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Optimization of Health Care Services with Limited Resources

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***Abstract*— Health services are an integral part of hospitals or health clinics. Maximum service can get if the availability of resources in the service center is very adequate, but the availability of resources cannot be ascertained that it will always be adequate, and excessive availability of resources can also result in waste. The problem that often occurs is the lack of optimal services provided to patients due to limited available resources. Various obstacles, such as services that are not permitted are repeated, uncertain service distances, and service time are optimal barriers to service. This study aims to solve the problem of optimizing health care services for patients in hospitals using a number of variables in the hospital environment such as available resources, namely doctors, nursing medical personnel, technicians, technical equipment. This study is subject to the aim of minimizing all costs incurred to perform services, namely travel time from places to provide health services to patients, medical staff costs to provide services of the type of service, and so on. These variables are explained in the form of mathematical models that are able to explain existing constraints and minimize costs and time when performing services. The modeling results were tested using Linear Ineraktive Discrete Optimizer (LINDO) programming to determine errors that might occur in the model. The test results provide information that the maximum value of the objective function is 88.00 at the 25th iteration step so that the new model is expected to optimize health services for hospital patients and existing health clinics.**

***Keywords*— health care; hospitals; optimization; patients; services.**

I. INTRODUCTION

The service model in the queue in a system that uses the first come first serve method can utilize resources optimally if the resources needed are still sufficient, but this will be a new problem if the demand for resources exceeds the number of available resources, this can cause the queue to become longer. Inadequate access to resources owned by service centers can be a problem, to overcome this challenge, real-time communication between resources is available at the service center (server) so that it can provide maximum service [1].

The occurrence of queues in patients is a big problem for hospital services [2], service satisfaction for patients is difficult because the queue takes a long time to wait and each patient may need to undergo a variety of other services [3]. The capacity plan is also proposed to work in terms of statistical data, and performance evaluation of plans carried out through the patient model. Static scheduling policies can reduce the waiting queue length to be lower and more stable. However, several potential problems cause patients to be scheduled too late. This situation really utilizes the consultation process at a low level before the queue length becomes a stable level. Thus, a dynamic scheduling policy is considered to improve the scheduling process so that the queue length can reach a stable and faster level. Dynamic policies use function levels to control the scheduling process based on different time slots. The level of the function includes dynamic factors that can change over time [4].

Communication between the resources available on the server uses a scheduling algorithm developed to allocate time for each health service that depends on the resources available to meet the health service needs of patients. Service requests can come from various sources or devices owned by patients connected to internet services which are then used by health service providers to enter services and obtain schedules from servers [1]. To reduce operational costs, it is necessary to optimize the limited utilization of resources.

If the growth of the elderly population increases, there will be a shortage of clinical staff in providing health care services. Troubleshooting that might occur needs to be corrected in providing better service to people who need health care, this reflects the hope that humans want to have a longer life [5].

In providing maximal health services to patients, smart health services are needed, namely the need to provide quality care to patients by reducing health care costs and, solving limited resource problems [6]. In various studies have carried out long-term optimization, by applying various strategies in the health care process [7].

Most hospitals experience some pressure on the provision of resources, such as the lack of quality care professionals, limited hospital equipment, and facilities, and the consequence of increasing operational costs. Hospital capacity planning, closely related to ensuring a balance between the quality of health services received and the costs incurred [8], Most hospitals spend resources, such as requiring quality professional care, limited hospital equipment, and facilities, and adding to their operational costs [9].

In the hospital, capacity planning relates to ensuring a balance between the quality of health care provided and the costs provided. In a plan, it involves predicting the specific quantity and attributes of the resources that will be needed to provide health care services at a certain level of quality and cost [10]. The most basic measure of hospital capacity planning is the number of inpatient beds that are in accordance with the number of doctors and the number of nurses. In general, the capacity model is intended to calculate the number of nurses needed, while the capacity of the management model should ideally also provide insight into opportunities to increase capacity use [11].

To provide health services to patients who need health care on demand or the occurrence of sudden health problems, it must be ascertained the actions that must be taken or the actions of the doctor as the management of the decision maker. The need to provide quality health care can be maximized against patients, and it is possible to reduce health care costs and overcome the problem of lack of limited nursing staff resources [7].

