



Research Paper

Applications of Optimization Techniques in Hospital Management: A Systematic Review

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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. Operations Research (OR) is gaining importance in public health interventions and programmes increasingly both nationally and internationally. As a result of which innovative operations research techniques have been developed for a wide range of healthcare applications such as operating room planning, staff scheduling in different department including emergency department also, breast cancer screening, radiotherapy treatment planning, long term care planning, home healthcare planning etc. 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 Optimization Techniques of Operations Research applications in health care with special reference to India.

Keywords: ABC analysis, Hospital management, Simulation methods, N/P hard problem, Resource allocation.

Introduction

The International Union against TB and Lung Disease (The Union) and many of its research partners define Operations research as follows:

“Research into strategies, interventions, tools or knowledge that can enhance the quality, coverage, effectiveness or performance of the health system or programme in which the research is being conducted”⁽¹⁾. Operations Research is the scientific study of operations for the purpose of making better decisions.

Definition by WHO (2003) as follows: “the use of systematic research techniques for program decision making to achieve a specific outcome.”

- C. W. Churchman, one of the pioneers of O.R. defined it as:

“The application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to problems.”

The term Operations Research was originally used in Britain during 2nd world war to connote scientific research done to integrate new radar technology into Royal Air Force tactics.

Operations Research (OR) is different from clinical or epidemiological research in that it examines the health care system rather than focusing on an individual or a group of

individuals. In addition, operations research has at its core, the goal of improvement of this system. To do this, it is necessary to identify challenges in the system and evaluate or recommend solutions. OR also starts with identifying problems or challenges in the health system, what differentiates OR from the use of routine data to drive quality improvement is that it is hypothesis driven. The hypothesis is evaluated using rigorous scientific methods that allow for analytical comparisons, so that inferences can be made about the target population and used to inform policy and practice. Operations research has been increasingly recognized as vital to the strengthening of health programmes. The true value of operations research to health programmes is not only the inclusion in global plans or the allocation of resources, but more importantly, the improvement of health via the impact of research results on programmatic and policy decisions and on practice. ⁽¹⁾

There are three primary characteristics of all Operations research viz.

- a) Optimization
- b) Simulation and
- c) Probability and statistics

Among the other methods of Operations Research we are using Optimization and Operations Research are the disciplines that deal with such problems on a scientific basis; that is, they apply scientific methods and information technology to problem solving and provide the problem owner with quantitative approaches to informed and rational decision-making

a) Optimization methods are already widely used in health care to solve problems that represent traditional applications of operations research methods, such as choosing the optimal location for new facilities or making the most efficient use of operating room capacity. The steps in an optimization process:

Structuring the problem: Specify the objective(s) and constraints, identify decision variables and parameters, and list and appraise model assumptions

Formulating the mathematical model: Present the objective function(s) and constraints in mathematical notation using decision variables and parameters.

Developing the model: Program the model in software to estimate the objective function(s) and constraints using decision variables and parameters as inputs.

Validating the model: Ensure the model is appropriate for evaluating different combinations of decision variables and parameters.

Selecting the optimization method: Choose an appropriate optimization method and algorithm on the basis of characteristics of the problem.

Performing the optimization and conducting sensitivity analysis: Use the optimization algorithm to search for the optimal solution and examine the performance of the optimal solution for reasonable sets of parameters

Reporting results: Report the results of the optimal solution and sensitivity analyses

Using the results for decision making: Interpret the optimal solution and use it for decision making.^{2.}

b) Simulation Methods: Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system.

Purpose of Simulation:

- Gaining insight in to the operation of a system
- Developing resource policies to improve system performance.
- Testing new concepts and/or systems before implementation.
- Gaining information without disturbing the actual system^{3.}

c) Probability: Probability is the measure of the likelihood that an event will occur in a Random Experiment. Probability is quantified as a number between 0 and 1, where, loosely speaking, 0 indicates impossibility and 1 indicates certainty.

