Chapter 1
A Taxonomy of Operations Research Studies in Healthcare Management

Serhat Tüzün and Y. Ilker Topcu

1.1 Introduction

The goal of researchers working in healthcare management is to control the rising costs and to increase accessibility for healthcare services. They try to do this by integrating the aspects of management with Operations Research (OR) techniques to determine the most efficient (or optimal) methods of providing patient care delivery (Langabeer 2007). The studies of OR in healthcare are not only about determining the methods for healthcare delivery, but also about simulating clinical systems to observe long-term risks.

Operations Research reached the stage of maturity in a very short time after it was first applied during WWII (Kirby 2003). It has been considered a discipline hard to grasp even though it spread to a wide application area. OR techniques are used to model and solve real-world problems in different areas such as production, logistics, etc. (Hillier and Lieberman 2005). Healthcare is yet another area, a relatively new one that Operations Research techniques are used in.

Healthcare is a business-like no other. Carter (2002) pointed out that it has multiple decision-makers with conflicting goals and objectives. Moreover, healthcare business has a high level of uncertainty as well as dynamic relationships among its components. Also, the managers in healthcare demand to lower the costs and increase the service quality. These aspects render management of healthcare and its operations reasonable to be studied with OR techniques.

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The objectives of OR studies in Healthcare Management are to control the costs and to improve the quality of healthcare services (Mclaughlin and Hays 2008). For the last two decades, hundreds of articles were published, special journal issues were put together, and conferences were organized. Various studies are carried out in different areas of healthcare. Some of these areas are resource allocation, scheduling, managing waiting lists, streamlining patient flows, facility location, cost-effectiveness analysis, triage in emergency services and disease treatment investigations (Pierskalla and Brailer 1994).

Although a comprehensive taxonomic classification was made by Hulshof et al. (2012), an up-to-date taxonomy is still a necessity. This chapter aims to provide a general overview of OR studies in healthcare management, using a different taxonomy approach than that of Hulshof et al. The literature has been thoroughly reviewed, and by classifying previous studies according to their preferences, a taxonomy for OR studies in healthcare management has been prepared.

1.2 OR Studies in Healthcare Management

Healthcare management research was first established in the 1930s. Although there had been some studies before, application of operations research in healthcare is accepted to have started during the 1970s. First publications were mainly about health planning and administration (Stimson and Stimson 1972; Shuman et al. 1975; Fries 1981). Later on, research areas on healthcare widely spread from top management to the smallest operation.

OR studies in healthcare management became popular during the 1990s. Using OR techniques in healthcare attracted a lot of attention in many countries and lots of studies are currently carried out (Luss and Rosenwein 1997). Many universities and research groups have shown interest in the subject. For example, McGill School of Environment (MSE) has a program called "Healthcare Operations & Information Management," directed by Vedat Verter. Although research is generally centered in the USA and Canada, a working group of Association of European Operational Research Societies (EURO) called Operational Research Applied to Health Services (ORAHS), which was initiated in 1975, provides a network for researchers involved in the application of systematic and quantitative analysis in support of planning and management in the health services sector.

There are already some bibliographic studies that organize the papers and classify them (Flagle 1962) classified the problems encountered in the area. Fries (1976) organized the papers before 1975; and the literature between 1970 and 1989 was classified by Corner and Kirkwood (1991). Also, minor classifications were made in the following years. Preater prepared a bibliography on the application of queuing theory in healthcare and medicine (2002); Cayirli and Veral reviewed the literature of outpatient scheduling in healthcare (2003); Lowery (1996) and Jun et al. (1999) investigated the simulation applications in health services. Due to these bibliographic studies, this study excludes papers published before 2000, and focuses on more recent years where the literature is building up more quickly than ever.

