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SIMULATION MODEL FOR EVALUATING INTENSIVE CARE UNIT CAPACITY

This paper employed the simulation model using Arena Simulation Software to evaluate the current ICU capacity condition by considering the principle of priority as applicable policy in a hospital in Indonesia to confirm the validity of the simulation model using 12 months period of actual operational data collected from an ICU department with 6 ICU beds in service. The proposed capacity evaluation model through simulation is expected to help identify and evaluate capacity alternatives in ICU. The result suggests that the proposed simulation model can be applied to evaluate ICU capacity since it can be used to identify and evaluate alternatives related to capacity expansion and can be performed in ICU with preference of average bed utilization rate.

Keywords: *simulation model; intensive care unit; hospital management.*

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ІМІТАЦІЙНА МОДЕЛЬ ДЛЯ ОЦІНЮВАННЯ МІСТКОСТІ ПАЛАТ ІНТЕНСИВНОЇ ТЕРАПІЇ

У статті продемонстровано використання імітаційної моделі середовища "Arena Simulation" для оцінювання стану місткості палати інтенсивної терапії з врахуванням принципу пріоритетності, що застосовується в лікарнях Індонезії. Для моделювання та подальшого аналізу використано дані за 12 місяців для палати інтенсивної терапії з 6 місцями в обслуговуванні. Запропонована імітаційна модель може бути корисною у виборі альтернатив місткості, а також прояснити, скільки місць інтенсивної терапії реально необхідні лікарні на постійній основі та наскільки економічно обґрунтованим є розширення даної палати в залежності від показника її середньої завантаженості.

Ключові слова: *імітаційна модель; палата інтенсивної терапії; лікарняний менеджмент.*
Рис. 2. Табл. 5. Літ. 22.

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ИМИТАЦИОННАЯ МОДЕЛЬ ДЛЯ ОЦЕНКИ ВМЕСТИМОСТИ ПАЛАТ ИНТЕНСИВНОЙ ТЕРАПИИ

В статье продемонстрировано использование имитационной модели среды "Arena Simulation" для оценки состояния вместимости палаты интенсивной терапии с учётом принципа приоритетности, применяемого в больницах Индонезии. Для моделирования и дальнейшего анализа использованы данные за 12 месяцев для палаты интенсивной терапии с 6 местами в обслуживании. Предложенная имитационная модель может помочь в выборе альтернатив вместимости и выяснить, сколько мест интенсивной терапии реально необходимы больнице на постоянной основе и насколько экономически обоснованным является расширение данной палаты в зависимости от показателя её средней загруженности.

Ключевые слова: *имитационная модель; палата интенсивной терапии; больничный менеджмент.*

Introduction. Hospital management often does miscalculations and wrong evaluation while determining the facility capacity needed in a system by looking at how many patients did not receive the maximum service due to ICU space constraints and its bed availability. This situation needs to be improved to provide accurate numbers

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of facilities needed at a hospital especially when it comes to ICU. ICU better calculations especially in terms of expansion planning and investments calculation, would ultimately lead to cost saving for a hospital.

Literature review. Research on hospitals capacity is one of the most important and main issues in healthcare services management, especially the problems of planning and evaluation of the existing capacity condition which predetermine the service level provided by the hospital and also costs and benefits that affect hospital financially. Determining the size of facilities can be calculated by the number of bed occupancy with the aim of achieving high level of utility and high return on investment. One of key principles in economics state that demand is equal to supply in a perfectly competitive market. Although demand and supply of health services do not follow a perfectly competitive market, some aspects of supply and demand rules still apply here. Demand for health services can be calculated based on bed occupancy (Murti, 2010).

"Good health is an important development outcome in its own right. Illness brings suffering, and healthier lives are likely to be longer and more fulfilling. These facts alone provide a rationale for development work that improves people's health. Yet improved health also brings broader benefits, including enhanced economic development" (DSEAD, 2010). Therefore, in this research, analysis will be conducted to study the evaluation of current capacity condition to provide a solution for the ICU to produce a viable implementation and also an improvement that will affect the ICU decision-making activities.