The higher the probability of an event, the more likely it is that the event will occur.

Statistics: A branch of mathematics dealing with the collection, analysis, interpretation, and presentation of masses of numerical data. It is widely used in Operational research.

Health care system in India:

Health care is one of the largest industries in the developed and a developing country, 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 approximately 280 billion by the year 2020.⁴

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.⁴

There are often many different options for improving health care policy or improving current practice in health care organizations. The optimal solution among those options, i.e., the solution that best achieves a defined goal, such as maximizing patient quality of life or minimizing patient waiting time for services, may not be readily apparent. Constrained optimization methods use mathematical techniques to help efficiently and systematically identify the best (optimal) of all possible solutions to a problem while considering the relevant constraints, such as budget limits or staffing capacity.²

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. The secondary approach is carrying out primary level research.

Importance of Healthcare:

- Affects all in society
- Greying population
- More chronically ill, co-morbidity
- Increasingly advanced technology
- Expenditures growing rapidly

Scope and Opportunities of Operations Research in Healthcare sector:

Applications of OR methods to medical decision making often seek to find an optimal choice among alternatives. In medical decision making there are four commonly considered perspectives: patient, physician, third party payer, and societal. New trends in medicine will provide opportunities for the development and application of ISE methods like.

Personalized medicine

Personalized medicine, which is noted to be the future of medicine, Liebman (2007), emphasizes the customization of healthcare interventions for individual patients using each person's unique clinical, genetic, genomic, and environmental information. Personalized medicine may lead to alternative interventions for patients and therefore may require the use of advanced mathematical modelling such as large-scale optimization to choose the best intervention.

Patient behaviour

An important issue in medical decision making understands the influence of patient behaviour. One example is patient compliance to medical recommendations, which can significantly influence any recommendations about medical decisions. As World Health Organization (WHO, 2003) reports, "Adherence to therapies is a primary determinant of treatment success. Poor

adherence attenuates optimum clinical benefits and therefore reduces the overall effectiveness of health systems.” It is therefore crucial to consider the effect of poor adherence in optimizing medical decisions and tailoring clinical recommendations based on patient behaviour. This is also a potential area of application for OR methods where medical and behavioural sciences need to be integrated. In particular, there is a need to develop mathematical models that represent human behaviour to better understand its role in medical decision making.

Natural History of Disease:

Most medical decision making studies require data-driven mathematical models to represent the progression of a particular disease without any intervention, i.e., the natural history of a disease if left untreated. Because there is typically no clinical data about the natural history of diseases such as breast cancer or end stage liver diseases, it is necessary to develop and use a theoretical natural history model. In the future OR methods may provide ways to estimate natural history models.

Future Medical Interventions:

Most medical decision making studies estimate disease progression and treatment outcomes using current available treatment options, and they assume that treatment options remain constant in the future. On the other hand, medical research and development often leads to new and improved therapies, such as in HIV and organ transplantation. As a result, in some cases where innovations are anticipated in the near future ISE studies using stochastic models in medical decision making.⁵

Challenges and issues in Processes of OR in Hospital:

While working in a hospital, a hospital administrator faces different types of issues like:

- In a hospital there are staffs with different skills from a super specialty doctor to a house keeping staff and in such scenario

there are chances of conflict in between the staff.

- The major peculiarity of a hospital is that it is emergent in nature i.e. and hospital has to be ready with emergency measures to cope up in case demand increases.
- The operation theatre timings are divided into various slots according to type of surgeries, any miss scheduling in these slot may lead to loss to hospital.
- In a particular hospital there are different departments working at the same time so departmental issues may happen in hospital.
- A doctor sitting in OPD may have to leave suddenly if any emergency case arrives and in that case the OPD patients suffer.
- Overload of work to nurses may lead to poor nursing care of patients.
- Due to overload of work lack of maintenance of data by the staff.⁶