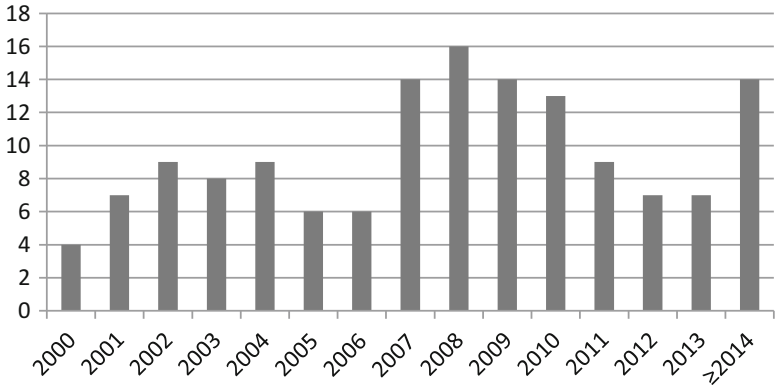

Fig. 1.1 Number of publications by years

The following keywords were used to find research papers published in the literature: healthcare operations management, healthcare management, health services, healthcare applications, health workforce planning, ambulance allocation, hospital resource allocation, outpatient scheduling, nurse–patient assignment, healthcare delivery, doctor/nurse workload, operating room planning, healthcare operations, doctor/nurse scheduling, health care production, emergency patient flow, health care services, and management decision support in the health service. The results of the search yielded over 500 articles, mainly in these journals: Annals of Operations Research, Artificial Intelligence in Medicine, Computers & Operations Research, European Journal of Operational Research, Expert Systems with Applications, Health Care Management Science, Health Policy, IIE Transactions, Interfaces, Omega, Social Science & Medicine, and Socio-Economic Planning Sciences. Before proceeding to the taxonomy, some exclusion criteria were determined in order to narrow the findings. Thus, we ended up with articles that were more related to the subject of "application of OR to healthcare management". These exclusion criteria were studies not in English, studies without models (Review papers), studies about improving treatment and diagnosis (screening, analyzing outputs, etc.), models based on probability and statistics, and models based on economic theory. As a result, 142 articles were within the criteria. Their distribution by the year of publication may be seen in Fig. 1.1.

1.3 Necessity for a Taxonomy: A Discussion

The size and growth rate of the literature demands a systematic way to classify various contributions in a manner that will vividly provide a panoramic view of what exists and will also clearly identify any existing gaps as suggested by Reisman (1992) and Reisman (1993).

Taxonomy may be defined as the science of identifying objects, and arranging them in a classification. According to Gattoufi et al. (2009), it is not only an efficient and effective tool for systematic storage as well as a tool for teaching/learning, and a tool for recalling knowledge, but it is also a neat way of pointing to knowledge expansion. It identifies voids, potential increments (or developments) in theory, and potential applications involving the existing theory. The basic motivations and uses for taxonomy may be listed as follows (Eksioglu et al. 2009):

- It defines or delimits the boundaries of a subject domain, and that is, in itself, useful information.
- It vividly, efficiently and effectively displays all of that domain's attributes/dimensions.
- It vividly, efficiently and effectively displays that any one of the possible combinations of these attributes/dimensions defines or delimits the boundaries of a subject sub-domain.
- It allows one to have a panoramic view of the entire "forest" while examining and classifying a given "tree."
- It allows one to unify disjointed and disparate subfields or sub-disciplines into a meaningful whole.
- It allows one to organize one's knowledge about the domain, and this has major implications for teaching, learning, storing, and recalling information.
- It allows one to identify voids and well explored territories in the extant literature base, which is very important for researchers, funding agencies, and other decision makers.

What is presented here is open for incremental evolution, as is the case in one of the greatest and best-known taxonomies of all time: The Periodic Table of Elements. The classification developed in this study is open to expansion when the scope of OR studies in healthcare management is enhanced, since any taxonomy is delimited with the boundaries of the universe it classifies.

OR studies in healthcare management have already generated a large enough literature to allow it to be considered as a separate and distinct field of knowledge. The increasing interest in the OR studies in healthcare management makes a systematic elaboration of this field more crucial to helping current researchers as well as attracting potential newcomers to the field.

Defining a taxonomy for OR Studies in Healthcare Management may seem to be overly detailed in terms of branching levels, as a result of trying to cover all literature in every subarea of healthcare management research. Although this detailed branching results in a taxonomy that is hard to work with, it increases its descriptive powers. Furthermore, it gives researchers the ability to aggregate sub-classifications and/or pruning outer branches easily. The taxonomy proceeds in a way illustrated by Reisman (1992), which can be seen in Fig. 1.2.

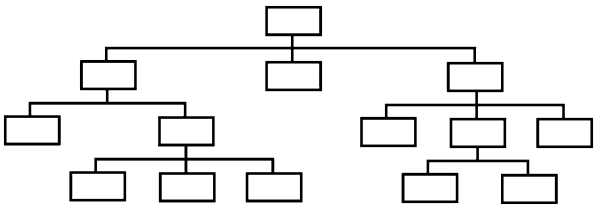

Fig. 1.2 Attribute vector description based taxonomy

1.4 A Taxonomy for OR Studies in Healthcare Management

In this section, the taxonomy for OR studies in Healthcare Management (HCM) is presented, and the main features that were considered while building it are introduced. We provide definitions as well as justifications for those main features and provide identification codes for some terms within the context of the taxonomy.