II. Material and Method

The need to provide health services is focused on areas such as inadequate resources, limited access to health services and technology, increasing access to data/information systems to health care, improving technology more efficiently and overcoming shortcomings in the availability of experienced professionals in the field of health care in remote areas or rural areas [12].

Traditional health services are overwhelmed, this is due to the rapid increase in the need for health services, experts, and medical practitioners are not sufficient to meet the needs of serving citizens. Many hospitals make mistakes in dealing with infectious diseases. On many occasions, the patient receives the wrong medicine. In many remote places on the planet that receive health-care is still a distant dream. Thus, with limited resources and increasing demand, traditional health needs must be smart, efficient and sustainable; that's where smart health comes in [12].

Smart health care can be conceptualized as a combination of various entities including traditional health care, intelligent biosensors, usable devices, information and communication technology (ICT), and smart ambulance systems. Smart health care components include existing body sensors, smart hospitals, and intelligent emergency responses. Another example where smart health can have a very significant impact is that it can help the daily lives of older people, devices that are used as a monitoring system for vital signs at low cost [13] and comprehensive health care survival that can help seniors by having as much independence as possible in their daily activities. Smart health care can increase the quality of life with life help for seniors where doctors, nurses, health reports are easily obtained in real time (all the time) [14].

Effective Smart HealthCare requires collaboration among many internal and external stakeholders, including patients, doctors, and health care professionals, and management of facilities in hospitals [15]. Collaboration is very important for home health management, where patient family members may also be involved. The effectiveness of collaboration, in turn, depends on communication and various information among different people in this arrangement [15]. Poor efficiency in the communication of doctors and nurses to patients and the inability to monitor the health of patients at home is the main contributing factor.

The determinants of success in the process of providing health services to the community are the availability of health care workers [16], availability of trained staff, solving problems of geographical barriers in rural / remote areas [12] [17] and includes health provider privacy, cost constraints, data security issues and other technical barriers [12]. To improve hospital services for patients, not only by optimizing the flow of patients in hospitals when patients receive services from different services, but they also need to be done to improve patient satisfaction and safety [7].

Smart City is the result of a long chain of decisions and Decision Support Systems (DSS) that are used in various large-scale project planning that develops traditional cities into smart cities. Program Evaluation and Review Techniques are methods that are widely used to plan and coordinate large-scale projects. It is generally accepted that people, money, time, and other equipment are needed to plan and implement the project. During particular project research and design period, it is very important to understand and the following are the rules that must be met [18] , as:

- All processes must clearly have different starting and ending points
- All estimates as initial values must be realistic
- All processes must be arranged in a certain order that produces a predetermined result (the critical path must be recognized)
- Owned resources can be transferred to meet needs, and
- Direct relationship in time and cost sharing (i.e. the costs of each activity are spread evenly over time).

The priority service queuing model is used closely with services that are closely related to death and disability (e.g. heart attacks, strokes and accidents), mass casualties (e.g. fires, sunken ships) or sudden and random occurrences of natural disasters [10]. Events of natural disasters such as volcanic eruptions and earthquakes do not occur within a certain period of time, people cannot make the best preparations to deal with them [19]. The incidents experienced in the patients mentioned above are treatments that must be dealt with quickly, which are called priority patients.

In health care is a model of queuing with different types of patients, in which one or more types of patients have priority over other types. It is more appropriate to consider the M / G / 1 queue model with the patient type. Patient type 1 priority is the highest priority handler, type 2 customer priority is the second highest priority customer and so on [20] .

Problems that occur in the real world can all be solved by mathematical modeling, problems can be modeled into mathematical forms that become equations [21], Mathematical principles are not only used for systematization, but also function to maximize results or minimize costs [22]. Models that emphasize cost effectiveness focus on the physical accuracy that will be used [23], and violating capacity limits can be done by giving a penalty value [24]. In the GU et al. Study, it introduced the Fog-Computing-Medical Cyber-Physical System (FC-MCPS) model, which presents mixed-integer-nonlinear-programming (MINLP) formulations on minimum cost issues with joint consideration of user associations, task distribution and VM deployment (virtual machine) [25].

