OR in Hospital Admission Systems: An Overview of the 20th Century

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Abstract. In this article a review of Hospital Admission Systems based upon articles published during the 20th century is presented. The past history of Operations Research as applied to the admission of patients to hospital in this period is examined and the major contributions, mainly in Great Britain and the United States, are reviewed. The usual procedure for admitting patients is highlighted and the main administrative problems associated with the admission and hospitalization of patients is identified. The sources, elements and methods employed by previous research are examined and a practical application geared by the use of the available information is described. It is hoped that this material can help the reader understand the evolution of this field over the 20th century and take a broad view on the subject. Additionally, a characterization of the documents analyzed in this paper in accordance with specific key elements is proposed.

Keywords: Operations Research · Hospital Admission Systems · Health Services · 20th century · Overview

1 Introduction

Operations Research (OR) is an exciting ground providing tools, perspectives and new ways to structure and think about theory and practice. The roots of OR in hospitals may be traced to Great Britain in the late 1940's and are related to the development of the National Health Services. The Nuffield Provincial Hospitals Trust in 1949 established a research group under the direction of L. Davies [43]. Within this activity a set of OR studies were made, frequently motivated by the need for a basis for architectural decisions – the nation faced a large hospital building program. Their first publication appeared in 1955; other pioneering studies were published by Bailey [1, 2], Welch [60] and others. It is interesting to note the influence that the organization of the nation in regions, each with its hospital board, had on research. Topics such as "Regional Planning", "Estimation of Regional Needs" and "Internal Hospital Activities" have formed branches of research.

The closest counterpart to British developments has been the passage of the Hill-Burton Act of 1954 in the United States of America. The purpose of this Act was to

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assist in the developing and carrying out comprehensive state-wide and local plans for the development of hospitals and health related facilities. The Act required States to create a planning program that would survey existing facilities and promote hospital construction plans. Hill-Burton funds have been the principal source of support for research on the organization of the health services in the United States. Research topics such as "Statistical Patterns of demand for hospital services", "Hospital facilities utilization" and "Economics of automating selected hospital activities" have formed branches of activities [33].

The first published papers are related to demand for Health Services and utilization of facilities in both the United Kingdom (UK) and the United States of America (USA). An examination of the early OR studies in Hospital Admission Systems (HAS) allows a classification of efforts according to problem areas. There is a set of problems relating to demand and utilization of facilities, from which one can trace the origin of some of the problem areas discussed in this paper. One is particularly concerned with the incidence of illness, accidents, intensity of medical care and the length of stay in hospitals. Such problems have attracted the attention of operational researchers such as Newell [40], Bailey [1], Balintfy [3], Thompson [69], Connor [16], Blumberg [11, 12] and Young [63]. To summarize, most of the early studies in Britain and the United States would be classed as queuing and flow studies and it is interesting to note that they arise from the branches of activities originated in both countries. Complex problems of probabilistic nature, sometimes dominated by systematic factors such as seasonal variation, scheduling rules and other mathematical features, have also attracted the attention of researchers.

It is possible to draw the growing interest in hospital admission systems or at least in their components from the late 1940s. One can find valuable feedback, namely the papers produced by Milsun et al. [40], Boldy [10], Stimson, [56] Murchie [41], Fries [27] and Lagergren [37]. One can also find many publications in the OR field for managing emergency services. Most of the earlier studies concentrate on management considerations and administrative issues such as the demand for services [32], service capacity [55], evacuation planning [22], and positioning of emergency vehicles [14]. Other interesting OR approaches arise from the literature. It is noticeable the appearance of soft models [48], hybrid models [64], expert systems [38] 3D data visualization [20] and interactive models [62]. Additionally, some studies have been carried out by an existing research group at the Federal University of Rio de Janeiro, most of which unknown. Among the research topics one can point out some specific issues such patient-oriented modeling of emergency admission systems [21] and 3D Visual simulation [20].

From what has already been mentioned, it can be perceived that there is a large amount of information concerning the topic. Thus, an evaluation of all these pieces of work points to the need to put together these initiatives into an integrated model. Therefore, it justifies to aggregate the information contained in all the works related to this topic and catalog it in accordance with specific key elements previously chosen.

This paper is organized as follows: In Sect. 2 the methodology of the study is presented. In Sect. 3 the results of the overview are presented and analyzed. A characterization of the analyzed manuscripts in terms of previously chosen key factors is proposed in Sect. 4 and, finally, in Sect. 5, the main conclusions are presented.

