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An Optimization Model for Hospital Emergency Room Based on Patient Growth and Capacity Management

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Abstract: According to government regulations of the Republic of Indonesia through the Ministry of Health, the hospital is a health service institution that organizes full individual health services that provide inpatient, outpatient and emergency services. The hospital can function as a place of final service by handling patients according to their abilities. Therefore, the facilities, infrastructure, and resources of the emergency room must be adequate so that they are able to cope with patients. In the case of COVID-19, the number of needs and capacities coupled with the need for demand forecasting and capacity management, especially in the emergency room at the Malahayati Hospital Medan is very necessary. So in this study, the mathematical model was built that could provide a solution to the problem of the need for demand forecasting and capacity management in the emergency room. The mathematical model for the exact outcome is determined by the relationship that exists between states and events. In this study, it is assumed that all events have a fixed probability, without considering drug administration and waiting time. For this reason, the method used the Support Vector Machine (SVM) which is expected to provide an estimate of how many people and capacity management needs are needed in the emergency room when the COVID-19 pandemic occurs. The mathematical model that was built was then simulated in the final part of this study using sample data taken from the Malahayati Hospital Medan.

Keywords: emergency installation, capacity management, demand forecasting hospital, and Support Vector Machine (SVM)

INTRODUCTION

Hospital capacity planning aims to strike a balance between the cost and quality of treatment delivered. Healthcare planning entails predicting the number and particular characteristics of the resources needed to provide healthcare services at a set cost and quality level (Raucci et al., 2021). The ratio of the number of inpatient beds to the number of physicians and nurses is the most fundamental indicator of hospital capacity planning. Capacity models are typically used to determine the number of nurses, while capacity management models provide insight into possible ways to improve capacity utilization. (Sitepu & Mawengkang, 2017).

Modeling and simulation are essential tools in solving epidemic disease outbreaks (outbreaks of disease in a particular community/area in numbers that exceed normal limits) that occur suddenly. Several models are proposed and studied to understand the spread of epidemics in connected networks. The research conducted by Younsi addresses the problem of epidemic spread in social networks by constructing and analyzing the nature of small-world networks (Younsi et al., 2015).

A social safety net is a specialized healthcare system designed using an agent-based approach. This model provides a framework for examining various aspects of techniques focused on improving the quality of life of patients with terminal or near-terminal illnesses. It plays an essential role in human activity and life. (Moradianzadeh et al., 2017).

Based on observations made in the United States, the coronavirus disease 2019 (COVID-19) pandemic has critically affected healthcare delivery. Little is known about its impact on the utilization of emergency services (ED), especially for conditions that may be medically urgent (Giannouchos et al., 2021). Emergency departments during the COVID-19 pandemic are at the heart of hospitals. Specialized human resources are

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considered essential service resources in a space that never has to be faced with a lack of human strength. Therefore, hospitals need to standardize the number and distribution of nursing staff in rooms to increase the efficiency and quality of patient services and productivity. They provide nursing services in the living room using the patient input model. Sampling limitations include period distribution limits and non-negative variables (Apornak, 2021).

There are anecdotal reports of decreases in emergency room occupancy and decreases in emerging non-Covid-19 diseases, including stroke and myocardial infarction (MI) amid the COVID-19 pandemic. Alarmingly, patients who become aware of their contact with people with COVID-19 refuse to seek treatment, even in severe life-threatening cases. Assessment of the association of the COVID-19 outbreak with five medical emergencies: acute myocardial infarction (MI), non-traumatic ischemic stroke subarachnoid hemorrhage, and appendicitis using data from two academic medical centers. (Jeffery et al., 2020).

In contrast, 1512 hospitals in 363 locations have been created in China, where the COVID-19 virus originated, to deal with emergencies and stop the spread of the disease. They are neighborhood hospitals that the Chinese government has reopened to address local public health issues (Chong et al., 2015). A fever clinic is a COVID-19 station for high-level care, and a temporary emergency ward is only a few of their extensive services (Matarazzo et al., 2021). Three features (full function of central response and action system and closed-loop management system) as well as three strategies (resource allocation prevention of nosocomial outbreaks and post-epidemic management of COVID-19) to respond to the COVID-19 pandemic-experience is documented for the only designated COVID-19 hospital in Shanghai. (Li et al., 2021).