In solving problems minimizing costs based on consideration together through user associations, task distribution, and the deployment of Virtual Machines can be completed with the formulation of MINLP (mixed-integer nonlinear programming), and by providing restrictions on: User limits, Task Distribution limits, Limitations Virtual Machine Placement, and QoS (quality-of-service) Limitation. The study concludes: To overcome the problem proposed by phase-based heuristic algorithm Linear Programming, so the algorithm has the advantage [25].

The difference with previous studies is explained that what are discussed in this study are the resource variables available at the hospital (doctors, nursing medical staff, and other technicians). It considers the location of health services, health service destinations, service centers, the number of medical staff, and the types of services. The cost of travel from the place to provide health services to patients, the cost of medical staff to provide the type of service, and the length of travel time from the service center to the place of request for service. Some other considerations are the length of time the patient medical staff who arrive at the patient's place before starting the service, the earliest time the patient receives service, and the time at the latest the patient receives service. The length of time required by the medical staff aims to arrive at the patient's place and the length of time required by the medical staff to leave the patient need service. So that in solving the problem of this research, a model that can solve problems to minimize travel costs, minimum service costs, and minimizes costs due to inaccurate time of service delivery, and maximize service to patient demand.

III. Result and Discussion

A. Data Collection

Data sources for benchmarking (a process commonly used in management or generally strategic management) in this study are medical data on health in hospitals and health services, so that numerical data obtained in the form of matrices can support the modeling process and provide clarity objective function of the model mathematically. Data is taken from the set of minimum function matrices, and explained in detail as in the table below:

TABLE I
THE FUNCTION STATES THE COST OF H MEDICAL STAFF TRAVEL FROM PLACE I TO THE J PLACE TO PROVIDE HEALTH SERVICES TO PATIENTS

α	*j = 1*	*j = 2*	*j = 3*	*j = 4*	*j = 5*
i = 1	6	7	6	1	1
i = 2	1	10	9	1	5
i = 3	4	9	4	1	5
i = 4	9	8	3	5	9
i = 5	4	3	10	7	7

Description: Costs for *h* medical staff travel in units of 10,000 rupiah. The table above explains the travel costs of medical staff *h* from α_{ij} (i = 1, j = 1) worth = 60.000, travel costs of *h* medical staff from α_{ij} (i = 1, j = 2) worth = 70.000, travel costs of *h* medical staff from α_{ij} (i = 1, j = 3) worth = 60.000, travel costs of *h* medical staff from α_{ij} (i = 1, j = 4) worth = 10.000, and so on.

TABLE II
THE FUNCTION STATES THE TRAVEL COST OF THE TYPE OF MEDICAL SERVICE K FROM PLACE I TO PLACE J FOR THE PROVISION OF HEALTH SERVICES TO PATIENTS

α	*j = 1*	*j = 2*	*j = 3*	*j = 4*	*j = 5*
i = 1	5	5	9	7	7
i = 2	10	3	8	10	4
i = 3	8	10	5	6	2
i = 4	8	7	10	5	3
i = 5	7	1	8	4	9

Description: The cost of travel for the type of medical service *k* in units of 10,000 rupiah. The table above explains the cost of travel based on the type of medical service *k* from α_{ij} (i = 1, j = 1) worth = 50.000, travel costs based on the type of medical service *k* from α_{ij} (i = 1, j = 2) worth = 50.000, travel costs based on the type of medical service *k* from α_{ij} (i = 1, j = 3) worth = 90.000, travel costs based on the type of medical service *k* from α_{ij} (i = 1, j = 4) worth = 70.000, and so on

TABLE III
THE FUNCTION STATES THE HONORARIUM OF MEDICAL STAFF H FROM PLACE I TO PLACE J FOR PROVIDING HEALTH SERVICES TO PATIENTS

β	*j = 1*	*j = 2*	*j = 3*	*j = 4*	*j = 5*
i = 1	7	10	1	6	7
i = 2	10	8	9	9	4
i = 3	5	4	3	5	1
i = 4	6	1	7	9	4
i = 5	9	2	8	8	6

Description: The cost of paying medical staff *h* in units of 10,000 rupiah. The table above explains the *h* medical staff honorarium fees from β_{ij} (i = 1, j = 1) worth = 70.000, medical staff honorarium *h* from β_{ij} (i = 1, j = 2) worth = 10.000, medical staff honorarium *h* from β_{ij} (i = 1, j = 3) worth = 10.000, medical staff honorarium *h* from β_{ij} (i = 1, j = 4) worth = 60.000, and so on.