2 Methodology

The aim of this study is to analyze the main features on the concept of Hospital Admission Systems (HAS) from a series of relevant manuscripts that have been disseminated in some of the most prestigious publications during the 20th century and characterize and aggregate the information contained in these works according to pre-specified issue. One is only interested in those manuscripts that can be considered essential references in the HAS field. Therefore, a set of relevant databases and web search engines is selected, namely: Web of Science, Current Contents Connect, Inspec, and PubMed as well as Academic Research Microsoft, Periódicos CAPES and Scholar Google. Additionally, in order to increase the reading, most of the considered manuscripts in the database are written in English, being only a very small portion of them written in French and Portuguese. The sources of information required for the present research consist of a group of specialized manuscripts in the OR and Health field. It is necessary to analyze works of good quality, so that our findings will be based on research and innovation developments that are observing good value criteria.

The analysis proposed here contains publications collected in two different moments. The first moment comprises the period until 1980 and is based upon an extensive unpublished review provided by one of the authors [18]. This bibliography covers most of the published papers in the United Kingdom and United States, as well as works developed by a research group at the Federal University of Rio de Janeiro. Theoretical text books as a class have been excluded, but those closely related with HAS have been considered. The bibliography was prepared by means of a card index and about 46 contemporary periodicals were scanned for relevant articles using inter library loan services.

The second moment comprises the period 1981–1999 and encompasses references taken from scientific databases of renowned prestige, completing the selection of manuscripts with the examination at important web search engines. We opted to work with the most prestigious catalogues in the area of OR applied to Health Services, complementing them with well-known search engines.

Here, the focus goes essentially to the articles present in the databases: Web of Science, Current Contents Connect, Inspec, and PubMed as well as in the web search engines: Academic Research Microsoft, Periódicos CAPES and Scholar Google, since they contain a wide range of top journals that report research findings. We have also included some MSc and Ph.D. thesis, Journals, Conference Proceedings from Operational Research Applied to Health Services (ORAHS) meetings and few working papers; in the understanding that some quality unpublished works tend to be in this type of manuscripts.

To search for works in the context of this research, the keywords “Hospital”, “Admission” and “systems” were used. Initially, a search using these keywords in the title, abstract or keywords of manuscripts was performed. A manual search was also accomplished to detect synonyms of the above words. In the next phase, the references cited in the manuscripts obtained, as well as other items listed in the search engines, were also examined and, when appropriate, included in the platform.

After the selection of manuscripts, key issues related with the main features of HAS were assessed in all the publications. The manuscripts were carefully cataloged in a database specially designed for this purpose. During this process, the authors individually

examined the information contained in each article and the most important elements were identified. If a discrepancy in the categorization of any reviewed article was noticed reassessment was performed until a consensus was reached.

3 An Overview

According to the bibliographic study carried out by De Oliveira [18] it is possible to trace by the 1950's the growing interest in the Hospital admission problem or at least in the components of it. Sufficient interest and activity existed to justify the first Conference on OR applied to Health Services [26]. Perhaps because of the regional organization of the British Health Services the predominant topic under discussion was the estimation of regional requirement and the corresponding need for medical facilities and personnel. General discussion centered on problems of estimating hospital capacity requirements, which in turn depend upon measures of incidence of illness and hospital length of stay. With this in mind, Balintfy [3–5] considered a ward census predictor model in close correspondence to real-system behavior by formulating the problem as a Markov Process. Singer [53] developed a stochastic model of the variation of state of health of patients within a hospital.

Because of the probabilistic nature of transitions of patients from one category to another, the composition of the inpatient population displays a high degree of variability which results in corresponding fluctuations in demand on human and material resources. Using the classification scheme provided by Connor [16] an index was developed to indicate the total amount of time required for bed-site care by which nursing personnel are allocated among the hospital wards. Newell [42] analyzed the number of hospital beds to be reserved for emergency. A simple mathematical model of the demand pattern is suggested and tested against data from a hospital of London. It concluded that any emergency beds provision should take into account constant weekly and/or seasonal differences. Moreover, Gue [30] suggested a method of distributing nursing workload to the ward nursing staff. He has studied the random variation of nursing care and predicted the effect of this variation on the waiting time between each patient's care, whereas Connors [17] provided a stochastic elective admission scheduling algorithm which uses empirical data in order to measure both patient's satisfaction and hospital efficiency. Bithell [8] has studied stochastic models to evaluate the variability of the utilization of hospital resources - especially of beds, as measured by the bed occupancy. It is shown how this extended theory can be used to compute transition matrices of complicated chains and to build models accommodating daily variations which are commonly observed throughout the week.

