

Operations Research on Hospital Admission Systems: a first overview of the 2005-2014 decade

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Abstract. The main characteristics of researches on Operations Research (OR) applied to Hospital Admission Systems (HAS) are described and analysed, not only in order to determine the interest of this topic and its evolution over the last decade, but also to improve our understanding on this issue. A database with information on this theme was built, considering relevant publications in OR applied to HAS, within the 2005–2014 period. The information contained in those works was catalogued in accordance with specific key elements previously chosen. Additionally, the developments on application of OR technics to HAS in the last decade are evaluated, observing what has been done, describing the related applications and procedures, and their practical implementation. The result is a review, providing a new insight on the recent enhancements of OR technics applied to HAS and trying to outline other pathways for the near future.

1. Introduction

The first applications of OR to hospitals dates from the late 1940's and are associated with the development of the National Health Services in Great Britain [42]. In the United States of America, the homologous situation happened as a consequence of Hill-Burton Act in 1946, given that the creation of a planning program that would survey existing facilities and promote hospital construction plans was required [58]. Since then, many specific topics in this theme appeared, namely "Regional Planning", "Estimation of Regional Needs" and "Hospital Activities", "Statistical Patterns of demand for hospital services", "Hospital facilities utilization", "Intensity of Medical Care", "Length of Stay in hospitals" and "Economics of automating selected hospital activities" [1], among others.

The concern with demand and resource utilization in hospitals sparked the interest in Hospital Admission Systems (HAS) or at least in their components, which has become a subject of research interest since the 1950s, both in UK and in USA. Such problems have attracted the attention of operational researchers such as Milsum [40], Bailey [5], Balintfy [6], Thompson [54], Connor [19], Blumberg [10] and Young [57].

Although it is possible to find, in the literature, valuable and interesting synthesis and reviews on the application of Operations Research (OR) technics to health care systems or to their components, namely the ones by Boldy [8], Brailsford and Vissers [11], Campbell [14], Cardoen et al. [15], De Oliveira [20], Fries [24], Günal and Pidd [28], Jack [33], Lagergren [36] and Royston [44], the authors of the present paper consider that further analysis on this subject is still needed, not only in order to provide better guidance to hospital staff, but also to provide additional information to policy makers and to all the entities involved in the health care system; moreover, due to the economic crisis framework in which the world stands now.

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The purpose of this paper is to present some of the work that has been developed concerning the theme of OR applied to HAS. An overview on the works on this theme is outlined, in order to better understand what has been done in this area, to gain insight on the future directions of this field and, thus, draw some improvements from the most recent developments. Here, we center our attention on the works developed since 2005.

The structure of the paper considers: in Section 2, the methodology of the study is presented; in Section 3, the results of this overview are described; and in Section 4, the main conclusions are presented.

2. Methodology of the study

Although some works about enhancements on OR technics applied to Health Systems have been published during the last decade, the authors opinion is that further developments and applications are still in need. The aim of this study is to analyze the main features on the concept of HAS from a series of relevant manuscripts that have been disseminated in some of the most prestigious publications in the last decade; characterize and aggregate the information contained in these works according to pre-specified issues and, finally, gather it in a database.

This literature analysis is quite large and it must be delimited, so that the quantity and diversity of data do not prevent us from achieving our purposes. Health care is an enormous field and there are many different ways of analyzing it. We should point out that we are only interested in those works 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, PubMed, Academic Research Microsoft and Scholar Google, since they contain a wide range of top journals that report research findings. Here, the focus goes essentially to specialized works in the OR and Health field published on books, journals, proceedings, as well as MSc and Ph.D. thesis and working papers, completing the selection with other relevant publications in this area. This selection was made in the understanding that published and unpublished quality works tend to be presented in this type of manuscripts, which is needed so that our findings will be based on research and innovation developments that are observing good value criteria. It is worth noting that similar process and sources of information were used by Cardoen et al. [15], Gonseth et al. [27] and Tam et al. [51], among others. 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.

