

Applications of Operations Research Techniques in Healthcare

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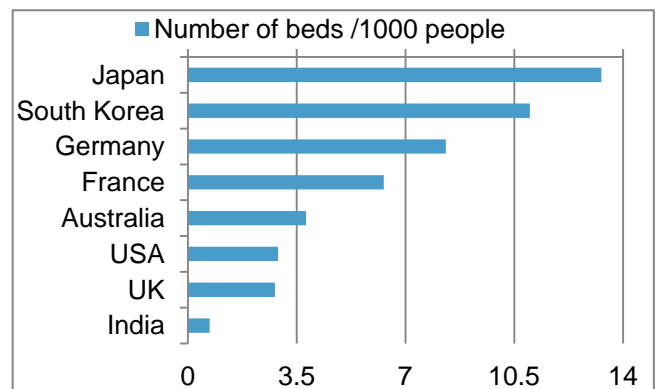
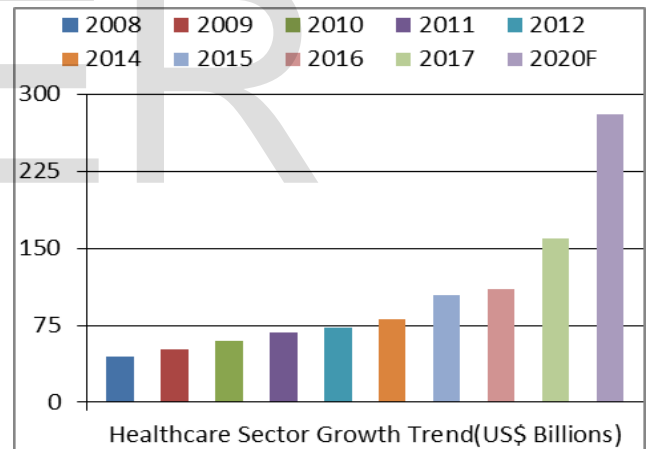
Abstract- Owing the scarce resources and increased population it has become quite difficult to the governments, especially those of developing countries to provide quality health services to their citizens. As a result of which Innovative operations research (OR) techniques have been developed for a wide range of healthcare applications such as operating room planning, emergency department staffing, breast cancer screening, radiotherapy treatment planning, long term care planning, home healthcare planning. Research in Healthcare can not only help Hospitals in better managing their patients but also in providing better treatment while achieving efficiency in doing so. This paper describes the Operations Research applications in health care with special reference to India. An overview of Indian health care sector is also provided.

Keywords: Public Health, Operations Research, Optimization, Healthcare Planning, Patient Scheduling, Staff Rostering, Forecasting

1 INTRODUCTION

Health care is one of the largest industries in the developed and developing countries, as well as it is a service-oriented industry. It is a particularly significant service industry given not only the criticality of quality and safety in delivering patient care. Healthcare has become one of India's largest sectors both in terms of revenue and employment. Healthcare comprises hospitals, medical devices, clinical trials, outsourcing, telemedicine, medical tourism, health insurance and medical equipment. The Indian healthcare sector is growing at a brisk pace due to its strengthening coverage, services and increasing expenditure by public as well private players. The total industry size is expected to reach \$280 billion by the year 2020. (Graph 1). According to the Investment Commission of India the healthcare sector has experienced phenomenal growth of 12 percent per annum in the last 4 years. Rising income levels and a growing elderly population are all factors that are driving this growth.

Besides being extremely understaffed the healthcare sector in India does not even have enough beds for its patients. With a world average of 3.96 hospital beds per 1000 population India stands just a little over 0.7 hospital beds per 1000 population. Moreover, India faces a shortage of doctors, nurses and paramedics that are needed to propel the growing healthcare industry. Lifestyle diseases has led to an increase in the spending on healthcare delivery.



Operations Research in context to Health Care is "Any research producing practically useable knowledge (evidence, findings, information, etc.) which can improve program implementation (e.g. effectiveness, efficiency, quality, access, scale up, sustainability) regardless of the type of research (design, methodology, approach) falls within the boundaries of operations research".