Kolesar [36] suggests a Markovian decision model for modeling a hospital admission scheduling system which allows a great deal of flexibility in the type of service and arrival distributions used. The model aims to exercise control over the hospital census and deals with the number of scheduled admission. It enables one to obtain good decision rules which are imbedded in a linear programming formulation. Shonick [50] considers a stochastic model for the distribution of a distinctive patient facility. Related waiting list size and waiting times are also discussed. This work is extended by Shonick and Jackson [51]. Offensend [44] presents a discrete time, discrete state stochastic model to describe the dynamics of admission systems based on patient census and on nursing workload.

Thompson, Avant and Spiker [58] have studied the problem of occupancy of the maternity suite. The queuing model is constructed from analogies with previous results obtained by Bailey [1], Welsh and Bailey [61], and by Flagle [25] for intensive care units. Young [63] treats the hospital as an information servo-control system, with input and output given by the flow of patients and the state of the system given by the bed occupancy. His study recognizes the existence of both chance and controllable deterministic factors in the environment, and deals with these simultaneously in order to provide meaningful decision rules for the hospital administration.

Resh [45] has studied the problem of scheduling patients for admission to surgery and used a two stage sequence of linear and non-linear mathematical programming models with stochastic constraints and integer solutions. The first stage is concerned with the optimal kind and number of patients to admit during the scheduled horizon. The second stage is concerned with daily optimal allocation of inpatients to operating rooms. Fetter and Thompson [23] proposed a tentative two stage model of an entire general hospital involving simulation followed by linear programming. The basic data consists of the frequencies and conditional probabilities for each route followed by patients through the hospital and the time spent in the various care zones. The linear programming model then maximizes overall bed utilization, subject to cost constraints.

Kolesar [36] discussing the problem of pre-scheduling elective admissions suggests a Markovian decision model followed by linear programming. Each of the suggested problems involves the optimization over all possible stationary decision rules of a linear function of the long run state probabilities, subject to linear constraints obtained from the steady state equations of the Markov chain. A general review of this model is examined by De Oliveira [19]. This model is restricted in the planning horizon because of its Markovian assumption. Within this restriction its use is demonstrated in deriving decision rules which, via the Linear Programming component of the model, can be devised either to maximize average census level or to minimize probability of overflow.

Finarelli [24] proposes a heuristic scheduling system designed to maximize the utilization of surgical beds, while satisfying constraints on (i) the number of patients not admitted as scheduled, (ii) the utilization of the surgical suite, and (iii) the overtime and/or cancellations associated with the operation theatre. Barber [6] uses chance-constrained mathematical programming to obtain the maximum number of new elective admissions that can be scheduled for a particular day, in order to provide global long term optimization of the hospital census. Swain et al. [57] use a heuristic scheduling system to control the pattern of additional elective admissions for a certain day, which will maximize the predicted patient days in the hospital over the intervenient days, subject to a constraint on the probability that the occupancy is greater than the number of available beds.

Thompson and Fetter [59] described the use of a simulation model of the maternity suite to predict the facility requirements for any patient loads and any desired service level. A new version of this simulation appears later in the literature. It includes an out-patient clinic, a surgical pavilion and a clinical laboratory. Smith and Solomon [55] analyzes admission policies for a large specialized hospital. The objective is to select the best policy which allows the stabilization of admission rate and hospital census. Handyside and Morris [32] describe a method were data relating the length of stay and

mean admission rate can be used to simulate the admission of Emergency patients, and to predict the effect upon bed occupancy of various rotational admission policies.

Robinson, Wing and Davis [47] examine six alternative methods of scheduling elective patients taking into consideration attributes such as the desired admission dates and its flexibility, the potential length of stay in the hospital, and the demand for services. Barnoon and Wolfe [7] describe a practical method of predicting discharges and scheduling admissions in a surgical unit having almost exclusively elective patients. They examine measures such as the utilization of the unit, the idle time of the medical staff and operating theatre in periods of high demand.

Goldman and Knappenberger [29] investigate alternative priority disciplines to deal with elective surgery cases in order to obtain maximum effectiveness in the operating suite. Rikkers [46] simulates the bed utilization in a hospital with flexible boundaries between units. Blewet et al. [9] simulate the use of sharing resources between specialties. Patients are categorized according to consultant, sex and diagnosis. Hancock et al. [31] use simulation to investigate the effects of the number of beds, percentage of emergency cases and the length of stay in the performance of the admission system. A practical method is developed for predicting the current size of hospital facilities, given the expected demand.