This study is the development of the previous study conducted by Z. Zhu et al. (2010) that found that discrete event simulation (DES) can be used accurately to capture variations in the system, and is flexible in simulating various what-if scenarios for estimating ICU bed capacity. Some adjustments are applied in order to adapt to the policies and conditions of hospitals in Indonesia.

Hospitals in Indonesia are classified into three types, these are type A (tertiary), type B (secondary) and type C (primary). There are some differences in every service provided by ICU basing on a type of a hospital in the aspect of workforce, facilities and infrastructure, equipment and services capabilities. Even though there are some differences in every service provided by ICU based on hospital type, ICU has 10 similar characteristics in their service system, and also certain medical ethics as controlled by the Indonesian Ministry of Health, the right indication factor, multidisciplinary collaboration in complex medical problems, patient's healthcare needs, role in coordination and integration of teamwork, the principle of priority, integrated quality improvement management system, professional partnerships, effectiveness, safety and economics factors as well as continuity of service (KMKRI, 2010).

The principle of priority is characteristic of ICU and will be our major consideration in building a simulation model in this study. Limited infrastructure of ICU push hospital management to have mechanisms to settle an enter priority of patients if the need or demand for ICU services is higher than the volume of services that can be provided. Under normal conditions, the ICU uses open booking and "first come first served" basis in their services but because of the limited number of ICU beds, the principle of priority can be applied whenever needed. The head of ICU is the one responsible for the suitability indication of patient care in ICU when the need for

ICU admission exceeds the available quantity of beds. The head of ICU then has to determine, which patients will be treated in ICU basing his/her decision on a patient's medical condition.

Problem statement and research objective. This study aims to evaluate the existing capacity of ICU and provide the evaluation result to be considered by hospital management as a decision maker so that it can contribute to effective and efficient investment into capacity expansion that will affect their performance using the simulation software to visualize the problem.

Research method. ICU provides advanced monitoring services and intensive therapy. Under the principle of priority, if ICU is full, patients who require intensive therapy with higher priority took precedence over any other. The appraisal of disease severity and prognosis should be used to determine the priority entry to ICU. The priority itself can be divided into 3 types: Priority 1 (the highest level), Priority 2 (medium level) and Priority 3 (the lowest level). For example, ICU can "swap" patient of Priority 3 with patient of Priority 2 or 1. In other words, lower priority can be swapped by higher priority.

For the simulation model, this study will analyze the flow process in ICU. As seen in Figure 1, there are 3 sources of inflow that consist of emergency installation, surgery installation and inpatient care unit that can be classified into 5 different medical functional unit (surgery, midwifery, disease in, neurology and childcare). Since the priority principle is considering the level of intensive therapy requirement, the inflow of this simulation model will be using the 12-months period of medical functional unit (MFU) actual inflow data. After a patient comes to ICU, there cannot be delay or waiting, since even a slight delay may affect patient severely and lead to irreversible consequences (Zhu et al., 2010).

There are two options in ICU admission: the first one is that ICU accepts a patient because there is capacity available, the second option is ICU transfer to another hospital's ICU if this ICU is full. There are 3 outflows available, ICU discharge (for a patient who has already finished treatment), ICU "swap" (for a patient with lower priority that have to be swapped because of an incoming patient with higher priority) and ICU transfer (for a patient that has to be transferred because ICU is full and there is no patient with lower priority to swap with). With this simulation, we will calculate the utilization rate so ICU can consider several options of scenarios to be applied.

From the explanation above, it can conclude that ICU has unique model characteristics of its flow chart which is visualized in Figure 1 and it will be the basis to build our simulation model using Arena Simulation Software considering a variety of procedures and variables needed.

Simulation. Simulation model does not always provide better or more trustworthy results. To see if simulation is designed similar to the situation under study comparison is done between the results of manual calculations and also the simulation results. Comparison is carried out using the existing data of the current system which consists of 6 beds, and also implemented under the condition of a new strategy of capacity using 7 beds and 8 beds. If the results match, then the simulation model designed reflects the actual situation in ICU well enough.

