UNY-Utilization of Nurse Yellow Zone/ UNR-Utilization of Nurse Red Zone/ UBG1-Utilization of Bed Green Zone 1/ UBG2-Utilization of Bed Green Zone 2/ UBY-Utilization of Bed Yellow Zone/ UBR-Utilization of Bed Red Zone/ PT-Patient Out/ d_j-Bi-O MCDEA BCC model/ $1 - d_j$-result

In phase two of the study, the Bi-O MCDEA BCC score was obtained from the DEA models using Eqs. (2)-(8). Referring to Table 4, it is observed that there are five DMUs (DMU 1, DMU 20, DMU 56, DMU 129, and DMU 224) that have a Bi-O MCDEA BCC score of 0. The efficiency of these DMUs was expressed as d_j in the Lingo software implementation. To calculate the actual efficiency score of each DMU, the value of 1 minus d_j was used, resulting in an efficiency score of 1 for these DMUs. In the evaluation and implementation process using the LINGO program, DMUs with an efficiency score of 1 are considered efficient, while those with scores less than 1 are considered inefficient. Therefore, based on the calculated efficiency scores, it can be concluded that the mentioned DMUs (DMU 1, DMU 20, DMU 56, DMU 129, and DMU 224) are efficient in the resource allocation and performance of IPDHUSM, as they achieved a maximum efficiency score of 1.

In the final phase of this study, the Cross Efficiency model is utilized to identify the most efficient DMUs. Before proceeding with the model, new input and output data need to be generated. These data are obtained from the outputs and inputs of each effective DMU, which were calculated in the previous step using the Bi-Objective MCDEA BCC model in the Lingo software. Table 5 presents the collected data for each DMU, including their respective inputs and outputs.

Table 5: The new input and output for the efficient DMUs

Items	DMU 2	DMU 21	DMU57	DMU 130	DMU 225
NNS1	0.0001	0.0001	0.0001	0.0001	0.0001
NNS2	0.0001	0.0001	0.0001	0.0001	0.0001
NNS3	0.2446983	0.2461148	0.2430071	0.2445581	0.2466055
NB	0.0001	0.0001	0.0001	0.0001	0.0001
CNG1	0.0004288954	0.0004288954	0.0001484698	0.0004288954	0.0004288954
CNG2	0.0002687641	0.0002687641	0.0005708027	0.0002687641	0.0002687641
CNY	0.0001	0.0001	0.0001	0.0001	0.0001
CNR	0.0001	0.0001	0.0001	0.0001	0.0001
UNG1	0.0001	0.0001	0.0001	0.0001	0.0001
UNG2	0.0001	0.0001	0.0001	0.0001	0.0001
UNY	0.0001	0.0001	0.0001	0.0001	0.0001
UNR	0.0001	0.0001	0.0001	0.0001	0.0001
UBG1	0.0001	0.0001	0.0001	0.0001	0.0001
UBG2	0.0002323727	0.0002323727	0.0002255681	0.0002323727	0.0002323727
UBY	0.0001	0.0001	0.0001	0.0001	0.0001
UBR	0.0001525692	0.0001525692	0.0001740755	0.0001525692	0.0001525692
PT	0.0001	0.0001	0.0001	0.0001	0.0001

**Note: NNS1-Number of Nurse Shift 1/ NNS2-Number of Nurse Shift 2/ NN3-Number of Nurse Shift 3/ NB-Number of Beds/ CNG1-Waiting Time for Checkup by Nurse Green Zone 1/ CNG2-Waiting Time for Checkup by Nurse Green Zone 2/ CNY-Waiting Time for Checkup by Nurse Yellow Zone/ CNR-Waiting Time for Checkup by Nurse Red Zone/ UNG1-Utilization of Nurse Green Zone 1/ UNG2-Utilization of Nurse Green Zone 2/ UNY-Utilization of Nurse Yellow Zone/ UNR-Utilization of Nurse Red Zone/ UBG1-Utilization of Bed Green Zone 1/ UBG1-Utilization of Bed Green Zone 2/ UBY-Utilization of Bed Yellow Zone/ UBR-Utilization of Red Zone/ PT-Patient Out