We have been building a database of publications in OR applied to HAS. The information in these works was cataloged in accordance with specific key elements previously chosen taking into account the topics that have been explored in the literature over the past six decades and also the methodological approach suggested by several authors. All the works are described in terms of the following eleven key elements, which also represent the components involved in a real system:

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

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

Moreover, the developments on the application of OR technics to HAS in the last decade are evaluated, observing what has been done, describing the related applications and procedures, and exploring their practical implementation.

We carried out a manuscript search using the terms "Hospital", "Admission" and "Systems", which we feel that would be the three keywords most likely to suit our purpose. Initially, we began by performing a search using the three previous terms in the title, abstract or keywords of the analyzed manuscripts. A manual search was also performed to detect synonyms of the above expressions. 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 database. After this process, the authors examined individually the information contained in each article and the most important elements were identified. If there was a discrepancy in the categorization of articles reviewed a reassessment was performed until there was a consensus.

3. Results of the study

Regarding the last decade, about 261 new manuscripts on HAS were found in the literature, which demonstrates the interest of the researchers in this theme. Table 1 contains a summary of the inclusion/exclusion procedure, namely the total number of articles found in each one of the databases / web search engines used, the number of duplicated works and the number of articles left, after excluding the ones which did not use any OR technics. Among all the works found, our focus goes to the 90 ones which use OR technics, wherein more than 75% of them are articles published in scientific journals, slightly more than 14% are conference proceedings and between 2% and 4% correspond to working papers, Phd Thesis and Books. To reveal a wealth of new material in a succinct way would be a very difficult task, while trying to do justice to all the individual authors in such short number of pages would be impossible. Therefore, we decided to present here a synthesis on the recent progress and only describe some of the contributions of the analyzed works, mainly in terms of the most used OR technics, aiming to present a more detailed review on this topic in a near future.

Table 1. Summary of the study selection

Sources	Articles found	Duplicated	Non rejected
Academic Research Microsoft	16	3	6
Inspec	1	0	0
Pub Med	17	3	2
Scholar Google	152	4	78
Web of Science	75	9	4
TOTAL	261	19	90

During the last decade, some reviews on Health Care Systems or on their components were published. In order to acquaint the reader with the contents covered in those contributions, a brief summary is presented. Jack and Powers [33] published a review of the literature on demand management, capacity management and performance, covering the period 1986-2006 and extending the review of Smith-Daniels et al [46]. Brailsford and Vissers [11] present the development of the European Working Group “Operational Research Applied to Health Services” (ORAHS) as a platform for OR in health, analyzing papers presented at ORAHS meetings since its origin, in 1975. European healthcare systems are the focus of this review and a two-dimension framework analysis is

proposed. Developments in applying OR approaches and techniques to healthcare are described and an overview of the main application areas and challenges is presented. Royston [44] presents his personal and selective overview on OR applied to health in the UK, based on his three decades of work in this area. Developments in health and care and in OR contributions to these improvements since the creation of the National Health at UK are described; a reflection on which aspects OR analysts working in health should consider is presented; probable future developments in health and care and subsequent challenges for OR, in order to continue making a significant impact on health care are discussed. Cardoen et al. [15] present a very thorough and meticulous review of recent OR research on operating room planning and scheduling. Works on several fields that are related either to the studied problem or to the technical features are analyzed; the obtained information is structured and pooled in such a way that contributions can easily be linked to each other and compared on multiple aspects. Significant trends in research on operating room planning and scheduling are summarized, and issues and areas currently not well covered and examined are identified. Günal and Pidd [28] published a review on discrete event simulation for performance modelling in health care. They focus on the most recent publications on the topic, especially on performance modelling within hospitals; the papers are classified according to the areas of application that appear in the literature, being the apparent lack of generality and the motifs why specificity dominates discussed. They concluded that most of the reported studies are unit and /or facility specific and also that health-care simulation applications that appear in the literature attempt to provide support for better operational decision-making and planning. Hulshof et al. [29] provide an overview of the typical decisions to be made in resource capacity planning and control in health care, and a review of relevant articles from the field of Operations Research and Management Sciences for each planning decision. For each planning and control decision, not only the key papers but also the methods and techniques applied in the literature to support decision making are reviewed. Considered futures for the use of simulation as a problem solving technique within healthcare settings are proposed by Eldabi et al. [23]. Using a synthesis of trends identified by a selection of experts in the field, academics and industrialists, critical analysis is applied to find the differences between what exists and what could be created based on outlining some major themes. A preference for whole system approaches with more joined up modelling or mixed methods to tackle problems rather than single-solution-based practices was observed. Options for the use of simulation within the healthcare domain are presented.

