An Optimization Model for Solving Integrated Hospital Capacity Planning Problem

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Abstract: There is no doubt that the demand for medical care is growing exponentially as a result of the increasing number of citizens. This scenario is also happening in the city of Medan, in the province of North Sumatra, Indonesia. Therefore, capacity management systems requiring details of beds and the availability of nursing staff should be considered for inpatient care. This paper presents a capacity model that provides a perspective on the capacity of nursing staff needed and the opportunities for increasing the use of ward capacity. A capacity model is created to measure the resources required. The problem is defined by the formulation of a mixed integer nonlinear optimization. The model is placed in a hospital in Medan City. The result is shown in the report.

Keywords: Modelling, Hospital Planning, Nursing-staff, Optimization

1. Introduction

Overall, there is a growing demand for health care. The whole phenomenon is due to the explosive increase in the world population and the gradual correlation between one nation and another. It also occurred in the Medan Area, North Sumatra Province, Indonesia.

Hospitals are encouraged to provide people with medical treatment as a medical practice. It is not shocking that people are now waiting for additional hospitals. Hospitals in Medan however are experiencing severe financial strain and capacity management issues. Increased costs for maintenance, operation and patient care have added to the problem dimension (Brailsford & Vissers, 2011; Pecoraro, Clemente, & Luzi, 2020; Rais & Viana, 2011). This has a major impact, namely that growing numbers of peoplefrom Medan are pursuing health services from their neighboring countries such as Malaysia and Singapore. Of course, this situation needs to be addressed immediately in order to improve the effectiveness of hospitals.

Patients with varying preferences, timings and circumstances are the primary objective of the healthcare system (Faezipour & Ferreira, 2013). Big data provides potential approaches to customized services, medical care, chronic disease prevention and telemonitoring, and the management of implanted appliances in patients. In this study, researchers explain certain aspects of data driven health: autonomous decision making (Gantner, 2015; Jones, 2020; Raghupathi & Raghupathi, 2014).

Service has the most crucial role in providing managerial health services for the health of patients in hospitals. It is increasingly important to reduce costs and improve resource allocation of funds the health department seeks to minimize the use of inappropriate sources of funds by adopting new strategies and tools to optimize existing ones. Beds are limited by the willingness needed to withstand increases in health costs that have intensified the search for alternatives for conventional inpatients. The direct result of this increase in demand is the increase in the number of hospitals. This is clearly seen in several cities in Indonesia, such as the city of Medan. It is seen that the increase in the number of hospitals in Medan is very significant. However, ironically in fact there is also an increase in the number of those seeking health services in neighboring countries, such as Malaysia and Singapore. There is no doubt that to overcome this situation there is a need to improve the performance of hospital health services in large cities. All operations related to hospital performance are limited in the scope of capacity, such as inpatient rooms, medical personnel, facilities and others. Therefore, to meet the patient's demand for health services, hospital management needs to have planning and capacity control from its operations (Aarabi & Hasanian, 2014; Elkhuizen, Bor, Smeenk, Klazinga, & Bakker, 2007; Pierskalla & Brailer, 1994; Ravaghi, Alidoost, Mannion, & Bélorgeot, 2020).

In health care management planning, there are two things that need to be considered, namely:

1. Large amount of data.
2. Uncertainty in health care services.

With the large amount of data and uncertainty of service, a data driven optimization approach is needed. The data driven approach is to analyze the collected data as much as possible within the hospital or company to ensure the accuracy and effectiveness of the decisions taken. If not, the majority of incorrect data will affect the making decision process.

With the new model of the Data Driven Optimization Approach HealthCare management using linear integer programming is expected to be able to:

1. Maximizing hospital services for patients
2. Minimize all health care costs
3. Empower all resources in the hospital for patients to be more responsible
4. Ensure that each patient gets full service.

The optimization method can be divided into exact methods (exact method or analytical method) and approach methods (approximate method). The most characteristic feature of the exact method is that this method will produce an optimal solution. To find out that the results obtained are optimal can be proved by analytically using mathematical methods. The main weakness of the exact method that encourages the use of the approach method is the time needed to obtain the optimal solution (Applegate, Bixby, Cook, & Chvátal, 1998). The method of approach is a method of settlement based on the concept of “try and error”, therefore this method does not guarantee optimal results. However, the approach method is not merely doing 'try and error' blindly, but using a systematic procedure to produce a 'good' solution that approaches the optimal solution. This method of approach can be divided into an approximate algorithm and heuristic algorithm (Kahraman & Topcu, 2018; Talbi, 2009).