OR is being utilized substantially more in hospital management, resource-constrained operations or treatment planning. Major healthcare optimization issues include logistics, disease diagnosis, service planning, medical therapeutics, resource scheduling and preventive care.

There are two main approaches for carrying out OR in healthcare. The first approach involves the analysis of secondary data as retrospective record reviews and utilizing such data that is already generated in the programs. Such data in the field often are not used to its maximum potential and much problem identification and gaps can be found out by reviewing the program reports and data sets.

The secondary approach is carrying out primary level research. There are four types of operation research studies as defined by the Population Council-exploratory/diagnostic, field intervention, evaluative and cost effectiveness studies, all not always mutually exclusive but often linked.

2 HEALTHCARE PLANNING

Planning is setting up of objectives and the devising strategies to attain those objectives. Healthcare planning is basically providing proper and adequate healthcare facilities where it is needed the most. In a country like India where there is a resource crunch and the population is huge (especially the aging population) it is very important to use proper healthcare planning. Also, when the life span is increasing and the birth rates are dwindling, there needs to be extra budget and healthcare resources to meet the need.

So it is our responsibility to make sure that none of these resources get wasted and there is optimal use of these resources as healthcare is a very sensitive topic to deal with as it involves the life of a human being. Many have started to use operational research as a technique to optimize these resources and minimize costs.

Operations research is used right from proper allocation of beds in the emergency room to the proper allocation of nurses in the intensive care units to selection of hospital location to forecasting the future demand.

2.1 Emergency Vehicles

The optimum allocation of emergency vehicles is very important because it the question of life and death of a person. While planning for this the two main objectives need to be kept in mind: there should be maximum population coverage by a single unit of vehicle;

minimization of the total travel distance from locations to the hospitals which helps them to reach faster

Various researchers have come up with literature related to allocation of the emergency vehicle. In Colombia, Rojas et al (2007) used linear programming to determine ambulance location and tested the effectiveness of results by using simulations. Simulation is a process involved with developing a model of some real phenomenon and then performing experiments on the model evolved with a view to predict the behavior of the system over time

A facility location model for ambulances that limits the number of units needed for performing at pre-specified service levels was developed by Ingolfsson et al. (2008). They used uncertainties and randomness into their convex optimization model using actual data from Edmonton, Canada. They found the model to be tractable with general-purpose optimization solvers for cities with population of up to one million.

The following shows a survey which was taken by Alabama company, it shows the patients complaint, the time taken to reach there at the right time, and the reasons (medical transports, immediate ambulances needed), etc.

2.2 Demand Forecasting

Demand forecasting is basically predicting the future demand of a particular product in advance. It includes both controllable and uncontrollable factors. Proper demand forecasting is of utmost importance as it forms a part of the basis of the input of the model. The techniques for demand forecasting can either be quantitative or qualitative, however quantitative requires data in the form of numbers which is more accurate

Finarelli and Johnson (2004) gave an elaborate nine-step, quantitative demand forecasting model for healthcare services-Effective forecasting of demand for healthcare services requires nine steps: 1. Gather historical data. 2. Analyze historical trends. 3. Recognize key demand drivers. 4. Recognize relevant benchmarks. 5. Demonstrate existing conditions. 6. Create core assumptions for population-based demand. 7. Create core assumptions for provider-level demand. 8. Make a baseline forecast of future demand. 9. Test effectiveness of projections to changes in core assumptions, while Cote and Tucker (2001) examined four common methods for predicting demand for healthcare services: percent adjustment, 12-month moving average, trend line and seasonality. The correctness of different forecasting methods was evaluated by Jones et al. (2008). They utilized data from daily patient arrivals at the emergency departments of three different hospitals and considered the following methods: time series regression, exponential smoothing, and seasonal autoregressive integrated moving average and artificial neural network models. Beech (2001) derived market-based healthcare service forecasting from a wide scope of accessible information for estimating the future demand. The data set includes primary as well as secondary service areas,

service-area populations by various demographic groupings, discharge utilization rates, market size and market share by service lines. They found that market dynamics can allow a variety of explicit assumptions and trends for developing scenarios of potential future demand.