Based on the facts that occurred in the United States, China, Italy, and Indonesia during the COVID-19 pandemic, it is necessary to know the amount of needed capacity based on demand forecasting and capacity management, especially in the emergency department. Optimizing the emergency services of a hospital during a pandemic is carried out through mathematical modeling based on demand forecasts and capacity management.

LITERATURE REVIEW

The emergency room also provides a reception facility for managing patients in a disaster situation, which is part of its role in helping disaster situations in each region (Pietrzak & Lennon, 2014). The Emergency Department is the main gate for the entry of emergency patients. The hospital emergency room has the task of providing temporary medical care and nursing care as well as emergency surgical services for patients with a medical emergency (Apornak, 2021). Emergency patient care is a service that requires immediate assistance, which is fast, precise, and careful to prevent death and disability(Raucci et al., 2021). This service is an essential emergency, so it is necessary to serve patients 24 hours a day continuously (Ahsan et al., 2019).

Support Vector Regression (SVR) is a method that can be used to solve optimization problems. Cortes and Vapnik introduced the application of the Support Vector Machine (SVM) for the case of regression (Avendaño-Valencia & Fassois, 2015). The purpose of the Support Vector Regression (SVR) is to determine a function *f(x)* as a hyperplane (separation line) in the form of a regression function that corresponds to all input data with an error. The output of the SVR is in the form of fundamental and continuous numbers. (Chichernea, 2014).

METHOD

The procedures carried out:

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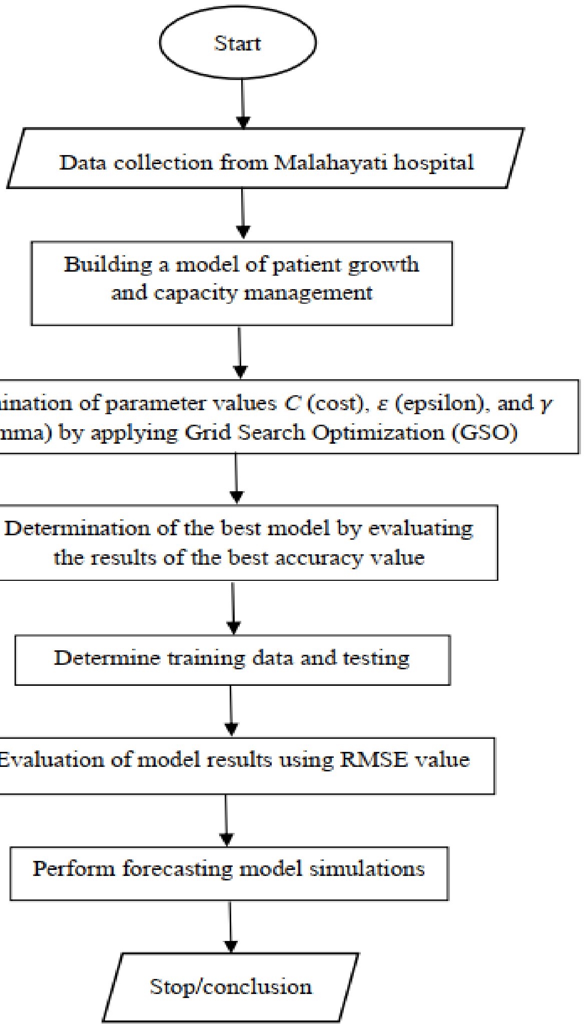

RESULT

This research uses data from Emergency Installation of RSI Malahayati in July-September 2021 (Delta variant) and January-July 2022 (Omicron variant), which will be used in forecasting simulations and optimization models with the following description:

Table 1 Patient Characteristics by Gender January-July 2022

Genders	Total	Percent
Male	57	53,77
Female	49	46,23

Table 2 Patient Characteristics January-July 2022 Based on Age

Age	
Mean	44,10377358
Standard Error	1,969987264
Mode	69
Standard Deviation	20,28226025
Minimum	6
Maximum	87

Table 3 Status of Patient's Covid At January-July 2021

Covid Status	Total	Percent
Covid suspect	44	34,1
Confirmed covid	22	17,05

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Table 4 Final Status of Patient Care July-September 2021

Patient Care Status	Total	Percent
PBJ (Walking treatment)	71	66,98
Moving Treatment Room	30	28,3
Home By Own Request	3	2,83
Refer to another hospital ICU	1	0,943
Exit (Died)	2	3,1

1. Deterministic Model

The first step is to formulate a deterministic model for the problem of increasing patient and nursing staff management capacity.

