RESOURCE ALLOCATION FOR HEALTHCARE ORGANIZATIONS

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***Abstract*—Executives of hospitals, specifically, privately managed hospitals in developing countries are facing tremendous pressure from the stake-holders to adopt state-of-the art revenue management strategies, in order to justify return on their investments (RoI). On the other hand, the hospital management face the challenge of providing quality and safe health-care services to all of their patients from both within and outside the country (demand) with limited resource capacity (supply). Revenue from surgeries account for about 40% of the total revenue in most of the hospitals. In this research, we consider surgical demand from elective surgeries and propose a two-phase method for the allocation of resources (supply) to surgeries (demand). The first phase, allocates resources to all the surgical requests. Second phase re-allocates surgeries based on competitive bidding of the surgical requests. Resource allocation is the distribution of limited resources (capacity) among competing consumers (or a firm′s customers). One way of fair allocation of resources to the consumers is through auctions. For the second phase, we develop a model for optimal allocation of multiple resources like operating rooms (ORs), nurses, equipments, and so on; to the surgical demand of hospitals through auctions. The various resources of hospitals like ORs and nurses, are represented as factors or characteristics of a generalized resource. A resource (generalized) is a realization of factors like ORs, nurses, and equipments. That is a resource (generalized) is a specific set of nursing staff and equipments being assigned to a specific OR in a specific time-slot. Optimally allocating resources to various bids (surgical requests) and scheduling the surgical requests to various ORs without any conflict on any given time-slot of a day is an NP-hard problem. The proposed model optimally allocates client (practitioners or agents) bids to the available capacity of resources (generalized). We analyse the application of the model for a business scenario.**

***Index Terms*—Healthcare management, hospital management, surgical suite, elective surgeries, resource allocation, auctions, and optimal allocation.**

I. INTRODUCTION

Healthcare services like other service categories are also impacted by globalization. Developing countries are attracting customers from other countries by offering high quality

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healthcare at a lower cost as compared to the cost of quality healthcare in their home country. Medical tourism in developing countries is gaining momentum in the recent past due to increasing standardization of healthcare processes and accreditations of hospitals to quality assurance bodies such as JCI (Joint Commission International, USA). Many hospitals, especially, the privately managed hospitals in developing countries like India, are facing increased pressure to manage the available resources (supply) efficiently by providing quality and safe healthcare services to all of its patients from both within and outside the country. These hospitals are also under tremendous pressure from its stakeholders to implement revenue management strategies to justify return on their investments (RoI). In this research, we propose a two-phase method to allocate limited surgical resources of hospitals to elective surgical demand (elective surgeries) by maximizing the revenue, apart from providing quality and safe health care to all of its patients (demand). Elective surgery includes those medical treatments which do not require to be treated as emergency and can be put on hold for a span of time before they actually receive medical treatment. Though beneficial to the patient, it is not categorized as essential. We highlight that this research addresses planning of elective surgeries and may not be applicable for the emergency surgical cases, as the planning of the emergency surgeries are primarily dependent on patients health condition.

Revenue from surgeries account for about 40% of the total revenue in most of the hospitals [?]. Managing the operating room (OR) suite and streamlining the processes related to OR suite in a hospital is a key strategic challenge to the senior executives of the hospital. ORs are expensive and resource intensive center in many of the hospitals. Shortage of experienced OR nurses and lack of standardisation of the OR processes makes the administration of the OR suite quite complex. Also, some of the most expensive equipment and supplies are used in the ORs. Another factor that need to be considered is the utilization of the ORs. Though most of the ORs appear to be fully utilized, studies in many hospitals have proven that the average utilization of the ORs range from 40% to 75%. The workflow in the ORs is also typically not optimized. By generating a process map of the existing activities in the ORs, hospitals can identify unwanted tasks, hidden inefficiencies and opportunities for improvement. Efficient ORs report non-labor costs per procedure that are 17% to 28% lower than the average ORs. Major concerns regarding the utilization of the ORs result due to poor on-time starts of cases and room turnover times. On an average, hospitals have a 27% on-time case start statistics and the best hospitals have 76% of their surgical procedures starting on time. Several studies address OR room planning and scheduling problem ([?]-[?]). A detailed literature review of operating room planning and scheduling is presented in [?]. Operations research literature has also addressed nurse rostering and scheduling problems ([?],[?]). This research addresses the allocation of client (practitioners or agents) bids to resources like ORs, nursing staff, and equipments by taking into account availability and capacity of various resources in a hospital.

The remaining part of this paper is organized as follows. First we define the problem in Section II. A resource allocation model for optimally allocating ORs and nurses to bids corresponding to surgeries of various specialities is presented in Section III. In Section IV, we analyse the proposed model on a business usecase. Finally in Section V, we conclude.