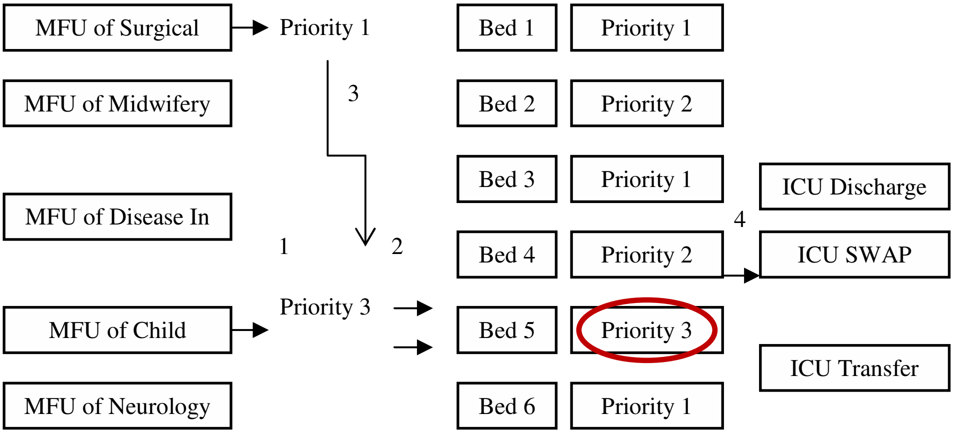

Figure 1. **Overall ICU patients' flow,** *authors'*

Table 1 is the set of data used in simulation on the existing system and also in the simulation of capacity strategy using 7 and 8 intensive care beds. This simulation is run in 900 days and had a warm up period for a year in order to get same number of patients treated by the hospital intensive care unit.

Table 1. **Existing data simulation model,** *authors'*

Patients group	Demand	Length
MFU of Surgical	ERLA (1.72, 3)	1 (4 days), 2 (3 Days), 3 (3 Days)
MFU of Midwifery	LOGN (7.03, 5.54)	1 (4 Days), 2 (3 Days), 3 (2 Days)
MFU of Disease In	NORM (1.18, 324)	1 (4 Days), 2 (4 Days), 3 (3 Days)
MFU of Child	ERLA (1.38, 2)	1 (4 Days), 2 (3 Days), 3 (2 Days)
MFU of Neurology	ERLA (3.81, 2)	1 (4 Days), 2 (3 Days), 3 (2 Days)

From the calculation shown in Table 2, the average bed utilization calculation from Arena Simulation is 71% with 5% difference under manual calculations. Therefore, we can conclude that this model can be used to evaluate the hospital intensive care unit capacity.

Table 2. **Simulation results for the existing condition of ICU, %,** *authors'*

Bed number	Arena bed utilization calculation	Manual bed utilization calculation	Differences
Bed 1	77	84	7
Bed 2	81	77	4
Bed 3	75	75	0
Bed 4	69	74	5
Bed 5	65	77	12
Bed 6	57	69	12
Average	**71**	**76**	**5**

Key results. The advantage of the designed simulation model is the visualization of the existing process. We can see clearly the whole process in ICU as a complex system with its characteristics. The simulation model is performed using several scenarios such as simulation of the existing condition using 6 beds, 7 beds, 8 beds, 9 beds and also the scenario with 10% raising demand in several condition using 6 beds, 7 beds, 8 beds and 9 beds. This simulation is also using scenarios with 20% raising demand in several condition using 6 beds, 7 beds, 8 beds and 9 beds. The results of those scenarios of simulation are summarized in Tables 3–5 and the comparison chart in Figure 2.