As previously mentioned, all the works contained in “our” database are classified in accordance with the key elements described in Section 2. Table 2 contains information on the percentage of the most cited categories of each one of the considered key elements, for the 90 manuscripts under analysis.

From Table 2, it can be seen that the most cited *entities* are *patients* and *nurses* (as for example in the works [2,3,7,11,13,16,17,18,21,22,30,32,34,35,37,38,39,43,45,47,48,49,50,52,55,56] and [3,32,49,55], respectively), while *admission*, *management* and *planning* are the three most frequent *activities* (in particular [2,11,12,13,17,21,26,30,31,34,41,43,45,48,52], [2,7,11,12,13,29,30,31,37,39,45,47,48,55] and [3,9,11,12,18,25,26,29,35,39,43,45,49,53,55,56], respectively); *beds* are most referenced *resources* (like in [2,3,7,9,12,13,18,21,30,34,35,39,41,48,55]), while *emergency* and *surgery* are the two most used *services* (for instance in [7,9,13,22,30,34,37,45,48] and [16,30,34,37,38,43,47,53,56], respectively). Most of the *planning decisions* are *geographic* and either *local*, *regional* or *national* (as illustrated in [26,30], [9,48] and [2,37,55], respectively), while *general*, *acute* and *teaching* hospitals are the most frequent *types of hospital* (as in [12,26,37,48], [7,37,41,48] and [12], respectively). *Inpatient* and *elective* are the two most cited *types of patients* (as in [2,9,12,13,25,30,35,37,45,48] and [7,9,25,30,31,34,37,38,43,52,56], respectively). The most mentioned *performance measures* are *care*, *capacity*, *flow* and *efficiency/performance* (as the case of [2,7,9,11,12,13,18,22,25,26,29,30,31,32,38,39,45,47,48,52], [3,12,13,16,18,22,26,30,31,32,34,35,37,47,48] and [3,7,11,12,16,21,22,25,31,32,38,39,48,50,52,53,55,56], respectively) being *decision*, *computational* and *discrete* the most used *models* in the reviewed literature (like in [7,30,31,45,48], [2,26,45,48] and [16,18,26,32,38,47,56], respectively). Most of the mathematical technics quoted are under the scope of *simulation*,

optimization and *mathematical programming*, which represent 38%, 34% and 26% of the sample, correspondingly (for example, as in [9,11,16,18,22,32,34,35,38,41,47,49,50,53,56], [2,11,18,25,26,29,30,37,41,43,45,48,49,53,55] and [3,4,7,11,12,13,17,21,29,31,37,39,41,52], respectively), being the tests performed with real data in 22% of the cases (like in [12,16,30,45,48,49,55]).

We also observe that, for every ten analyzed articles, one can found approximately forty eight references on *performance measures*, twenty three on *activities*, fifteen on *mathematical technics*, thirteen on *entities*, eleven on *resources*, nine on *services*, seven on the *type of patients* and on the *type of models*, three on *planning level* and on the *possible applicability* and two on *hospital type*.