TABLE IV
THE FUNCTION STATES THE FEE FOR THE TYPE OF SERVICE TO K FROM PLACE I TO PLACE J FOR THE PROVISION OF HEALTH SERVICES TO PATIENTS

β	*j = 1*	*j = 2*	*j = 3*	*j = 4*	*j = 5*
i = 1	3	1	4	3	8
i = 2	9	10	6	6	7
i = 3	3	4	7	10	1
i = 4	2	7	2	4	4
i = 5	6	6	3	6	6

Description: Service type honorarium fee *k* in units of 10,000 rupiah. In the table above, it explains the honorarium fee based on the type of service *k* from β_{ij} (i = 1, j = 1) worth = 30.000, honorarium fee based on type of service *k* from β_{ij} (i = 1, j = 2) worth = 10.000, honorarium fee based on type of service *k* from β_{ij} (i = 1, j = 3) worth = 40.000, honorarium fee based on type of service *k* from β_{ij} (i = 1, j = 4) worth = 30.000, and so on.

TABLE V
THE FUNCTION STATES THE COST OF THE TIME NEEDED BY MEDICAL STAFF H TO ARRIVE AT THE PLACE OF THE I PATIENT WHO NEEDS SERVICE

t	*j = 1*	*j = 2*	*j = 3*	*j = 4*	*j = 5*
i = 1	1	5	9	1	6
i = 2	10	7	10	7	8
i = 3	8	2	9	4	10
i = 4	7	4	7	3	9
i = 5	10	8	9	10	3

Description: conversion of 1 minute of time needed by medical staff *h* in units of minutes to units costing 10,000 rupiah (time span 10 minutes to 100 minutes to costs 10,000 to 100,000). The table above explains the costs of the time needed by h staff from t_{ij} (i = 1, j = 1) worth = 10.000, costs for the time needed by staff h from t_{ij} (i = 1, j = 2) worth = 50.000, costs for the time needed by staff h from t_{ij} (i = 1, j = 3) worth = 90.000, costs for the time needed by staff *h* from t_{ij} (i = 1, j = 4) worth = 10.000, and so on.

B. Problem Description

The main problem described in the provision of optimal health services based on the concept of "Smart Health" is how to provide services as early as possible with limited use of health resources, which when conducting health care services, medical staff *h* depart from place *i* to place *j* for provide health care services so that the results of modeling that are made can solve these problems, while the results of modeling smart health services are as follows [26]:

- Minimize the cost of h medical staff travel from place i to place j at the time of providing health services to patients.
- Minimize the cost of travel for medical services type k from place i to place j at the time of providing health services to patients.
- Minimize the cost of medical staff h from place i to place j for providing health services to patients.
- Minimize service type costs to k from place i to place j at the time of providing health services to patients.
- Minimize the time needed for medical staff h to arrive at the place of i patients who need services.
- Maximizing service to patient requests.

The main assumptions of this modeling are:

- Each type of health service can fulfill health care for each patient according to the type of request for the type of care service k.
- The number of medical staff is limited.
- The types of diseases experienced by patients can be handled by available medical staff.