Table 3. **Bed utilization result comparison between scenarios of bed number under existing condition,** *%, authors'*

Bed number	Manual calculation of existing condition	Arena simulation			
		6 beds	7 beds	8 beds	9 beds
Bed 1	84	77	78	78	77
Bed 2	77	81	78	78	76
Bed 3	75	75	74	72	71
Bed 4	74	69	69	70	68
Bed 5	77	65	66	64	61
Bed 6	69	57	58	56	55
Bed 7			54	54	52
Bed 8				39	37
Bed 9					34
Average	**76**	**71**	**68**	**64**	**59**

Table 4. **Bed utilization result comparison between scenarios of bed number and 10% higher demand,** *%, authors'*

Bed number	Arena simulation			
	6 beds	7 beds	8 beds	9 beds
Bed 1	79	77	77	75
Bed 2	78	78	75	76
Bed 3	78	75	75	74
Bed 4	72	72	71	68
Bed 5	70	69	69	68
Bed 6	64	63	64	64
Bed 7		61	61	61
Bed 8			55	55
Bed 9				48
Average	**74**	**71**	**68**	**65**

Table 5. **Bed utilization result comparison between scenarios of bed number and 20% higher demand,** *%, authors'*

Bed number	Arena simulation			
	6 beds	7 beds	8 beds	9 beds
Bed 1	81	82	81	81
Bed 2	79	79	79	80
Bed 3	82	82	81	80
Bed 4	78	79	77	78
Bed 5	76	75	78	76
Bed 6	72	71	72	72
Bed 7		70	70	70
Bed 8			67	66
Bed 9				63
Average	**78**	**77**	**76**	**74**

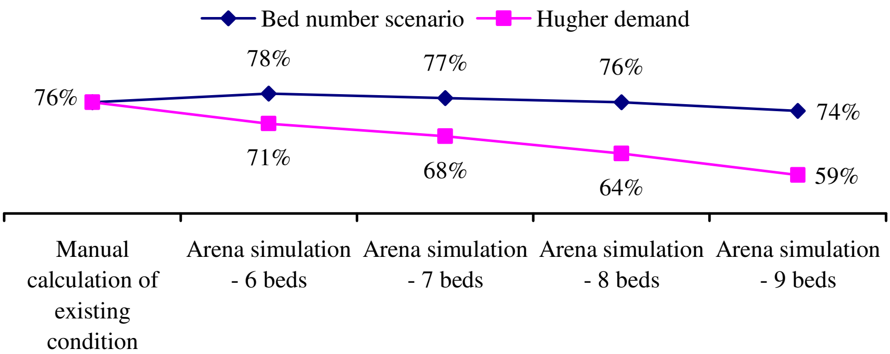

Figure 2. **Comparison of several scenarios,** *%, authors'*

ICU management as a decision maker has to consider also the idle capacity option. To determine the number of bed being added to ICU, the aspiration level method is employed to know the preferences of hospital management in decision-making. From the interview with hospital management, they want to add capacity if the average bed utilization is above 60%. The results of our simulations suggest that ICU may added two extra beds to their capacity, because as seen above, the average bed utilization of 7 beds is 68% and the average utilization of 8 beds is 64% which mean bed utilization is above 60% or the idle capacity is below 40% if the demand of intensive care unit is still the same. But if the demand is 10% or 20% higher, ICU management may add up to 9 beds because the utilization rate would be still above 60%.

For this reason, the simulation can show the utilization rate that can be useful in decision-making so that the hospital management can provide better decisions, especially when evaluating their current capacities.

Conclusion. This research provides input to the development of research that can provide capacity evaluation tools on bed utilization number in different facility condition especially for ICU using the principle of priority that will help decision-makers make better decision related to capacity condition. Based on the proposed method, ICU can add two extra beds into their system. As mentioned earlier, based on the interview with hospital management they want to add capacity if the average bed utilization is above 60%. The simulation results suggest that ICU may added two extra beds, as from the Arena Simulation calculations the average bed utilization of 7 beds is 64% and the average utilization of 8 beds is 68% which mean the utilization of bed is above 60% or the idle capacity is below 40%.

Further investigations. This study is a relatively new field for Indonesia. This study was conducted in one hospital so we cannot generalize the result on the whole sector. Therefore, similar studies for other hospitals would provide common pattern on this issue to explore common situations that occur in ICUs. More comprehensive work should be also done to relax some assumption that have been made, further research is expected to be carried out basing not only on the patients arrival time to a medical functional unit but also covering other factors such as the source of patient (emergency room, inpatient care unit etc.). Further research may also consider cost and revenue functional in order to provide better suggestions for capacity planning.

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Стаття надійшла до редакції 21.09.2015.