Since it is extremely difficult to examine the admission system in all its complexity by means of analytical methods alone, an integrated model was planned by De Oliveira [19]. The aim of this model is tree-fold. Firstly, it attempts to analyse alternative scheduling policies with a more flexible lead time. Secondly, it seeks to examine possible ways of reducing the variability of the census. Thirdly, it allows examination of the response of the system to the introduction of control over variables of the model. It is shown how even partial information about patients can improve the appointment system and waiting line management. Each of these models can account for different, yet only partial features of the HAS. Nonetheless, each one sheds light into different points and complementary aspects of the admission system. An integrated information support system, which may be looked upon as a model in its own right is recommended. This system utilizes fully the information available in the data base and allows the hospital administration to benefit as much as possible from such information.

Jun et al. [35] published a survey that focus on the application of discrete event simulation to single or multi-facility health care clinics and systems of clinics. It showed that a large amount of research has been conducted concerning both patient flow and resource allocation and that simulation is particularly appropriate to approach the difficulties in this area. Smith-Daniels et al. [54] published a review of the literature on demand management strategies and capacity services until 1986. They also take a look at the applications and in healthcare. It is argued that the creation of Healthcare Organizations means that decisions about the capacity and resources are better defined, due to the clear objectives of these organizations. This review was later extended by Jack et al. [34] covering the remaining period of the 20th century. The main contribution is to synthesize research on demand management, capacity management and performance. However, there are limitations of this study because, among others, several conference papers and unpublished dissertations that are also worth to be revised are not included in the study.

Many publications in the OR field for managing emergency services can be found. Most of the earlier studies concentrate on management considerations and administrative issues such as the demand for services [32], service capacity [55], evacuation planning [22], and positioning of emergency vehicles [15]. Other interesting OR approaches also arise from the literature. It is noticeable the appearance of soft models [48], hybrid models [64], expert systems [38] 3D data visualization [20] and interactive models [62]. At the Federal University of Rio de Janeiro research involving patient-oriented modeling of emergency admission systems [21] and 3D Visual simulation [20], among others, was accomplished. Features common to these studies are long waiting times, bottlenecks in attendance, flow problems and configuration of human and material resources. The necessity of conciliate all these facets leads to the need to assemble them in an integrated model.

4 A Characterization

A model of an admission system is generally composed of a structured set of components connected together and to the environment for a particular purpose. The system boundaries are usually defined arbitrarily. The model described is, therefore, a part of reality. The model describes how the parts are organized. The dynamics describes how the parts interact. The interaction is usually performed by a method. The method generally requires quality, effectiveness and efficiency.

The system status indicates the situation in a certain instant. The most important aspects of this state should be monitored. As the system state is modified over time, these should be described in detail, including the respective statistics of the changes. The changes produced in the state of a system is generally controlled statistical pattern (historical or estimated), from which samples are taken. These patterns can be adjusted to theoretical or empirical distributions that will operate a model.

The elements to be used in the model are all those which are involved in a real system. These are the material and human resources and infrastructure. Each element has its own features, called attributes, which are fixed or variable values associated with an element along the simulation. An element can have one or more attributes. Attributes may be correlated to each other. The difference found in the attribute value can cause a change in the system state and contribute to the efficiency of the model. The time elapsed between a stimulus and a significant change of state is one of the important variables to assess the response of the model. The attribute can possibly be described numerically.

Entities are objects or people involved in the real system. Although entities are individually identifiable, they can be grouped into classes. An entity is said to be permanent when it is always present in the system. On the other hand, it is said temporary and its permanence is restricted to only part of the simulated period. Activity is a function within the system where entities remain, alone or with others, for some time causing a change in the system state. Thus, the activities can be considered as operations and/or procedures that have duration of time and require the availability of entities necessary for its development. Activity defines an active state during which one or more entities work together for a predetermined period of time. The duration of an activity is generally defined as a random variable described by a probability distribution. Specific duration of

Table 1. Percentage of articles in terms of the key elements

Key elements	Percentage		
Entities	patients 75%	nurses 12%	
Activities	admit 30%	manage 10%	
Resources	Beds 43%	Financial 10%	Surgery room 10%
Services	Emergency 45,40%	Surgery 25%	
Planning level	Regional 45%	National 41%	
Hospital Type	Acute 31%	Teaching 31%	Emergency 19%
Patient Type	Inpatient 45%	Elective 30%	Booked 16%
Performance	care 10%	capacity 10%	demand 10%
Model Type	Stochastic 20%	Discrete 20%	Decision 15%
Mathematical	Simulation 34%	Statistics 24%	Optimization 18%
Theory vs. Practice	Theoretical 86%	Practical 12%	

an activity is determined by a sampling process. By integrating research findings from across a number of different studies, this research synthesis comprehensively examines the main features on the concept of HAS addressed in all the analyzed works and making possible their characterization in accordance with the following eleven key elements.