Several models for optimizing and / or computing Algorithms related to uncertainty, dynamic / online, structured and / or distributed data on a large scale: Optimal Optimization in Distribution Optimal (data uncertainty) Online Linear Programming (the Smallest Dynamics) with Nonconvex Regularization (data structure) ADMM method with several blocks (data size).

Limited optimization can also benefit direct real clinical decision-making in medical care where doctors and patients experience barriers such as distance from medical facilities, medical insurance benefits, and inadequate accessible health services. The elements of optimization are limited to objective function(s), variable decision(s) and constraint(s). The objective is the decision-making vector function, which is a quantitative metric to be minimized / maximized by the decision-maker. It is a major obstacle for health authorities to avoid rising healthcare prices, by improving the allocation of limited services and by implementing cost-cutting policies.

2. Problem Formulation

The growing need for medical services provided to patients has created significant challenges for their management and decision-makers. High prices, tight expenditure and limited resources are included in the barriers. Most hospitals in Medan face resistance, such as lack of qualified healthcare staff, inadequate hospital facilities and escalating operating costs.

In the case of hospitals in particular, the aim of capacity planning is to ensure that the standard of medical care provided is consistent with the cost of delivery. Such preparation includes estimating the amount and unique characteristics of assets used to provide health care at defined cost and quality standards. As far as hospital capacity management is concerned, the most striking feature is the amount of inpatient beds according to doctors and the number of nurses. Capacity decisions in hospital beds were usually made on the basis of the target occupancy rate. Other hospital units, such as ICUs, also see a much higher level of utilization regardless of their high prices.

The other important factor to be taken into account is waiting time due to the system of allocation of bed availability in order to improve the quality efficiency of hospitals (Ataollahi, Bahrami, Abesi, & Mobasheri, 2013; Bachouch, Guinet, & Hajri-Gabouj, 2012).

The alternative strategy is to provide a well-organized hospital capacity planning and a system for bed allocation to solve this scenario.

3.Deterministic Optimization Model

The main problem is to organize optimally the use of various assets in the hospital as far as possible in the context of our problem. In our situation, doctors, nurses, beds, rooms, medical supplies and technicians are the multifold resources. In this case, the most relevant model for the problem is to construct is an integer programming problem.

Notation need to be defined in order to create the optimization model:

Sets:

I : Hospital departments

J : Medical doctors type

K : Nurses type

L : Available beds

R : Rooms

E : Medical equipments

The variables for the problem:

DI_{ij} : The amount of doctors of type j in department i

SI_{ij} : The amount of nurses of type k in department i

SBI_{ij} : The amount of nurse-aids of type k in department i

TI_{ij} : The amount of technicians of type j in department i

D_{ij} : Doctors of type j added in department i

S_{ij} : The amount of type k nurses added in department i

SB_{ij} : The amount of type k nurse-aids added in department i

TPA_{il} : Initial number of beds l in department i

TP_i : Number of beds l to be added in department i

Binary variables:

$$x_{lr}^{i} = \begin{cases} 1, \text{if bed } l \text{ is for room } r \text{ in } i \text{ department} \\ 0, \text{ otherwise} \end{cases}$$

$$y_{r}^{i} = \begin{cases} 1, \text{ if room } r \text{ is applied in } i \text{ department} \\ 0, \text{ otherwise} \end{cases}$$

$$z_{i}^{e} = \begin{cases} 1, \text{ if medical equipment } e \text{ is put into } i \text{ department} \\ 0, \text{ otherwise} \end{cases}$$

Parameters:

bd_{ij} : Cost of doctor of type j in department i

bs_{ik} :Cost of nurses k in department i

bsa_{ik} : Cost of nurse-aids k in department i

bt_{il} : Cost of using beds l in department i

bw_{il} : Cost for waiting to get bed l in department i

ba_{lr}^{i} : Cost for getting bed l for room r in department i

cr_{i}^{r} : Cost to prepare room r in department i

cme_{i}^{e} : Cost for operating medical equipment e in department i

ct_{ij} : Cost of technician j in department i

md_{ij} : Upper bound amount of doctor for each type j can be slotted to each department i

mn_{ik} : Upper bound amount of nurse each type k can be assigned to each department i

mna_{ik} : Upper bound amount of nurse-aids each type k can be assigned to each department i

mb_{il} : Upper bound amount of beds l can be slotted to each department i

mt_{ij} : Upper bound amount of technicians type j can be assigned to department i

ρ_i : Fund can be provided for department i

The challenge of hospital management problem in terms of its capacity is to settle the number of doctors, nurses, beds and technicians to be slotted and to arrange for the spare bedrooms and medical equipment to minimize the total cost of the expenditures.