The following is explained the notation used in the model:

1) Set

i = Presents a set of places where health services occur
j = Presenting the next set of health service destinations $(i, j) \in N = (0, 1, \ldots, n)$
o = Declares service center
h = Presenting a set of medical staff $h \in H = (1, ..., n)$
k = Presenting the type of service $k \in K = (1, ..., n)$

2) Parameter

α_{ij} = Travel costs from place *i* to place *j* for providing health services to patients
β_{kh} = Medical staff costs h to provide the type of service to *k*
t_{ij} = Time of travel from the service center *i* to the place of service request *j*
τ_j = Time of service to patients *j*
W = Waiting time from medical staff who arrive at the patient's place before starting service
a_i = The earliest time the patient *i* receives service
b_i = At the latest the patient *i* receives service
S_{ih} = The time needed for medical staff *h* to arrive at the place of *i* patients who need services, and $S_i = a_i$
D_i = The time needed by medical staff to leave the place of *i* patients who need services. So there is a time interval $S_i \in [a_i, b_i]$, $D_i = maks\{w_i + \tau_i, a_i + \tau_i\}$
y_{khj} = Parameters that are worth 1 if the type of service *k* can be provided by medical staff *h* in the place of patient *j* who need it is worth 0 if not
z_{ij} = The parameter is worth 1 if the place of patient *j* has priority than where the patient *i*, is worth 0 if not.

3) Decision Variable

In this model, the decision variable is a binary variable. x_{ij}^{hk} = 1, if medical staff *h* which gives the type of service *k* through the patient's place, and = 0, if not.

C. Formulate Model Constraints

Formulating model constraints is done by determining the actions or determining the initial value of the problem and emphasizing the limitations of the model to be built. The following describes the limitations or constraints that need to be met in the model [26]:

- That each patient is only served once by the medical staff to completion, so that the service is carried out only once and cannot be done repeatedly or cannot perform services partially, which means that medical staff go and return only once in each service to one patient.
- The medical staff departs immediately after the patient's service is completed, which means the medical staff and type of service provided for the place of service of i to the destination of the next service j is zero.
- Medical staff can only go and return to the patient's place where it is needed, which means that medical staff leave and return only once in each service to one patient.
- Elimination of sub-tour.
- Determine the waiting time needed, namely the total waiting time after the initial time the patient receives service - the time needed by the medical staff to arrive at the patient's place - the time of travel from the service center to the service request.
- Determine the time of delivery of services that arrive at each patient's place, namely the length of time at the start of providing services to patients until completion of providing services.
- Determine the value of punishment if medical staff arrive faster or slower at the place of patients who require services, namely punishments of inaccurate medical staff arrive at the patient's place, where the time needed by medical staff to arrive at the patient's place will decrease , and will increase if it arrives longer than the time determined by bi (the time at the latest the patient receives service).
- That medical staff can provide services only if the medical staff is qualified to carry out the type of health service, i.e. medical staff departing from place i to place j must qualify according to the request for the type of service k to be given to the patient.
- The time limit, that medical staff must immediately go to the location of patients who need a higher priority to carry out services, which means that the time needed by medical staff to leave the patient's i location that is receiving service should be limited if there is a request for health care services from r priority patients, so medical staff must leave immediately.
- Range of decision variable values, giving decision value ranges using binary integer numbers, namely 0 and 1.

D. Discussion of the Model

The objective of this problem is to minimize travel costs, service fees and fees charged because it is not on time so that all requests for patients are served. The Optimization model can be written as follows [26]:

$$\textbf{\textit{Minimum A}} = \sum_{i\in N}\sum_{j\in N}\boldsymbol{\alpha}_{ij}\sum_{h\in H}\boldsymbol{x}_{ij}^{h} + \sum_{i\in N}\sum_{j\in N}\boldsymbol{\alpha}_{ij}\sum_{k\in K}\boldsymbol{x}_{ij}^{k} + \sum_{i\in N}\sum_{j\in N}\boldsymbol{\beta}_{ij}\sum_{h\in H}\boldsymbol{x}_{ij}^{h} + \sum_{i\in N}\sum_{j\in N}\boldsymbol{\beta}_{ij}\sum_{k\in K}\boldsymbol{x}_{ij}^{k} + \sum_{i\in N}\sum_{j\in N}\boldsymbol{t}_{ij}\sum S_{ij}^{h} \quad (1)$$

