OPERATIONS RESEARCH TECHNIQUES AND ITS' APPLICATION IN HEALTHCARE SERVICE DELIVERY DECISION MAKING: A REVIEW OF EVOLUTION

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ABSTRACT

Operations Research & its applications have made noticeable contribution in the field of healthcare since 1960. It has been used in complex decision making under uncertainty. The prime objective of this article is to the aim of this article is to identify the chronological development of the application of OR tools, techniques and various models in healthcare sector. Usage of different OR tools, techniques and its trend for optimization, planning, and decision-making are studied through a descriptive literature review of scientific papers published between 1952 and 2016. A rising pattern in the usage of operational models is observed with the predominance of resource optimization approaches and strategic decision-making for healthcare sector.

Keyword: Operations Research, OR Techniques Evolution, Healthcare Delivery.

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1. INTRODUCTION

From the beginning of the era of operations research, middle of the 20th century, Operations Research (OR) has been one of the very popular techniques for creating solutions for the many industries. One of these pertains to healthcare sector, wherein decisions are primarily identified with supply-demand balancing of assignment of resources, movement and staff booking and healthcare service-delivery planning. Many tools and techniques had been invented and applied

for getting optimal solutions for complex issues of healthcare sector. Due to complex nature of healthcare system and larger number of dynamic variables and resultant changes or advanced techniques developed for specific purposes, some tools & techniques are no longer used in the contemporary world.

2. REVIEW METHODOLOGY

A descriptive literature review was conducted on OR tools, techniques and applications a fair if not comprehensive in order to derive picture of the field in health care. The study presents evolution of OR tools in the healthcare area derived through understanding of ideas and different perspectives. Few well known specialized databases like, Science Direct, Scopus, Springer Link, and PubMed were used for eliciting publication details. Text terms related to Operations Research and Healthcare was used in order to generate publication details from time to time up to 2016.

3. LITERATURE REVIEW

Since its beginnings as a resource optimization tool, OR ventured in the health care sector, having today a significant number of applications based on quantitative models. The development of OR applications is evident from the literature reviews the focuses from 1960's when resource optimization was the main objective. As time progressed, the patients' safety key to healthcare issues attained greater importance and it develops as one of the main driving forces for the evolution of the discipline in health care. Figure 1 summarizes the evolution of problems of interest and approaches over time. These issues are discussed in detail in the following subsections.

3.1. The decade of the 1960's

Despite the patient's care and treatment was a priority, OR models had the important duty of relieving the economic effects of war on healthcare services management, consequently, focusing mainly on the optimization and correct allocation of the available resources. The need to find methods to balance OR's main objectives arose in this decade: resource use versus quality patient's attention. Flagle identified --based on his experience-- the main scenarios for the action of OR within the medical scope in the United States at that time. Reviews were divided in four sections, some approaches focused on the solutions for facility use, patient flow, resource optimization and allocation issues / problems. He also suggested orienting the development of OR in the health sector toward stochastic systems and probabilistic decision models. After a year and using similar classification, Feldstein put forward the relevance of quantitative-based decision methods and their use as support tool for decisions of the medical staff based on common sense and value judgment, which were, during inception of evolution considered as main decision tools. Among the principal applications were: medical treatment selection, medicine inventory management and monitoring, required hospitalization time determination, bed number planning and medical and nurse staff scheduling.

3.2. The decade of the 1970's

Brant E. Fries (1976) stands out for his attention and follow up with the development of OR in the health care. In his documents, Fries contributed with a list of over more than 350 references organized in 15 different medical areas of interest. Another summary for OR applications in medical and hospital issues during the 60's and part of the 70's was delivered by Papageorgiou. It concurs with Fries in some items of his classification. The author points out that use of linear programming and variable maximization and minimization functions are used.

Figure 1 Types of OR Tools Used in Publication (Decade wise)

Source: Scopus Statistics, 2016

Despite OR was consolidating as one of the most important tools for decision making and optimization in health care, Rosenhead (1978), with know-how on healthcare services' situation and development both in United States and the United Kingdom, focused his contribution on using strategic planning horizons and brought out certain the flaws in the applicability of certain decision-making tools and models. Barber (1977) also pointed certain limitation with respect to applicability of some decision-making tools. The limitation include, the need to define a sole objective for OR optimization. Secondly, problems related to accuracy and distortion about social issues its quantification and its use as input data for OR models.