Table 2. The three most cited categories of each key element

Key elements	Percentages of the categories		
Entities	Patient 62%	Nurses 12%	Doctors 6%
Activities	Admission 44%	Management 39%	Planning 37%
Resources	Beds 40%	Units 11%	Financial 10%
Services	Emergency 32%	Surgery 20%	Intensive care 11%
Planning Level	Local 9%	Regional 7%	National 6%
Hospital Type	General 8%	Acute 7%	Teaching 4%
Patient Type	Inpatient 30%	Elective 21%	Booked 9%
Performance	Care 46%	Flow 41%	Efficiency/performance 40%
Model Type	Decision 17%	Computational 14%	Discrete 13%
Mathematic Technics	Simulation 38%	Optimization 34%	Mathematical Programming 26%
Theory vs. Practice	Real data 22%	Just theoretic 8%	Also implemented 6%

Our literature examination revealed many publications in OR applied to HAS during the last decade. Despite the space constraints, a brief synthesis of some of the analyzed works on OR technics applied to HAS, published in prestigious journals, will follow.

In [12], queuing theory is used to quantify the impact of targeting occupancy rate for all wards at 85%. A decision support system, based on the Erlang loss model, is used and validated. To improve hospital resource efficiency and health care service level, in [39], a multilevel integrative approach based on mathematical programming modeling and simulation analysis is proposed to the planning problem. The performance evaluation is carried out at the operational stage through simulation analysis, and a few effective operational policies are suggested and analyzed to enhance the trade-offs between resource efficiency and service level. In [13], Operations Research technics are used to describe the complexity and dynamics of emergency care chain of cardiac in-patient flow. The optimal bed allocation over the care chain, given a maximum number of refused admissions, is determined and the relation between natural variation in arrivals and length of stay and occupancy rates is analyzed, concluding that both variability in length of stay and fluctuations in arrivals result in large workload variations. Having in mind that managing hospital bed planning is difficult, due to the demand

increase and restricted hospital resources, a decision support tool based on an integer linear program for hospital bed planning is proposed in [7]. Elective and acute classes of patients are considered as well as several other constraints, namely incompatibility between pathologies, no mixed-sex rooms and continuity of care, are taken into account. A patient admission scheduling hybrid tabu search algorithm, that supports operational decisions in a hospital and automatically assigns patients to beds, is described in [21]. The algorithm not only takes into account the medical needs of the patients and their preferences, but it also keeps the number of patients in the different departments balanced. The performance of the algorithm is compared with an integer programming approach using a randomly generated data set. In [52], the impact on welfare implications of a 0-1 linear programming model to solve the operating room planning problem, taking a patient perspective, is evaluated. For a given planning period, the model determines the allocation of the operating room block times to surgical sub-specialties, i.e. the so called Master Surgical Schedule Problem, together with the subsets of elective patients to be operated on in each block time, i.e. the so called Surgical Case Assignment Problem. The model performance is verified by applying it to a real scenario; the computational results obtained indicate that the model can solve all test problems. A multi-neighborhood local search procedure to solve a healthcare problem, known as the Patient Admission Scheduling problem, is proposed in [17]. Local search is performed, lower bounds are computed and the application to the dynamic case, in which admission and discharged are not predictable in advance is proposed. Favorable results are obtained. Tactical plans allocate available resources to various care pathways and determine the selection of patients, on a particular stage of their care pathways, to be served; in [31], a method to develop a tactical resource allocation and an elective patient admission plan are proposed. A Mixed Integer Linear Programming framework is used and involves the cooperation with multiple resources, multiple time periods and multiple patient groups with various uncertain care pathways, thereby integrating decision making for a chain of hospital resources. Computational results indicate that more equitable distribution of the resources and control of patient access times, of the number of patients served and of the fraction of allocated resource capacity are obtained. A three-phase, hierarchical approach for the weekly scheduling of operating rooms is developed in [53]. The aim is to suggest an integrated way of facing surgical activity planning in order to improve overall operating theatre efficiency, in terms of overtime and throughput as well as waiting list reduction, while improving department organization; a bin packing-like problem, the blocked booking method and simulation software are used. A model for the surgery admission planning problem and a meta-heuristic algorithm for solving it are presented in [43]. The algorithm uses simple Relocate and Two-Exchange neighborhoods, governed by an iterated local search framework. The problem's search space associated with these move operators is analyzed in terms of patient waiting time, surgeon overtime, and waiting time for children in the morning on the day of surgery. Computational results for a set of benchmarks, based on the admission planning problem in a chosen hospital, are presented. Different categories of cardiothoracic surgery patients can be distinguished based on their requirement of resources; in [3], the planning problem is considered at the tactical level to generate a master surgical schedule that realizes a given target of patient throughput and optimizes an objective function for the utilization of resources. The problem was mathematically approached using mixed integer linear programming with a stochastic length of stay. Good performance on target utilization levels was obtained. With the aid of a pre-existing data-integrated simulation model to evaluate nurse-patient assignments, two policies to make nurse-to patient assignments, when new patients are admitted during a shift, are developed in [49]; in one of them, a heuristic policy assigns a newly-admitted patient to the nurse who has performed the least assigned direct care among all the nurses and, in the other, a partially-optimized policy seeks to minimize the difference in workload among nurses for the entire shift by estimating the assigned direct care. Results comparing the two policies are presented. A new method, simple to use as the ratio method while minimizing the roundabout approaches of these methods, is proposed in [41] to determine the number of acute hospital beds. The simulation of an unusual increase in admission requests had no consequence on the bed number selected, which indicates the robustness of the method; software was developed and is available for use. In [18], a