2.1.1 9 Step Quantitative Demand Forecasting Model For Healthcare



Developing countries like India, where there is lack of space and proper infrastructure optimal allocation of healthcare centers is very important. Hence, OR scholars have studied where to keep this kind of centers for maximum accessibility by the people. Murawski and Church (2009) considered the issue of improving health service accessibility by connecting the existing facility locations of the transport network to metaled roads. Their integer-programming model is sufficient for rural areas of underdeveloped countries where, during bad weather conditions, availability is reduced because of the lack of basic access to roads. A marginal different problem is solved in Ndiaye and Alfares (2008). They consider the issue of selecting public service locations for nomadic population groups that seasonally change their locations.

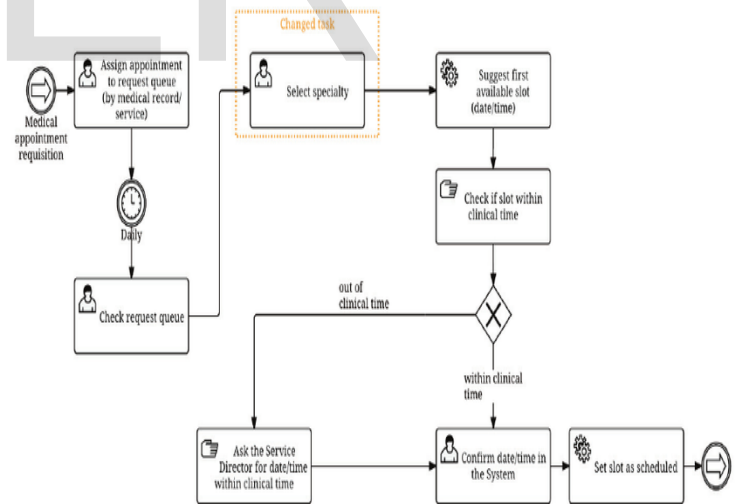
The authors have presented a binary integer-programming model to decide the ideal number along with the areas of the primary healthcare units that can fulfill seasonally varying demands.

3 HEALTHCARE MANAGEMENT

3.1 Patient Scheduling

Patients have to make appointments to visit specialists. This gives rise to the problem of long waiting time at clinics and hospitals before consultation. Hence appointment scheduling or patient scheduling is an important field of research in healthcare. Researchers have used various OR techniques to make appropriate appointment schedule so as to minimize waiting time. Making optimal patient-staff schedules and patient-facility schedules can help to save time and reduce cost. A good appointment schedule aims at least waiting time for patients and minimizes overtime for staff constrained by the patient load and staffing. OR models are developed by authors to answer the given three questions:

- 1) How many patients should be scheduled on a given day?
- 2) How should appointment slots be allocated to these patients on a given day?
- 3) What will be the optimal sequencing of heterogeneous patients?



Patrick et al. (2008) gave a model for patient scheduling based on varying priorities as a Markov decision process. Markov decision processes provide a mathematical framework for modelling decision making in situations where outcomes are partly random and partly under the control of a decision maker.

Turhan et al. (2013) used heuristic models called Fix-and-Relax and Fix-and-Optimize for Patient Admission Scheduling. Fix-and-Relax is used to find an initial solution

to the problem which is further improved using Fix-and-Optimize.

Green and Savin (2008) gave a single server queue model for last minute cancellation of appointments by patients. . Simulation was used by Patrick and Puterman (2007) to achieve resource utilization and flexibility in appointment scheduling.

3.2 Resource Scheduling

Resource scheduling is a set of techniques and methods used to determine the requirement of resources to complete a given work and when it will be required. Nowadays, it has become important for hospitals to reduce their operational costs without affecting its quality in terms of providing health care services. This can be done using resource scheduling. Resources mainly include health professionals (e.g. doctors, nurses), rooms (e.g. examination rooms, operating theaters), equipment (e.g. x-ray machines, CT scanners) and supplies (e.g. blood, bandages). But more importance is given to staff scheduling and operating room scheduling.

3.2.1 Staff Scheduling

Staff scheduling, or rostering, refers to the process of assigning schedules and making work timetables for staff members in a clinic or hospital to meet the demand for its services. In order to do this first shifts are assigned to all staff members to meet the requirements at different timings, and duties are then assigned as per the respective shifts. Personal preferences of staff should also be considered.