Both the new data from the input and the new data from the output are represented by v and u, respectively. Eq. (9) represents the Cross Efficiency score of DMU_j , E_{0j} which was calculated by using the best weights for the input and output of DMU_0. The ideal weights for the r^{th} output and i^{th} input of $DMU_j$are respectively, u_{r0} and v_{i0}. The values for the r^{th} output of DMU_j are y_{rj} meanwhile and the value for the i^{th} input of DMU_j is x_{ij}. Besides, the ideal weights for the r^{th} output and i^{th} input of DMU_0 are u_{r0} and, v_{i0} respectively. Eq. (9)

determined the E_{0j} value for each DMU. After that, Microsoft Excel was used to solve the cross-efficiency matrix using the value. Table 6 below shows the result.

Table 6: The result of the efficiency matrix

	DMU 1	DMU 20	DMU 56	DMU 129	DMU 224
DMU 1	0.0793122	0.074066	0.085192	0.079831	0.072235
DMU 20	0.0788654	0.073646	0.084712	0.079381	0.071825
DMU 56	0.0813962	0.075428	0.087657	0.082365	0.074199
DMU 129	0.0789522	0.07391	0.084745	0.079529	0.071924
DMU 224	0.0787117	0.073502	0.084547	0.079227	0.071684
Mean	0.0794476	0.07411	0.085371	0.080066	0.072373

From Table 6, DMU 56 is the most efficient alternative among the five efficient alternatives, with a value of 0.085371, which is the highest value of the mean. The comparison between the current alternative and the improvement alternative is shown in Table 7 below.

Table 7. Comparison between DMU 0 (current) and DMU 56 (improvement)

Items	DMUs	
	DMU 0(Current)	DMU 56
Number of Nurse Shift 1	$6(1^{G1}, 1^{G2}, 2^{Y}, 2^{R})$	$6(1^{G1}, 1^{G2}, 2^{Y}, 2^{R})$
Number of Nurse Shift 2	$6(1^{G1}, 1^{G2}, 2^{Y}, 2^{R})$	$8(2^{G1}, 2^{G2}, 2^{Y}, 2^{R})$
Number of Nurse Shift 3	$4(1^{G1}, 1^{G2}, 1^{Y}, 1^{R})$	$4(1^{G1}, 1^{G2}, 1^{Y}, 1^{R})$
Number of Bed	$36(12^{G1}, 12^{G2}, 6^{Y}, 6^{R})$	$38(13^{G1}, 13^{G2}, 6^{Y}, 6^{R})$
Waiting for Checkup by Nurse GZ1 (minutes)	21.17	14.1
Waiting for Checkup by Nurse GZ2 (minutes)	21.57	14.76
Waiting for Checkup by Nurse YZ (minutes)	6.79	2.08
Waiting for Checkup by Nurse RZ (minutes)	9.64	7.08
Utilization of Nurse GZ1 (%)	106.22	73.66
Utilization of Nurse GZ2 (%)	106.26	75.85
Utilization of Nurse YZ (%)	69.52	64.9
Utilization of Nurse RZ (%)	69.51	64.93
Utilization of Bed GZ1 (%)	69.03	71.06
Utilization of Bed GZ2 (%)	64.36	72.78
Utilization of Bed YZ (%)	46.57	58.44
Utilization of Bed RZ (%)	38.54	47.99
Patient Out	102	143

**Note: GZ1-Green Zone 1/ GZ2-Green Zone 2/ YZ-Yellow Zone/ RZ-Red Zone

Based on the comparison table above, it is evident that there is a need to increase the number of nurses in Nurse Shift 2 for GZ1 and GZ2. Both zones require an additional nurse during this shift. However, the number of nurses per day remains the same for the other zones. Furthermore, the results indicate that an increase of one bed is needed for both GZ1 and GZ2. Therefore, a total of two additional beds are required in IPD, bringing the total bed count to 38 beds, compared to the existing 36 beds. This adjustment is necessary to accommodate the increasing number of patients being admitted to IPDHUSM.