Equation (1) states the travel costs of *h* medical staff from place *i* to place *j* for the provision of health services to patients, stating the cost of travel for the type of medical service *k* from place *i* to the provision of health services to patients, stating medical staff honorarium costs *h* from place *i* to place *j* for the provision of health services to patients, the function states the type of service fee to *k* from place *i* to place *j* for the provision of health services to patients, stating the cost of the time needed by medical staff *h* to arrive at the patient *i* service. There are several limitations or constraints that need to be fulfilled.

$$\sum_{j\in N}\sum_{h\in H}\sum_{k\in K} x_{ij}^{hk} = 1 \quad \forall \boldsymbol{i} \in N \setminus \{0\} \quad (2)$$

Equation (2) states medical staff only serves each patient once

$$\sum_{i\in N} x_{ij}^{hk} - \sum_{i\in N} x_{ji}^{hk} = 0 \quad \forall \boldsymbol{j} \in N \setminus \{0\}, \forall \boldsymbol{h} \in H, \forall \boldsymbol{k} \in K \quad (3)$$

Equation (3) is proposed to ensure that medical staff departs immediately after completion of the patient's service.

$$\sum_{j\in N}\sum_{k\in K} x_{0j}^{hk} = 1 \quad \forall \boldsymbol{h} \in H \setminus \{0\} \quad (4)$$

$$\sum_{j\in N}\sum_{k\in K} x_{j0}^{hk} = 1 \quad \forall \boldsymbol{h} \in H \quad (5)$$

Equations (4) and (5) to ensure that medical staff can only go and return to the place of the patient who is in dire need.

$$\sum_{i\in R}\sum_{j\in R}\sum_{h\in H}\sum_{k\in K} x_{ij}^{hk} \le |\boldsymbol{R}| - 1 \quad \forall \boldsymbol{R} \subseteq \boldsymbol{N} \setminus \{0\} \quad (6)$$

The sub-tour elimination is given in Equation (6)

$$w_j = maks\left(a_i - s_i - t_{ij}, 0\right) \quad \forall \boldsymbol{j} \in \boldsymbol{N} \setminus \{0, i\} \quad (7)$$

Equation (7) determines the waiting time needed.

$$\sum_{i\in N}\sum_{h\in H}\sum_{k\in K} x_{ij}^{hk}\left(s_i - t_i - t_{ij} + w_j\right) = s_i \, \forall \boldsymbol{j} \in \boldsymbol{N} \; \{0, i\} \quad (8)$$

Equation (8) gives the time of service that arrives at each patient's place.

$$N_i\left(s_i\right) = y.w_i + \lambda.max\left(s_i - b_i, 0\right) \quad (9)$$

Equations (9) determine the value of penalties if medical staff arrives faster or slower in the place of patients who need service.

$$x_{ij}^{hk} \le y_{jhk} \quad \forall \boldsymbol{i} \in \boldsymbol{N},\ j \in N \setminus \{0\},\ \boldsymbol{k} \in K, h \in H \tag{10}$$

Equation (10) provides that medical staff can provide services only if the medical staff is qualified to carry out a type of health service.

$$D_i + t_{ij} + t_j \le r_{ij} D_j \quad \forall \boldsymbol{i} \in \boldsymbol{N},\ j \in N \setminus \{0\} \tag{11}$$

Equation (11) presents time limitations. Priority r states that medical staff must immediately go to the location of patients who need higher priority to carry out services.

$$s_i \in [a_i, b_i] \ \forall \boldsymbol{i} \in \boldsymbol{N} \tag{12}$$

$$x_{ij}^{hk} \in \{0,1\} \ \ \forall \boldsymbol{i}, j \in N, h \in H, \boldsymbol{k} \in K \tag{13}$$

Equations (12) and (13) state the range of variable decision values.

IV. CONCLUSIONS

The smart health service optimization model is the optimization of health service delivery based on the Smart Health concept, by providing quality care services as quickly as possible to patients by reducing health care costs and, overcoming the problem of lack of limited nursing staff resources with maximum use of resources. This model is a model that minimizes travel costs, service costs and other costs that arise due to inaccuracies in providing services to patients. Obtained information that the maximum value of the objective function is 88.00000 at the 25th iteration step.

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