i. Costs for doctors

$$\text{Cost}(1) = \sum_{i\in I}\sum_{j\in J} bd_{ij}(DI_{ij} + D_{ij}) \quad (1)$$

ii. Costs for nurses

$$\text{Cost}(2) = \sum_{i\in I}\sum_{k\in K} bs_{ik}(SI_{ik} + S_{ik}) \quad (2)$$

iii. Costs for nurse – aids

$$\text{Cost}(3) = \sum_{i\in I}\sum_{k\in K} bsa_{ik}(SBI_{ik} + SB_{ik}) \quad (3)$$

iv. Costs for beds

$$\text{Cost}(4) = \sum_{i\in I}\sum_{l\in L} bt_{il}(TPI_{il} + TP_{il}) \quad (4)$$

v. Costs associated with patients having to wait for beds l in department i

$$\text{Cost}(5) = \sum_{i\in I}\sum_{l\in L} bw_{il}(TPI_{il} + TP_{il}) \quad (5)$$

vi. Costs to assignbedl ∈ L if it is administeredto room r ∈ R

$$\text{Cost}(6) = \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} ba^{i}_{lr} x^{i}_{lr} \quad (6)$$

vii. Costs to access a room r when selected

$$\text{Cost}(7) = \sum_{i\in I}\sum_{r\in R} cr^{i}_{r} y^{i}_{r}, \qquad \forall i \in I, \forall r \in R \quad (7)$$

viii. Costs to operate medical equipment e if it is located in department i

$$\text{Cost}(8) = \sum_{i\in I}\sum_{e\in} cme^{e}_{i} z^{e}_{i} \quad (8)$$

ix. Costs for technicians

$$\text{Cost}(9) = \sum_{i\in I}\sum_{j\in J} ct_{ij} TI_{ij} \quad (9)$$

As can be shown, there are nine cost elements.

The objective function is denoted as follows:

$$\text{Minimize } \sum_{j=1}^{9} Cost(j) \quad (10)$$

The constraints of the problem are expressed as follows.

$$DI_{ij} + D_{ij} \le md_{ij}, \qquad \forall i \in I, \forall j \in J \quad (11)$$

$$SI_{ik} + S_{ik} \le mn_{ik}, \quad \forall i \in I, \forall k \in K \tag{12}$$

$$SBI_{ik} + SB_{ik} \le mna_{ik}, \quad \forall i \in I, \forall k \in K \tag{13}$$

$$TPI_{il} + TP_{il} \le mb_{il}, \quad \forall i \in I, \forall l \in L \tag{14}$$

$$\sum_{j \in J} TI_{ij} \le \sum_{j \in J} mt_{ij}, \quad \forall i \in I \tag{15}$$

$$\sum_{l \in L} x_{lr}^{i} \le y_{r}^{i}, \quad \forall i \in I, \forall r \in R \tag{16}$$

$$\sum_{i \in I}\sum_{j \in J} bd_{ij} D_{ij} + \sum_{i \in I}\sum_{k \in K} bs_{ik} S_{ik} + \sum_{i \in I}\sum_{k \in K} bsa_{ik} + \sum_{i \in I}\sum_{l \in L} bt_{il} TP_{il} + \sum_{i \in I}\sum_{l \in L} bw_{il} TPI_{il} + \sum_{i \in I}\sum_{r \in R}\sum_{l \in L} ba_{rl}^{i} x_{rl}^{i} + \sum_{i \in I}\sum_{r \in R} cr_{r}^{i} y_{r}^{i} + \sum_{i \in I}\sum_{e \in E} cme_{i}^{e} z_{i}^{e} + \sum_{i \in I}\sum_{j \in J} ct_{ij} TI_{ij} \le \sum_{i \in I} \rho_{i} \tag{17}$$

$$DA_{ij}, D_{ij}, S_{ik}, SA_{ik}, SB_{ik}, SBA_{ik}, TPA_{il}, TP_{l}, TI_{ij} \ge 0 \text{ and integer} \quad \forall i \in I, \forall j \in J, \forall k \in K, \forall l \in L \tag{18}$$

$$x_{lr}^{i}, y_{r}^{i}, z_{i}^{e} \in \{0,1\}, \quad \forall i \in I, \forall l \in L, \forall r \in R, \forall e \in E \tag{19}$$

Expression (9) means that the maximum amount of doctors may not be higher than the upper bound number of doctors that can be assigned for each section. Expressions (10) – (12) are analogous to expression (9), the number of nurses, the number of assistant nurses and the number of beds respectively. Expression (13) is to ensure that the room is reserved for beds. Expression (17) specifies that expenditure should be no more than the Fund provided for in Expressions (18) and (19) are restrictions on integrity.