Table 1 Notation Model of Optimization in Hospital Emergency

Notation	Description
D_j	Doctor *j* in the emergency room
DE_{ij}	Doctor *j* seconded in the emergency room
S_j	Nurse *j* in the emergency room
SE_{ij}	Nurse *j* seconded in the emergency room
X	Number of patients arriving at the emergency room
nS	Number of nurses *j* in the emergency room
nD_j	Number of doctors on duty in the emergency room
nBE	Initial number of available beds in the emergency room
nBA	Number of beds added to the emergency room
X_t	Forecasting the number of patients at time *t*
OE	Number of oxygen cylinders in the emergency room
P_j	Patient in *j*-th bed being served
Wd_j	Doctor's service time to patients *j*
Ws_j	Nurse service time to patients *j*
W_j	Total service time for to patient *j*
Wt_j	Waiting time for patient *j* after being served by a nurse and waiting for a doctor
α_j	Percentage of type-*j* doctors needed in the emergency room
β_j	Percentage of type-*j* nurses needed in the emergency room
γ_j	Percentage of type-*j* nurses are seconded in the emergency room
δ	Percentage of bed requirements in the emergency room
μ_j	Maximum number of beds that can be added to the emergency room
bd_j	Cost of type-*j* doctor in the emergency room
bs_j	Cost of type-*j* nurses in the emergency room
bb_j	Cost of bed in the emergency room
bo_j	Cost of using oxygen in the emergency room
ρ_j	Maximum available funds for the emergency room

Before modeling the objective function and driving function, the researcher illustrates the situation with the timing of services for both doctors and nurses as follows:

	Patient 1	Patient 2	… Patient-*n*
Waiting time for patient	$\leq W_s$ maks	$\leq W_s$ maks	$\leq W_s$ maks
Doctor's service time	$\leq W_d$ maks	$\leq W_d$ maks	$\leq W_d$ maks
Waiting time from nurse to doctor	$\leq W_t$ maks	$\leq W_t$ maks	$\leq W_t$ maks
Number of nurses in the emergency room	$= n_s$		
Number of doctors in the emergency room	$= n_d$		
Number of patients arriving	$= n$		
Maximum number of beds	$= \mu_j$		
Patient arrival rate	$= \Delta j$		

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So that the optimization model is obtained:
Objective function:

$$\min \sum_{j=1}^{\mu_j} (Ws_j(S_j + SE_j) + Wd_j(D_j + DE_j) + W_{tj}) \quad (1)$$

Constraints:

$$Ws_j + Wd_j + W_{tj} \leq W_j \quad (2)$$
$$S_j + SE_j \leq ns \quad (3)$$
$$D_j + DE_j \leq nd \quad (4)$$
$$W_{tj} \leq T \quad (5)$$
$$j = 1,2, ..., \mu_j, \dots, n \quad (6)$$

2. Minimizing Operational Costs In The Emergency Room

Objective function:

$$\min \sum_{j=1}^{\mu_j} bd_j(D_j + DE_j) + bs_j(S_j + SE_j) + bo_j X_t + bb_j(nBE + nBA) \quad (7)$$

Constraints:

$$\alpha_j(nBE + nBA) \leq D_j + DE_j, j = 1,2, \dots, n \quad (8)$$
$$\beta_j(nBE + nBA) \leq S_j,\ j = 1,2, \dots, n \quad (9)$$
$$\gamma_j(nBE + nBA) \leq SE_j,\ j = 1,2, \dots, n \quad (10)$$
$$\delta(nBE + nBA) \leq \mu_j,\ j = 1,2, \dots, n \quad (11)$$
$$\sum_{j=1}^{n} bd_j(D_j + DE_j) + bs_j(S_j + SE_j) + bo_j X_t + bb_j(nBE + nBA) \leq \rho_j \quad (12)$$
$$D_j, DE_j, S_j, SE_j, nBE, nBA \in Z \quad (13)$$

The objective function (7) is proposed to minimize operational costs by considering the costs of doctors, nurses, oxygen, and bed services. The constraint function (8) explains that the percentage of bed needs must be less than the number of doctors available and seconded to the emergency room. Likewise, with the number of nurses obstacles (9)-(10) on duty in the emergency room, the emergency room can still serve patients optimally if there is a surge in patients. Meanwhile, the percentage of the number of beds in the emergency room and those that will be added must be adjusted to the capacity of the emergency room and additional emergency room rooms during the pandemic constraint (11). The use of fees in the emergency room must also pay attention to the number of funds provided for the emergency room (12). One thing that must be underlined is that the number of health workers, beds, and the oxygen are all integers (13).