Leksakul et al. (2014) developed a nurse scheduling model using Genetic Algorithm to maintain highest level of service, minimize hospital staffing cost and equitably distribute overtime pay. Grano et al. (2009) developed a model with a two stage approach which considers hospital requirements as well as nurse preferences.

A rostering problem occurs when any nurse declares that she is unable to complete a job assigned to her. A solution to this problem was given by Pato and Moz (2008) using Genetic Algorithm and Moz and Pato (2005) using Goal Programming.

In various situations, patients need specific nurses with special skills. Punnakitikashem et al. (2008) developed a stochastic programming approach to tackle nurse to patient assignments. Mullinax and Lawley (2002) gave a mathematical model and heuristic approach to assign nurses to seriously ill infants.

Felici and Gentile (2004) presented a model with an objective of maximizing staff satisfaction using a polyhedral approach.

3.2.2 Operating Room Scheduling

Operating Rooms are the largest cost center and revenue center in a hospital. And hence it becomes increasingly important to effectively manage them so as to minimize

cost and maximize revenue. Studies show that on an average, operating rooms are utilized to only 40% to 75% of their capacity. This can be improved using Operating Room Scheduling. Various studies have been conducted by OR practitioners which study Operating Room Scheduling. Magerlein and Martin (1978) reviewed literature on surgical demand scheduling. He distinguished between advance scheduling (process of fixing a surgery date for a patient) and allocation scheduling (operating room and the starting time of the procedure on the specific day of surgery) in his study.

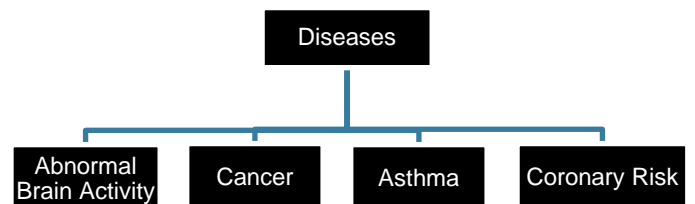
Lamiri et al. (2008) developed a stochastic model which considers two types of demands for surgery for operating room planning: electric (can be pre-planned) and emergency (arrives randomly and surgery must be performed immediately). Wang et al. (2014) investigated an operating theater allocation problem with uncertain surgery duration and emergency demand.

4 HEALTHCARE PRACTICE

Besides addressing various other healthcare management aspects, OR researchers have made significant contribution to drug treatment planning, infectious disease prevention and control and organ donation.

4.1 Disease Diagnosis

A review on the application of the Analytic Hierarchy Process to numerous problems in medical decision making is provided in Liberatore and Nydick (2008). They summarised 50 different articles from seven categories: diagnosis, patient participation, therapy/treatment, organ transplantation, project and technology evaluation and selection, human resource planning and healthcare



evaluation and policy.

Abnormal brain activity is investigated in Chaovalitwongse et al. (2003) (2006) (2008) by using a mathematical-modelling framework for minimizing errors in classification.

Cancer diagnoses are the focus of the work by Bortfeld et al. (2008) and Sofer et al. (2003). They gave a robust optimisation formulation of the problem that generalizes

mathematical-programming formulations using clinical data.

Paltiel et al. (2004) introduced "Asthma Policy Model" as a Markov state-transition simulation to forecast asthma-related symptoms, acute exacerbations, quality-adjusted life expectancy, healthcare costs and cost effectiveness.

Finally, coronary risk prediction was studied by introducing the Logical Analysis of Data and discusses how it can be used for disease prediction.

4.2 Treatment Planning

Within Medical Therapeutics, an area that has been receiving special attention is radiation therapy. Still, several other areas of planning and intervention have been the subject of study as reflected in the papers by Paltiel et al. (2004), Lee et al. (2008) and Zenios (2004).

Recently, Holder (2004) gave a comprehensive discussion of linear- and non-linear programming models for Intensity Modulated Radiotherapy Treatment (IMRT).