3.3. The decade of the 1980's

In a selective literature review, Boldy & O'Kane (1982) also agree with Fries (1976) in part of his classification and delivered an interesting conclusion about his contribution: they observed a larger amount of OR application papers between 1970 and 1973 than in the overall scientific production of the two previous decades. Although many applications and case studies related to this topic were not included in Fries' list, the upsurge and development of OR in the health care during these years is evident. Resource planning and its optimal management has always been a key element within economic and social development. As Kemball-Cook & Wright (1981) mentioned, when considering certain cost-benefit relationships, limited resources, and lack of qualified personnel, OR seemed like a feasible tool for problem solving and decision making processes in certain "problem areas" like health care. In this review, they presented numerous application cases of this kind. However, some years after, Reynolds (1987) studied OR application in decision-making and data gathering processes for policy planning and definition of national programs in different countries on primary healthcare attention. As these are social matters from a community, the author concluded that traditional OR tools would not be very useful in some cases since countless variables –sometimes not identifiable or measurable—were involved. This also relates to Rosenhead's ideas and the issues presented by Barber. In 1987, Boldy put forward the relationship between OR models and decision support systems (DSS) in the health sector. Through the compilation of case studies and OR applications in strategic decision making, the author emphasized in DSS features posed by Sprague (1980), which he found relevant for decision making in the health sector. These were grounded on today's CDSS (Clinical Decision Support Systems) functioning.

3.4. The Decade of the 1990's

A little before and during the 90's, the optimization and productive approach of OR applications in health revolved around social aspects. The use of quantitative-based decision models for problem solving and decision making in health care was addressed by Parker. This author also made great emphasis in the relevance of applying them in developing countries. Parker suggested the use of heuristics and programming models grounded on quantitative decision models (QDMs). Moreover, he noticed that the upsurge of OR for problem solving processes of social issues or "Social OR" would not be feasible in developing countries since the value of decision making models applied was restricted and these were not applied due to the non-quantitative nature of certain problems and the limited competences of analysts, information access, and technological obstacles. This problem of the nonquantitative nature of social problems relates again to Rosenhead and Reynolds' conclusions. Later, through the collection of 286 scientific papers and case studies (which were divided in seven categories), Datta (1993) concluded that the applicability of basic OR models was feasible, mainly, in problems related to hospital management, certain diseases' control and public health. On the other hand, problems revolving around strategic planning, such as facility location, nutrition plans, and health management, would need different and more elaborated methodologies and approaches. Pierskalla & Brailer's (1994) review is mostly centered in operative and tactical applications. These authors divided their work in three main categories: design and planning of the system, operation management, and medical management. Toward the end of the decade, Royston (1998) poses the need to achieve a balance between certain aspects (planning horizon, scope, approach, complexity, etc.) in the application of OR models in the health care. In addition, this author mentions some of the most used ORMS (Operations Research and Management Science) tools, for example, scenario forecasting and analysis methods, neural networks and expert systems, simulations, and multi-criteria analysis methods. Lagergren (1998) summarizes the influence and impact of modeling approaches in the health care. This author highlights that technology improvements in hardware and software allowed, to a great extent, the creation and use of more complex models.

3.5. Beginnings of the 21st Century

In this period, and in a general way, resource management is still a high priority in the health systems management. The first decade of the 21st century witnessed the upsurge of Decision Support Systems (DSS) and the establishment of the concept of Clinical Decision Support Systems –CDSS, OR models became the force in the functioning of these computer tools and its fast development led to an assessment requirement so as to compare them to traditional medical decision-making procedures. Rais & Viana's (2010) work gathers a great amount of sources concerning OR applications in health care. Taking into account their conclusions and the high amount of sources, the study of OR development in health faces the arduous task of differentiating successful models' implementations, their advantages, disadvantages, and improvement opportunities in order to attain a general overview of the discipline's evolution, current status, and future. The scientific journals that published literature reviews related to the development of OR in the healthcare are shown in Fig. 2. In this list, the European Journal of Operational Research stands out for having the highest number of reviews. It is also important to underline that the rising levels of scientific contributions brings an upward trend in the number of specialized journals focused in the study of OR applied to health care.

4. DESCRIPTION OF THE ANALYZED SCIENTIFIC PRODUCTION

In this section, a general analysis of scientific production related to the application of Operations Research methods in the health sector is discussed. The information was selected

from the Scopus citation database. In the first place, OR influence in the health care can be estimated in a general way through the presence of keywords like “Operations Research” – “Operational Research” as well as with search terms like “Health” or “Healthcare”. The citation database reports a total of 2563 documents related to the use of OR in the health field between the years 1952 and 2016 (Fig.3). These documents were classified as follows: 1698 scientific papers, 283 review papers, 279 conference papers, and 312 documents of other types. A similar result is obtained when using the same search terms in the PubMed database (2581 documents). Approximately, a 52% of the documents indexed by Scopus were published in Medicine journals and 18.2% in Decision Science journals. Regarding the geographical origin of the publications, the United States and the United Kingdom lead the first two places in the ranking for the number of documents indexed, followed by India, Canada, and Switzerland.