The study found that the proposed resource allocation resulted in a significant reduction in the waiting time for a check-up by a nurse in each zone. Specifically, the waiting time decreased from 21.17 minutes to 14.1 minutes for GZ1, from 21.57 minutes to 14.76 minutes for GZ2, from 6.79 minutes to 2.08 minutes for YZ, and from 9.64 minutes to 7.08 minutes for RZ. The resource allocation recommended by DMU 56 was particularly effective, as it resulted in a waiting time for a check-up by a nurse that met the KPIs of IPDHUSM, which was set at 15 minutes (Rahim 2022).

DMU 56's resource allocation plan resulted in a decrease in the utilization of nurses in GZ1 and GZ2, from 106.22% to 73.66% and from 106.26% to 75.85%, respectively. There were also slight reductions in nurse utilization for YZ (from 69.52% to 64.9%) and RZ (from 69.51% to 64.93%). On the other hand, DMU 57's proposal led to a slight increase in the utilization of beds. Specifically, the utilization percentages for GZ1, GZ2, YZ, and RZ increased to 71.06%, 72.78%, 68.44%, and 70.99%, respectively. These changes in resource utilization were made to align with the optimal allocation recommended by DMU 56. Moreover, the quantity of inputs and outputs associated with DMU 56 will serve as a point of reference and guidance for IPDHUSM. This reference will be instrumental in enhancing the patient flow chart within the IPD. By examining the inputs and outputs of DMU 56, the hospital can gain valuable insights into optimizing its processes and procedures, ultimately leading to improved patient care and more efficient operations within the department. The decision to implement the new work schedule and resource allocation was driven by the aim to achieve the KPIs set by the department. It is worth noting that a good utilization percentage for the service sector, including beds, doctors, and nurses, is typically between 70% and 80% according to Zulkefli *et al.* (2016). By implementing effective planning and ensuring adequate resource distribution, the management aims to improve patient flow efficiency, operational flow, and service quality in both the inpatient department and IPDHUSM. These measures will contribute to achieving the desired KPIs and enhancing overall performance.

4. Conclusion

The primary objective of this study was to determine the optimal resource allocation approach for IPDHUSM. By employing a hybrid method that combines DES and DEA, the researchers were able to effectively identify the most suitable resource allocation strategy that aligns with the KPIs. The findings of the study indicate that the current resources available in IPDHUSM are insufficient to meet the demands of patients. However, the recommended new work schedule has demonstrated a significant reduction in the waiting time for check-ups by nurses, particularly in GZ1 and GZ2, successfully meeting the ward's KPIs. These results have substantial implications for the management of IPDHUSM, serving as a benchmark for both current and future resource planning and strategy development. Furthermore, with the implementation of the proposed resource allocation, which includes an increase in the number of beds and nurses, especially in the crowded zones of GZ1 and GZ2, the IPD will be better equipped to provide quality care to patients. The research outcomes, specifically the identification of DMU 56 as the most optimal and efficient resource allocation solution among DMU 2, DMU 21, DMU 130, and DMU 225, will support management in making informed decisions within their allocated budget, ultimately enhancing the service quality and operational efficiency of IPDHUSM. In conclusion, this study's results hold great potential in assisting management in making effective decisions that improve the quality of services provided while optimizing resource utilization in IPD. These findings contribute to the ongoing efforts to enhance the efficiency and effectiveness of the inpatient department, ultimately benefiting both the healthcare providers and the patients they serve.

My future plan for this research involves predicting the resource allocation requirements within the inpatient department for a specified future period. For instance, I intend to employ a System Dynamic simulation model to predict the necessary number of beds and nurses over the course of the next 10 years. Moreover, these predictive results can serve as valuable references for other hospitals when planning and optimizing their inpatient department services. By providing insights into resource needs and allocation strategies, this research can contribute to the enhancement of healthcare services across various healthcare institutions.

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