IMRT, as well as three-dimensional conformal radiotherapy (3DCRT), are addressed in Ferris et al. (2004). The problems are described in quadratic, linear, piece-wise linear and non-linear formulations.

Kidney dialysis therapy initiation for evaluating cost and effectiveness is investigated in Lee et al. (2008). They used Approximate Dynamic Programming and Simulation to determine an optimal therapy and a strategy for maximizing patient welfare.

Lee and Zaider (2004) described a clinical decision support system for treatment planning in Brachytherapy and used Mixed Integer Program for optimization.

Davies and Brailsford (2004) described a simulation model for screening complications related to diabetes.

5 SPECIALIZED AND PREVENTIVE HEALTHCARE

Increase in longevity, escalating health-care costs and the emergence of new diseases in recent years have forced medical decision-makers to focus strongly on preventive and specialized measures.

5.1 Organ Donation And Transplant

Most research work on organ transplantation focuses on policies for allocating donated organs to the waiting patients, liver and especially kidney transplants being the most monitored problems.

Zenios (2002) addressed the mix of direct and indirect exchanges of organs that maximise the expected total discounted quality-adjusted life years of the candidates in the participating pairs. They developed a double-ended queuing model for an exchange system with two types of donor-candidate pairs. They found direct exchanges to be preferable. They analysed allocation, queuing and

simulation models as the core OR methodologies for medical decision making.

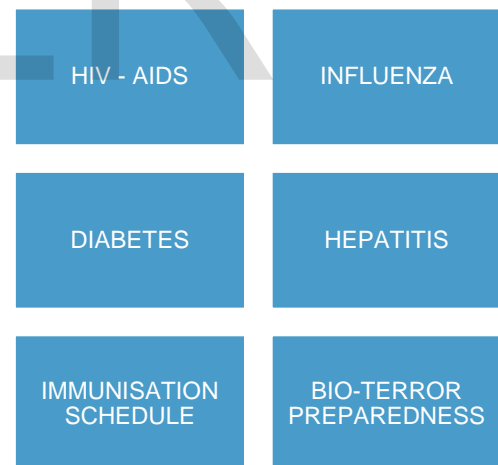
A software solution for optimising kidney pair donation based on maximum edge-weight matching algorithm is presented in Segev et al. (2005). The algorithm first constructs a graph in which each node is an incompatible donor-recipient pair and each edge is a potential match between the two connecting nodes. The graph can be constructed by entering the blood type, antibody and antigen information for each pair of nodes.

Liver transplants are analysed by Alagoz et al. (2004). They studied how to optimally time liver transplant to maximise the patient's total reward.

Shechter et al. (2005) designed a biologically based discrete-event simulation to test changes in allocation policies for liver diseases. Another simulation model which allows a comparison of different policies for allocating donor hearts on pre-transplant outcomes is presented in van den Hout et al. (2003).

5.2 Prevention Of Diseases

Optimization problems related to the prevention of diseases concern mostly vaccine selection. Sewell and Jacobson (2003) developed the vaccine selection algorithm to cover the entire immunisation schedule. They developed an integer-programming model to assess the economic premium that exists in having combination vaccines available.



Hall et al. (2008) addressed a vaccine formulary problem for generic childhood immunisation schedules. They formulated an integer-programming model to find the maximum number of vaccines that can be administered without extra-immunisation. An exact Dynamic Programming algorithm along with a randomised heuristic for the integer-programming model is developed to solve the model.

, Earnshaw et al. (2007) addressed a resource allocation problem for HIV prevention and developed a linear-programming model for improving on past allocation

strategies. Brandeau et al. (2003) used non-linear optimisation techniques combined with epidemic modelling to determine the optimal allocation of limited resources for epidemic control in multiple, non-interacting populations.

[8] <https://www.statista.com/chart/3696/the-countries-with-the-most-hospital-beds/>

6 CONCLUSION

In the last two decades, Operations Research communities have become interested in the increasing applications of OR techniques in healthcare sector. In this paper various studies undertaken in the field of OR for betterment of healthcare services have been discussed. Although OR researchers have been able to tackle a number of problems in healthcare services, there is still much scope left for improvement and research in this area.

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