4.1. Decision Trees

A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. It is one way to display an algorithm that only contains conditional control statements. Decision Tree and its applications are very popular from the decade of 1970s. The analysis of medical decisions to be taken, medical diagnosis, and identification of treatment substitutions are some of the most frequent uses for decision model. It is quite clearly visible that, total published research articles from 1970 to 2016 for, which include portion of Decision Modelling is around 4,600. There was a steady upward growth for this tool from 1970 to 2012. After 2012, there is upward spike until the year 2015.

4.2. Scheduling Models

The resource-constrained project scheduling problem (RCPSP) is a very general scheduling problem which may be used to model many applications in health care practice. Doctors, Nurses and Medical Staff are mainstream of the healthcare sector. The patient’s timely service is almost based on adequate amount of medical staff available as and when required. If in the case of overstaffing, it will add overhead cost to the healthcare industry. So, balancing between supply and demand should be required. To fulfil the supply-demand balancing requirement, scheduling models are very popular. Scopus reported about 11839 research related papers from 1960 to 2016 related with the use of scheduling tools and techniques. During the period of 2004-2008, it has noticeable amount of contribution in scheduling in healthcare.

4.3. Programming Models

Integer and Linear programming is a widely used model type that can solve decision problems with many thousands of variables. Mathematical modelling is very much useful and it is also popular for getting optimal solution for the problems which are less complex in nature for the healthcare sector. It had used linear, non-linear, dynamic and mixed modelling technique to get solution for the less complex problem to support the decision making. According to the Scopus statistics, this is the highest and frequently used tools and technique under the field Operations Research for Healthcare segment. The sudden growth in the use of the technique is noticeable from the year 2000 to 2008. Again, it has earned much popularity to solve less complex medical field related issues from 2009 to 2016.

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Figure 2 Review of Literature of OR in Healthcare Published in Scientific Journal

Source: Scopus statistics, 2016

Figure 3 Number of Papers Indexed in OR for Healthcare

Source: Scopus statistics, 2016

Figure 4 OR Tools Used in Indexed Publication

4.4. Queuing Theory

Queuing theory is the mathematical study of waiting lines, or queues. A queuing model is constructed so that queue lengths and waiting time can be predicted. It was founded by A.K.Erlang (1908). Waiting time can be considered as most crucial factor as far as patients' satisfaction is concerned. Optimization of Waiting line in order to minimize the waiting time or reducing the Queueinglength is most conducted studies around the OR community. Scopus database reported around 1052 published documents for the Queuing Theory for the time duration between 1961 and 2016. Out of all, there were about 71% research papers, 22% conference papers, and 5% review articles for healthcare industry. It is depicted from Figure 4 that, till the year 2000, there was a steady growth and afterward upward spike can be seen till 2008. From the year 2008 to 2012, there is slight upward trend for the usage of such OR technique. However, in 2016, the use of Queuing theory in research for decision making has been reduced. As compared to use of other OR techniques in healthcare, Queuing Theory is least used.

4.5. Location, Allocation, and Routing Models

Setting up location for ambulances, mobile hospitals and the concept of satellite hospitals, Location identification and routing models plays an important role. Minimum time should be the criteria in the case of medical service delivery. Heat maps are considered to be most popular technique to identify the location and routing. These routing models have not achieved much popularity or have not been widely used and accepted as seen in figure 4. This technique has similar trend as Queuing modelling.

4.6. Markov Chain Models

A Markov chain is "a stochastic model describing a sequence of possible events in which the probability of each event depends only on the state attained in the previous event". Markov Chain Models are very much new and in trend these days for healthcare segment. Generally, it had been used to manage the inventory and to reduce the waiting time for the healthcare. Since, its inception from the decade of 1990s, it has shown growth and signs of popularity in the usage for healthcare sector widely.

4.7. Discrete-Event Simulation

A discrete-event simulation (DES) models the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system. Simulation Models now a days have got much popularity in the sector of healthcare. It is basically useful for identification of What-If analysis. It allows management to run various different conditioned simulation for the identification of waiting time, resource allocation, staff required, other resources required etc. Now, there is an upward trend in the area of healthcare for the usage of simulation. Various simulation packages allow running a controlled simulation such as SIMUL8, System Dynamics etc.

5. CONCLUSIONS

There are different kinds of problems in the healthcare sector which requires having different solution using different approaches, tools and techniques. Various Operations Research methods / tools and techniques have been used to solve healthcare related issues. Some less complex requires mathematical model, on the other hand complex will have to use other modelling techniques such as, routing models, scheduling models or queuing models etc. It was

started from 1960s with basic OR Techniques and now in 2018 with simulations and Markov Chain Analysis Models to solve problems of healthcare sector. Rising numbers of publications of different approach indicates that healthcare sector has taken OR approaches very seriously in order to find out solution for various healthcare issues.

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