The full taxonomy is illustrated in Fig. 1.3. In the proposed taxonomy, each contribution can be given an identification code based on domains grouped in five classes:

Class 1: Study Specifications. This class shows how the study is specified. This is subdivided into three domains. The first domain describes the type of study; the second describes the source of the data used; and the third describes the type of problem treatment.

Class 2: Subject. This class shows what is analyzed. Each research paper analyzes one or more subjects. There are seven main subjects and the rest is grouped as "other".

Class 3: Methodology. This class shows the methodology used in the research. Each research paper consists of one or more methods. There are eleven main methods; and the rest is grouped as "other".

Class 4: Problem Specifications. This class shows who and what the problem is analyzed for. This is subdivided into three domains. The first domain describes the people affected by the problem; the second describes the area that the problem occurred in; and the third describes the affected facility by the problem.

Class 5: Location Specifications. This class shows where the research was carried out. The model constructed or the problem analyzed can be applied to large, medium or small scale; or it can be non-location-specific.

1.5 Results of the Taxonomy with Selected Articles

In this section, by using a group of articles which represent rather different approaches and which address different issues of OR studies in HCM, the taxonomy of Fig. 1.3 is tested for its robustness and its ability to discriminate in a rigorous manner.

1. Study Specifications
   1.1. Type of Study
      1.1.1. Model Construction using an Existing Method
      1.1.2. Model Construction using a Modified Method or Integration of Methods
      1.1.3. Method Comparison
   1.2. Data Used
      1.2.1. Real Data
      1.2.2. Both Real and Synthetic Data
   1.3. Problem Treatment
      1.3.1. Situation Analysis
      1.3.2. Decision Making (Problem Solving)
2. Subject
   2.1. Planning and Design
   2.2. Performance Measurement
   2.3. Capacity Management
   2.4. Scheduling and Assignment
   2.5. Resource/Budget Allocation
   2.6. Patient Flow and Waitlist Management
   2.7. Location
   2.8. Other
3. Methodology
   3.1. Linear/Integer Programming
   3.2. Multi Objective Programming
   3.3. Simulation
   3.4. Data Envelopment Analysis
   3.5. Queuing Theory
   3.6. System Dynamics
   3.7. Stochastic Methods
   3.8. Multi Attribute Decision Making
   3.9. Game Theory
   3.10. Bayesian Belief Network
   3.11. Artificial Neural Network
   3.12. Other
4. Problem Specifications
   4.1. Concerning People
      4.1.1. Management
      4.1.2. Doctor/Physician
      4.1.3. Nurse or Non-Medical Staff
      4.1.4. Patients
   4.2. Concerning Area
      4.2.1. Hospital/Clinic
      4.2.2. Non-hospital Organizations
      4.2.3. Public Health
   4.3. Concerning Facility
      4.3.1. Entire Clinic/Hospital
      4.3.2. Emergency Room
      4.3.3. Operating Room
      4.3.4. Ambulance
      4.3.5. Nursing Home
      4.3.6. Hospital Room
      4.3.7. Other
5. Location Specifications
   5.1. Large Scale
      5.1.1. Worldwide
      5.1.2 Continent Based
   5.2. Medium Scale
      5.2.1. Country Based
      5.2.2. State Based
   5.3. Small Scale
      5.3.1. City/Town Based
      5.3.2. Specific Location Based
   5.4. No Location Specific

Fig. 1.3 A taxonomy of OR studies in healthcare management

One hundred forty-two articles were investigated in detail to see the general idea of the researchers that contributed to the OR-in- HCM literature. In the first class, there are three domains; type of study, data used, and problem treatment. In the type of study domain, the most observed attribute is “model construction using a modified method” or “integration of methods” (1.1.2), followed by “model construction using an existing method” (1.1.1). “Comparison of methods” (1.1.3) is slightly less frequent than these two, since there are not enough studies to make a clear comparison. In data used, “usage of both real data and synthetic data” (1.2.2) is more frequent than “just using real data” (1.2.1), which can be explained by the difficulty of collecting real data as well as the highly popular usage of simulation that easily creates loads of synthetic data. For treating the problem, it is mostly “decision making” (1.3.2) rather than “situation analysis” (1.3.1). So, speaking for the study specifications, the papers mostly consisted of “decision making” with the “usage of both real and synthetic data” by “constructing a model using a modified method”.