II. MOTIVATION AND PROBLEM DEFINITION

Senior management of hospitals apart from providing quality healthcare to its patients, have tremendous pressures to justify return on investments (RoI) to the stakeholders. As the operating room suite contributes quite a large percentage to the total revenue of hospitals, in this section we propose a two-phase approach for allocating elective surgeries to the various resources of the operating room suite. In the first phase, the requests for elective surgeries are allocated to various resources - operating rooms, nurses, and so on, depending on the availability of the various resources. Allocation could be made using various approaches such as integer programming (IP), mixed integer programming (MIP), and so on, which are proposed in the literature ([**?**]-[**?**]). The time horizon that is considered for allocation in the first phase should be sufficiently large to allocate all the requested elective surgeries. For the first phase, only certain percentage of the total available capacity over a day could be considered for allocation. The remaining capacity of the day or the additional capacity created through over-time of the day are made available for allocation in the second phase. Second phase allocates competing surgical demand through auctions. The practitioners or agents who are willing to get their surgeries re-allocated by paying additional premium would bid in the second phase. The flow diagram of the two-phase resource allocation approach for surgical requests is presented in Figure 1.

In general, the allocation problem in operations research and economics deals with allocation of constrained supply (capacity) of resources to the demand for the resources. As the supply is constrained the resources are allocated based on the consumers$'$ valuation for the resources. A way for fair allocation of the resources to the consumers is through auctions ([**?**],[**?**]). In the remaining part of this paper, we develop a model for optimal allocation of resources (multiple resources) to surgical demand for various specialities in a hospital through auctions. We refer to this problem as surgical suite resource allocation problem.

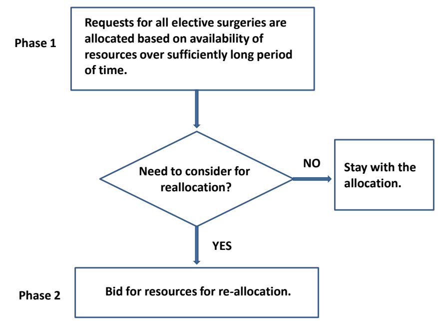

Fig. 1. Two-phase resource allocation method for surgical requests

The various resources of hospitals like ORs and nurses, are represented as factors or characteristics of a generalized resource. So, a generalized resource r, referred to as a resource in this paper, is a realization of factors like ORs, nurses, and equipments. That is a resource (generalized) is a specific set of nursing staff and equipments being assigned to a specific OR in a specific time-slot. If r is a realization of n factors $A_1, A_2, \ldots, A_n$, then a set of constraints could be imposed between, (i) bid(s) (bidder(s)) and the factors $A_1, A_2, \ldots, A_n$, and (ii) the factors $A_1, A_2, \ldots, A_n$. For example, constraints like - (i) for each bidder (practitioner), at-most one surgery could be scheduled in a specific time-slot, in a specific OR with a specific set of nursing staff and equipments, and

(ii) each nursing staff (a factor of r) indexed s, is assigned at-most N_r surgeries on any given day for a particular speciality corresponding to r (combination of the factors nurses and time-slot).

Apart from the constraints that are imposed on the various factors associated with the resources, the optimal allocation problem in general would also involve sequencing or scheduling of the resources induced by various factors associated with the resources. For example, a schedule is obtained by assigning OR, nursing staff and equipments for an allocated surgery scheduled for a particular time-slot. The optimal allocation in this context is obtained by computing the optimal allocations over all schedules (realizations). In this work, the term *allocation* refers to the generalized allocation (over all realizations). However, the models are presented for a specific realization of generalized allocation.

In the generalized sense, resource allocation for surgical bids is NP-hard.

Theorem 1 : Generalized surgical suite resource allocation problem is NP-hard.

Proof : Follows from the fact that the OR scheduling [**?**] and the nurse scheduling [**?**] problems are NP-hard. □