multi-stage stochastic methodology to balance inpatient bed unit utilizations in a hospital is proposed. Queuing network analysis and optimization are used to achieve balanced targets of bed unit utilization while building hospital staff involvement. Discrete event simulation is, then, used to maximize flow through the system including nonhomogeneous effects of daily and hourly peak loading, nonexponential lengths of stay, and blocking behavior. A major hospital is analyzed with the methodology and results being validated against field data. A nonhomogeneous discrete time Markov model for modeling a patient flow through the care system is presented in [26]. This model can be used for admission scheduling, resource requirement forecasting and resource allocation, in order to satisfy the demand or resource constraints or to meet the expansion or contraction plans in a hospital and community based integrated care system. It is also a useful tool for care managers and policy makers who need to make strategic management decisions. An application of the model to an elderly care system is described. In order to create an expedited patient care queue for admission to a hospital, an optimal admission threshold policy using controls on the scheduled and expedited gateways for a new Markov decision process model is characterized in [30]. A practical policy based on insight from the analytical model that yields reduced emergency blockages, cancelations, and off-unit census via simulation based on historical hospital data is presented. The lack of adequate numbers of hospital beds to accommodate the injured is a major problem in public hospitals; a dynamic system that announces the status of each bed when it changes with admission or discharge of a patient is proposed in [2] and implement national-wide to control the occupancy of beds, in order to manage cross hospital referral patient in crowded hospitals that do not have enough beds for admission patient. A national wide network for bed management, that helps to distribute injured patient in the hospitals, is provided. In [55], Markov methods, Petri net and genetic algorithms are used; development of models and the recourse to intelligent optimization for solving problems, such as improve work force efficiency and the percentage of bed occupation and also regulate shift work program, are described; cost reduction and work force planning are achieved.

4. Conclusions

In this study, we analyzed the literature on Health Admission Systems over the period 2005-2014, mainly through works published on books, journals, proceedings, as well as on MSc and Ph.D. thesis and working papers. It is important to note that, throughout this decade, an increase in the number of publications under this scope is observed, which shows the growing interest of researchers in this area.

The hospital, as provider of services for patients, has long been recognized as an obvious subject for OR Methods. Most studies focus on variability, prediction, flow and census control. The stochastic models have been used mostly to study census variability and prediction. The optimization models and mathematical programming algorithms have been applied chiefly for designing admission policies and to exercise control over the census and the flow. Complex problems which may not be treated analytically have been studied experimentally through the use of simulation. However, only a little more than a fifth of the analyzed works are based on real data and less than 6% of them were implemented in practice, which shows that there is still much to be done in this area.

Finally, we stress out that our intention was to analyze the main characteristics of the research in OR applied to HAS, an ambitious task interacting with many other fields of research, namely several health fields, economics and management. We also observe that the authors continue to study this issue extending the time horizon under consideration.

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