Review of Literature

B. Satheeshkumar, S. Nareshkumar, S. Kumaraghuru (2014) gave an illustration of how much a hospital need appropriate number of nursing staff to manage the continuous service to the patient by using of linear programming techniques.⁷

Manmohan Patidar, Sanjay Choudhary (2015) felt the need to solve the complex scheduling problems which plays the significant role of linear programming techniques.⁸

Woolf et al., (1968) applied PERT to a medical research project at the Hospital situated in Toronto. The researchers suggested the use of PERT technique in complex medical research work.⁹

Kwak et al., (1976) applied PERT techniques for the National Centre for Drug Analysis (United States Food and Drug Administration).¹⁰

V.R. girja, M.S. Bhat (2013) studies a paper which states that the emergency department in known as the most critical part in a hospital.¹¹

Jones (1984) proposed PERT as a potent technique for Hospital pharmacists in integration of their departmental planning process with strategic planning for the institution.¹²

Lee et al. (1999) developed an effective clinical pathway for patients with lobectomy conditions. The team met on monthly basis and proposed a clinical path on lobectomy. A total of 24 discharged patients were reviewed retrospectively. Based on these findings a critical pathway was found and initiated and the PERT/CPM was applied in 6 case.¹³

Sam Afrane Alex Appah (2014) investigates the application of queuing theory and modelling techniques to the queuing problem at the outpatient department at Anglo Gold Ashanti hospital in Obuasi, Ghana. They used a descriptive, observational as well as ex-post facto case study approach.¹⁴

Somayeh Ghazalbash Mohammad, et. all (2011) presented a mixed integer programming model to minimize Cmax as well as idle time of operating room in hospitals. The paper considers that operating room scheduling important operational challenges in most hospitals.¹⁵

Abdulrahim Shamayleh (2013) presented a simulation model to analyse a surgical theatre of a local hospital in KSA. The focus was to analyze the performance of the surgical theatre (generally) and Post Anaesthesia Care Unit (PACU) (mainly) so as to assist making decisions regarding PACU staffing. The surgical theatre consists of ten operation theatre rooms and the PACU unit with a bed capacity of fifteen beds. The results can be applied by the manager as a tool to plan and manage the Operating room and PACU.¹⁶

Rafat Mohebbifar, Edris Hasanpoor, et.all (2013) did systematic analyzing of outpatient waiting time. The paper used descriptive cross sectional study in the hospital of one of the medical universities located in the north west of Iran.¹⁷

Application of OR in different segments of Hospital Management:

a) 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. 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?⁴.

b) 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. Resources mainly include health professionals (e.g. doctors, nurses), rooms (e.g. examination rooms, operating theatres), 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.⁴

Staff Scheduling:

Physician Scheduling:

Physician scheduling is defined as assigning a physician to duty such as surgeries, clinics, scopes, calls, administration and others over time slots /shifts according to planning horizons with different types of preferences and constraints. Physician scheduling is a type of staff schedules with more complex regulation. Physician scheduling problem have two rosters planning cyclic/ ad-hoc which refer to planning period must be reconstructed because physicians may have different work rosters each week. Whereas cyclic planning refer to set models for doctors, with or without weekly rotation. However, physician

scheduling is represented by day-to-day scheduling, in which the physician is given various duties.¹⁸

Nurses Scheduling:

Nurse Rostering problem is a type of staff scheduling issues. It is defined as a procedure to organize a time table that satisfies the demand of each person without conflict. Nurse rostering is N/P hard problem which involves two steps; the first step is to determine the number of staff to be scheduled, and second step is to allocate them in the time horizon for the schedule.¹⁸

Z. L. Samantha et al they developed a three-stage approach to nurse scheduling at the community health centre. Firstly, a mixed integer linear programming (MILP) model identifies optimal weekly combinations of nurse shifts using existing total nurse hours. Secondly, staff variability heuristic accounts for weekly fluctuations in total nurse hours. Lastly, a discrete event simulation (DES) model evaluates the improvement in client-centred key performance indicators, including wait times, for the weekly optimised schedules.¹⁹

c) Medical Records Department:

The medical records department (MRD) is one of the most important sources of information about patient diseases and their treatment, and performance assessment of healthcare staff. This department facilitates using medical records in addition to protecting medical records against unauthorized disclosure.^{20, 21}. The most important tasks of MRD include supporting and protecting current and future care of the patient, official activities, continuous training programs, healthcare research, auditing and financial measures of the patients, efficiency management and risk management, service quality assurance, legal and quasi-legal requirements and all patient-related services.^{22, 23}

Other tasks include

- Patient admission processes, including registration and identification of patients

- Retrieving patient information and delivering it to authorized individuals and entities
- Patient discharge processes and completion of medical records after discharge or death of the patient
- Coding of disease and surgical procedures
- Filling patient records
- Evaluating MRD services
- Completing and reporting monthly and annual statistics
- Legal issues related to assigning patients' information to other authorities.^{24, 25}

Because of the importance of the MRD in efficiency, quantitative and qualitative evaluation and improvement of healthcare activities, the activities of this department should use scientific and standard methods.²⁶

There are many quantitative tools to assess the above items. The application of these methods help managers to understand various processes of the department completely, monitor productivity, manage staff, and control the operational costs of the MRD. They also provide solutions for solving problems. These tools include regression analysis, process statistical control, and various operational research techniques including discrete-event simulation, queue theory, linear programming, and so on²⁷⁻²⁹

According to the importance of using approaches, techniques and quantitative models for the optimal management of the MRD and health information management, this study aims to investigate the application cases of different OR techniques in the MRD and the related processes.

Used of OR techniques such as linear programming, discrete event simulation, Markov model, queuing theory, optimal state determination and DEA, and a combination of simulation and linear programming techniques, simulation and DEA for cases such as listing, scheduling and registering patients, optimizing the discharge processes, improving the performance of the MRD such as patient information retrieval,

circulating medical records, information provision to individuals, and the management of department manpower, increasing the efficiency and effectiveness of the department, facilitating performing ongoing processes and optimizing the use of the patients' electronic medical records³⁰

d) Store Room Management

With the advent of advanced Medical Technology and drugs, the expenditure on health care delivery is increasing disproportionately as compared to the resources available. Of all the inventory control systems ABC is the most suitable for medical stores. Hence the ABC method use for drug inventory in a hospital.

ABC analysis popularly known as "Always Better Control" is a very useful approach to material management based on Pareto's principle of "Vital few and trivial many" based on the capital investment of the item. According to Pareto's theory 10% items consume about 70 % of budget (Group A). The next 20% consume 20 % of financial resources (Group B) and remaining 70 % items account for just 10% of budget (Group C).³¹

Conclusion

OR is a distinctive instrument leading to greatest benefit to health system end users at lowest cost. It's worth has been well recognized both globally and nationally. Time has come to harness the potential of this research in order to realize the public health targets and goals. Concerted efforts are required from multiple partners and stakeholders to foster and galvanize OR projects in public health. Teams of academicians, policy makers, programme managers, epidemiologists, biostatisticians, community health specialists, and health economists should join hands to execute quality OR to answer public health system relevant problems and solve them timely. Translating the outcomes of the research into practice will lead to a better health system in terms of four A's. These are Accessibility, Affordability, Availability and Acceptability bridging the prevailing disparities and inequities.

The concentration of these research techniques is to always direct the program usage to accomplish best outcomes. It balances data sources and procedures required in the program cycle and endeavour to create ideal picks up in accomplishing targets and objectives. Using the tremendous scope of subjective and quantitative devices, this exploration has delivered noteworthy outcomes worth applying and testing in the genuine field. It additionally recognizes issues; regularly program chiefs incorporate in operations of public health products and test the feasible solutions for them.

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