- Entities: actors involved, namely: administrators, auxiliary personnel, doctors, nurses, patients, psychologists and technicians.
- Activities: type of actions performed, such as: admit, discharge, transfer, allocate, control, evaluate, inform, manage, monitor, plan, schedule and predict.
- Resources: like units, services, rooms, wards, beds, financial, surgery room and equipment.
- Services: such as ambulatory, emergency, surgery, intensive care, pharmacy, blood bank, radiology, tomography, laundry and X-ray.
- Planning level: political and/or geographic scope: tactical or strategic, municipal, national, regional.
- Type of Hospital: public, private, general, acute, emergency, outpatient and teaching.
- Type of Patient: booked, emergency, elective, inpatient and outpatient.
- Performance measures: accessibility, quality of care, efficiency, satisfaction, capacity, demand, work load, length of stay, utilization rate and waiting time, among others.
- Type of model: for example, stochastic, deterministic, decision, continuous, and discrete.

– OR methodology applied: for instance, Simulation, Mathematical Programming, Optimization, Queuing Theory, Stochastic Process, Statistics, and Visualization.
– Theory versus practice: Comments on theoretical and/or practical implementation of the results.

The number of references over the period in study is quite large and it had to be delimited, so that the quantity and diversity of data did not prevent to achieve one's purposes. A set of 139 publications was considered; more than 84% of the sample are articles published in scientific journals, being the PhD thesis slightly more than 9%.

All the analyzed works were gathered in a database and cataloged in accordance with the eleven attributes previously listed and described. It is interesting and important to be aware of which are the key elements and correspondent classes more referenced in the literature. Table 1 contains information concerning the most references classes for each key element. In this table, one can see that the most cited *entities* are *patients* and *nurses* (as for example in the works of [13, 15, 49, 52]), while *admission* and *management* are the two most frequent *activities* (in particular [13, 15, 28, 52]); *beds*, *financial* and *surgery room* are most referenced *resources* (like in [15, 37, 49, 52]), while *emergency* and *surgery* are the most used *services* (for instance in [13]). Most of the *planning decisions* are either *regional* or *national* (as illustrated in [49]), while *acute*, *emergency* and *teaching* hospitals are the most frequent *types of hospital* (as in [28, 39, 60]). The most mentioned *performance measures* are *care*, *capacity* and *demand* (as the case of [13, 15, 52]) being *stochastic*, *discrete* and *decision* the most used *models* in the reviewed literature (like in [19]).

Additionally, one observe that, for every ten analyzed articles, it can be found approximately thirty-five references on *performance measures*, twenty on *activities*, nine on *entities*, eight on *resources* and *services*, six on *mathematical technics*, four on the *type of patients*, three on the *type of models* and on its *possible applicability* and one on *planning level* and *hospital type.*

5 Conclusions

From this work, we can conclude that the application of OR methods to HAS has been a subject of study for many years. The first published works attempting to apply such methods to the admission problem stem from the development of the Health Services both in Britain and the United States, when a series of problems relating demand and utilization of hospital facilities were defined. The original approaches to these problems arose from analogies with similar processes occurring in industry and related areas. At first, progress was made towards a better understanding of the nature of the system, more so in identifying the best decisions. Whenever OR made a contribution it was to reveal to the hospital administration and planners the predominantly stochastic and variable nature of the admission problem.

It appears that the most suitable variable for developing the first OR models of the admission system, has been the hospital census upon which the models are based. The organization of inpatient facilities, however, is complex; it varies from hospital to hospital and involves a series of factors and additional variables, which means that the admission problems of particular hospital should often have features of their own. Thus,

although approaches have many theoretical grounds in common, they often vary since the particular circumstances of the hospital studied differ.

Most studies focus on, at least, one of three main features of the census upon which the admission policies rest, i.e. variability, prediction and census control. The stochastic models have been used mostly to study census variability and prediction. The optimization models have been used chiefly for designing admission policies and to exercise control over the census. Complex problems which may not be treated analytically have been studied experimentally through the use of simulation.

It can also be concluded that one of the biggest concerns stated in the literature is related to the performance measures and is similarly distributed mainly by the quality of care, capacity and demand. It can be perceived that activities also assume a prominent role in the literature, with the admission of patients being addressed in almost a third of all the studies, followed by management. Entities take the third place, representing approximately 10% of the total number of articles, with patients being the focus of three quarters of these manuscripts.

Because of the limited scope of the studies during the period in analysis and the complexity of the hospital environment it is noticeable that, while many models have been proposed, they appear to have had little success in their practical implementation. The authors also observe that they continue to study this issue.

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