4. Data of the Problem

The data sources in this study are data from a hospital located in Medan. Data obtained can support the modeling process and provide mathematical objective function clarity. The data are explained in detail as in the table below.

Table 1. Costs for doctors (j) in department i in providing health services to patients.

Type	1	2	3
DI+D	156	174	219

Table 2. Costs for nurses in the department i in providing health services to patients.

Type	1	2	3
SI+S	25	136	113

Table 3. Costs for nurse assistants in department i in providing health services to patients.

Type	1	2	3
SBI+SB	53	70	101

Table 4. Costs for bed l in department i in providing health services to patients.

Type	1	2	3
TPI+TP	115	84	85

Table 5. Costs of space r in department i in providing health services.

R	1	2	3
cr	5	3	2

Table 6. Operating costs of medical equipment e in the department i in providing health services.

cme	7

Table 7. Operating costs for the department i in providing health services.

ct	4

5.Local Search Approach

Branch-and-bound method is a common way of addressing the issue of linear integer programming. However in the case that the problems are large dimensions, such a method can be highly costly in overall computer processing time, and notably the algorithm stops without addressing the problem solution. We addressed a reduced problem where most integer variables remain unchanged and only a limited subset of variables is processed to move in discrete steps.

This can be applied within the program structure by labeling all variables with integer values as non-basic and addressing a reduced problem for those who are held to be superbasic within their limits.

The step of the algorithm can be written as follows:

Step 1 : Address the problem by relaxing the integrality conditions.

Step 2 : Get an integer feasible solution heuristically.

Step 3 : Partition the set I of integer variables to be the set of I_1 in which their values are at their bounds and they were nonbasic at the continuous solution and the set I_2,$I = I_1 + I_2$.

Step 4 : Do a local search on the objective function, keeping the variables in I_1 nonbasic and making discrete changes in the values of the variables in I_2.

Step 5 : From Step 4 solution, check the reduced costs of the variables in I_1. If there are variables can be released from their bounds, put them to set I_2moreover, go back to step 4, otherwise Stop.

The algorithm provides a conceptional structures for creating specific strategies in solving particular classes of problems. For instance, the heuristic process for rounding of variables non-integer in Step 2 can be adjusted to suit the structure of the constraints, and Step 5 may involve providing just one variable to the set I_2.

In practice, implementation of the algorithm may require the choice of tolerance for the bounds of the variables and on particular their integer infeasibility. The process in Step 4 is influenced by such choice, as a discrete step for an integer variable which is super basic may be carried out if all of the integer basic variables stay within the specified tolerance of integer feasibility.

In general, if there are no restrictions capable of remaining integer feasible in the integer basic variables, the figures in set I_2 must be configured to be superbasic as distinct changes occur in the superbasic. This is possible because the problem involves a large number of slack variables.

6.Results

After implementing the approach mentioned in the previous Section, we obtain the results as follows.

Table 8. Number of Doctors Needed

Type/Department	1	2	3
1	7	10	15
2	8	8	10
3	6	9	20
4	8	6	10
5	5	7	8
6	7	7	10
7	8	8	9
8	9	10	10

Table 8 describes, for example, that there would 7 doctors of type 1 are needed for department 1 in the hospital.

Table 9. Number of Additional Doctors Needed

Type/Department	1	2	3
1	10	15	20
2	15	12	16
3	10	16	22
4	12	15	15
5	16	11	12
6	12	14	18
7	11	12	14
8	12	14	10

Table 10. Number of Nurses Needed

Type/Department	1	2	3
1	10	16	11
2	0	12	10
3	0	14	8
4	0	15	15
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 11. Number of Additional Nurses Needed

Type/Department	1	2	3
1	15	20	16
2	0	15	15
3	0	24	20
4	0	20	18
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 12. Number of Nurse-Aids Needed

Type/Department	1	2	3
1	7	9	10
2	8	6	9
3	7	8	10
4	2	6	9
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 13. Number of Additional Nurse-Aids Needed

Type/Department	1	2	3
1	10	12	15
2	8	9	18
3	11	10	18
4	6	10	12
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 14. Number of Beds Needed

Type/Department	1	2	3

1	15	10	14
2	10	9	11
3	20	12	10
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 15. Number of Additional Beds Needed

Type/Department	1	2	3
1	28	20	25
2	18	15	10
3	24	18	15
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

Table 16. Number of Technicians Needed

Type/Department	1	2	3
1	8	9	10
2	5	7	12
3	5	5	5
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

7.Conclusions

An optimization model addresses in this paper is to solve an integrated planning of hospital capacity management. The capacity problem can be modeled as an integer program. The model obtained is implemented in a hospital located in Medan city. A feasible neighborhood integer search is proposed for solving the large scale integer programming problem.

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