DISCUSSIONS

We will discuss of the results in this research. Simulations and software tools accompany this research.

1. Algorithm in the mathematical model

Step 1: Categorize patient data based on the patient's condition (measured by oxygen saturation, blood pressure, comorbid or not), gender, age group, and end-of-treatment condition.
Step 2: Forecast the increase in patients based on the demand forecast with SVR
Step 3: The data that has been classified from the SVR results is used as data in deterministic modeling
Step 4: Simulate the data according to the model by identifying the objective function and constraints on the model

2. Requirements forecasting model simulation with Support Vector Regression (SVR)

The simulation for forecasting needs in this study uses the help of Rapidminer Studio Version 9.10 software. Gender variables are labeled 1 = Male, 2 = Female; Age variable in the form of integer data (units in years); variable length of hospitalization is measured based on the date of admission and date of discharge; Diagnosis variable is labeled 1 = Susp. Covid, 2 = Confirmed Covid, 3 = Susp. Covid + comorbid, 4 = Confirmed Covid + comorbid.

Table 2 Import Data on Rapidminer

Rown No.	Gender	Age	Length Treatment	Diagnosis	Description
1	2	20	9	1	1
2	2	27	5	1	1

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3	1	32	5	2	1
4	1	66	6	3	1
5	1	35	7	2	1
6	2	33	7	2	1
7	2	67	7	3	1
8	1	77	7	3	1
9	2	30	6	1	1
10	1	25	7	3	1

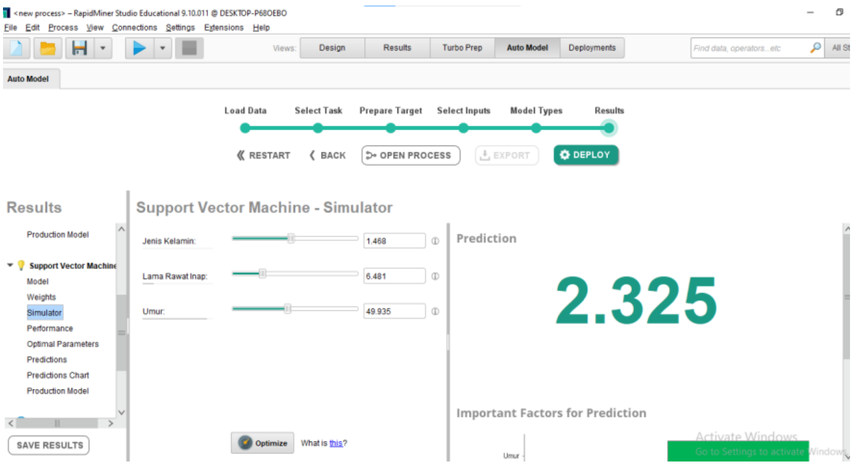

Fig. 1 Prediction Results Using SVM Model

From fig 1 above, the resulting kernel model:
Total number of Support Vectors: 77
Bias (offset): 2,782
w[Gender] = -29.998
w[Age]   = 43,980
w[Length of Hospitalization] = -1.234
Because the variable to be predicted is a diagnostic variable to determine the type of disease of the patient, the simulation results obtained a value of 2.325 ~ 2, which means that the simulation results produce patients who are predicted to be confirmed with Covid. Then calculate the minimum waiting time for a patient to be served in the emergency room using the model in equation (1) constraint (2) and (3) with the steps shown.

CONCLUSION

This research produces an optimization model for hospital emergency services based on demand forecasts and capacity management during the COVID-19 pandemic, assuming that every event has the same (deterministic) opportunity. This model can be developed for cases of uncertainty and more significant integer programming problems that depend on the scenario. In this research also, a direct search approach for the integer model is proposed.

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