III. RESOURCE ALLOCATION MODEL

A surgery for a speciality (say orthopaedic) requires OR, nurses and equipments with some specific requirement for carrying out a surgical procedure. A resource r would have factors like specialities, OR, nurses, and equipments. We don′t consider allocating equipments (a factor) in the model. However, it is not difficult to extend the model to a more general case. The hospital operates between the days, Monday to Saturday, indexed d. Surgeries of various specialities consume different time (surgical time) to complete. For example, ophthalmology surgeries would complete in 15 minutes, whereas, cardiology surgeries would take 2-3 hours. Hospitals have an estimate on the number of surgeries Q_{rd}, for each r on any given day d, based on the average surgical time of various specialities and the number of ORs. The bids indexed i bid on resources r, for a given day d. A bid i for a resource r on a given day d, B_{ird} specifies the number of surgeries of a specific speciality that want to be performed. If no value is specified for B_{ird}, then the value is set to 0. The bid also specifies a price (per unit price), $P_{ird}(x_{ird})$, that would be paid for resource r depending on the number of units (number of surgeries), x_{ird} , allocated on a given day d. The decision variables of the model are x_{ird} and y_{rds}. The variable x_{ird} denotes the number of surgeries of resource r (OR, nursing staff for a particular speciality) allocated to the bid i on a given day d. The variable y_{rds} denotes the number of surgeries allocated to a nursing staff indexed s of a particular speciality associated with r on a given day d. It is assumed any nursing staff can be allocated at-most N_r surgeries per day of a particular speciality associated with r. Assuming the number of skill levels of nursing staff is L, in the model δ_{sl} would be 1 if nursing staff s is grouped under the skill level l, otherwise, δ_{sl} would be 0. For example, if the skill levels are (i) senior - between 5 to 10 years experienced nursing staff (l=1), and (ii) between 1 to 5 years experienced nursing staff (l=2). For a senior nursing staff s, $\delta_{s1} = 1$ and $\delta_{s2} = 0$. In the model, M_{lr} denotes the least number of nursing staff of skill level l required for the speciality associated to r. The objective function of the model maximizes the revenue from the surgical suites of a hospital.

Allocation Model: maximize $\sum_{i=1}^{N}\sum_{r=1}^{K}\sum_{d=1}^{D} P_{ird}(x_{ird})x_{ird}$

subject to $\sum_{i=1}^{N} x_{ird} \leq Q_{rd}, \forall 1 \leq r \leq K, \forall 1 \leq d \leq D,$

$$M_{lr}\sum_{i=1}^{N} x_{ird} \leq \sum_{s=1}^{S} y_{rds}\delta_{sl}, \forall 1 \leq r \leq K, \forall 1 \leq d \leq D,$$

$$0 \leq x_{ird} \leq B_{ird}Q_{rd},\ x_{ird} \text{ an integer},$$

$$0 \leq y_{rds} \leq N_r,\ y_{rds} \text{ an integer},$$

$$\forall 1 \leq i \leq N, 1 \leq r \leq K, 1 \leq d \leq D,$$

$$1 \leq s \leq, 1 \leq l \leq L.$$

Table I: Availability of Senior Nurses

Speciality	Number
Cardiology/Orthopaedic	1
Orthopaedic/Ophthalmology	2
Ophthalmology	1

Table II: Availability of Junior Nurses

Speciality	Number
Cardiology/Orthopaedic	4
Orthopaedic/Ophthalmology	3
Ophthalmology	2

Table III: Estimated Capacity

Speciality	Number
Cardiology	4
Orthopaedic	12
Ophthalmology	15

Table IV: Bid of Client-1

Speciality	Units	Unit price (USD)
Cardiology	2	10,000
Orthopaedic	8	7,000
Ophthalmology	5	2,000

Table V: Bid of Client-2

Speciality	Units	Unit price (USD)
Cardiology	3	9,000
Orthopaedic	4	8,000
Ophthalmology	2	3,000

IV. ANALYSIS OF THE MODEL

In this section we analyse and validate the proposed model in the following business use-case. We consider a hospital with 3 ORs and 13 nurses. The nurses are categorized as (i) senior - nurses with 5 to 10 years experience (l=1), and (ii) junior - nurses with 1-5 years experience (l=2). Also number of nursing staff available at senior and junior levels for various surgical combinations are tabulated in Tables I and II, respectively. For example, from Table I it can be seen that the number of senior nurses available who can handle both orthopaedic and ophthalmology surgical cases is 2. Estimated capacity of surgeries (of various specialities) per day that could be handled by 3 ORs based on average surgical time of various surgical specialities is set as shown in Table III. Every surgery is required to be planned with one senior and one junior nurse. Also, any nurse of their respective speciality can be planned for exactly 2 cardiology, 4 orthopaedic, or 8 ophthalmology surgeries. On a particular day, clients 1 and 2 bid for resources of various surgical specialities as shown in Tables IV and V, respectively.

With these settings, the model suggests that it is optimal to allocate 8 orthopaedic and 5 ophthalmology surgeries to client 1 and 4 orthopaedic and 2 ophthalmology surgeries to client 2. The revenue generated by this allocation is 98,000 USD. For client 1, even though it is feasible to allocate 2 cardiology, 4 orthopaedic and 5 ophthalmology surgeries instead of 8 orthopaedic and 5 ophthalmology surgeries, the latter allocation as compared to the former allocation generates an increased revenue of 8,000 USD for the hospital.

V. CONCLUSION

In this work, we proposed a generalized resource allocation model for healthcare services organizations to optimally allocate surgical bids (demand) to various resources such as ORs, nursing staff, equipments and so on (supply). The various resources of hospitals like ORs, and nurses, were represented as factors of a generalized resource, which is referred as a resource in this work. We also factored in nursing staff of various skills levels in the model. The proposed model was analysed in a business usecase. Generalising and analysing the model for other applications would be our future study.

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