The second and third classes are the classes that give researchers direction. It is better to interpret these two classes by looking at them together. Thus, the researcher may be able to pick the method to use for the subject he/she works on. However, first, one would need to check where previous studies have focused on. In the second class, "patient flow" and "waiting list management" (2.6) is the most researched subject. This is followed by "scheduling and assignment" (2.4), and "performance measurement" (2.2). "Resource/budget allocation" (2.5), "planning and design" (2.1), and "capacity management" (2.3) are more generalized subjects, for which researchers need to consider more factors, which means they are harder to model. Thus, they are not as attractive as the first three subjects. "Location" (2.7), and "other" (2.8) subjects have found fewer study areas than the rest, but these studies have been done mostly in recent years, which can be considered new research areas introduced to the discipline.

In class three, where methods are compared, "simulation" (3.3) is the most common method used to model in healthcare management, both alone or integrated with other methods. Simulation is mostly used to model "planning and design" (2.1), "scheduling and assignment" (2.4) and "patient flow and waiting list management" (2.6). Mathematical programming models such as "linear/integer programming" (3.1) and "multi-objective programming" (3.2) are also frequently used in order to model "scheduling and assignment" (2.4), "resource/budget allocation", (2.5) and "location" (2.7). Following common methods are "data envelopment analysis" (3.4), which is used mostly for "performance measurement" (2.2) and "stochastic methods" (3.7), mostly to model "capacity management" (2.3) problems. "Multi attribute decision making" (3.8), "game theory" (3.9) and "artificial neural networks" (3.11) are the least used methods as they have been introduced to healthcare operations management area in recent years.

Fourth class is where the problem details are explained. It includes three domains. In the first domain, concerning people, the most affected and investigated group in the papers is "management "(4.1.1). It is followed by "patients" (4.1.4), affected mostly in modeling "patient flow and waiting list management" (2.6) problems. "Doctor/physician" (4.1.2) and "nurse or non-medical staff" (4.1.3) groups are included generally in "scheduling and assignment" (2.4) problems. The second domain seeks whether the problem occurred inside or outside the hospital. Most of them are "hospital/clinic" (4.2.1) problems; the rest is "non-hospital" organizations (4.2.2) or "public health" (4.2.3). Concerning facility is the third domain in this class. Most of the studies include "the entire facility" (4.3.1). "Emergency room" (4.3.2) and "operating room" (4.3.3) are also important research areas for operations research methodology, especially for "linear/integer programming" (3.1) and "queuing theory" (3.5). "Ambulances" (4.3.4) and "nursing homes" (4.3.5) are the facilities that have been gaining importance in recent years.

The last class is the location where the research in a given paper is carried out. This resulted in "specific location based" (5.3.2) to have the highest frequency. "Country based" (5.2.1) is the second one, because researchers do research under the regulations of specific countries. "Worldwide" (5.1.1) and "continent based" (5.1.2) are the lowest location types that appear in these papers, since it is hard to construct a model that can be applied to a very large scale in a world with so many varieties.

1.6 Conclusions and Further Suggestions

Selection of papers for any taxonomy is a subjective work. The taxonomy described in this chapter tries to represent a variety of studies with different journals, different authors from different countries, differing paths to theory extension, differing application sectors and differing research strategies.

Being a new Management Science sub-discipline, the OR literature in healthcare management is growing exponentially like the other new sub-disciplines. This literature is recording advancements in theory and in solution methodology while at the same time expanding its domain of applications. When the previous bibliographic studies are compared with this taxonomy, it can be seen that new research areas are added to the discipline; new methods are used to model problems, and new approaches are applied to improve outputs. In spite of all these developments, research subjects are still divided as Fries (1976) stated; and simulation is still the most commonly utilized method to model problems as Jun et al. (1999) mentioned.

This taxonomy is formed with the motivation to determine application areas and specifications of OR studies in healthcare management as guidelines for future avenues of research. For future research, the most focused areas can be determined and the deficiencies in those areas can be satisfied with different approaches. For example, performance measurement problems are usually modeled with data envelopment analysis and from the management point of view. Therefore, using different methods or looking from a different angle, management can help eliminate the drawbacks of the previous studies. Or the least focused areas can be chosen to work on, such as performance measurement of the emergency room, which has not yet been studied. Also, with the addition of new areas as a result of the growing literature, improvements on this taxonomy can be made.

Appendix

The articles selected for the taxonomy can be seen in the following tables, with their classifications. The domains or attributes corresponding to endnodes are marked with ‘X’. Shaded columns represent domains or classes which branch, so that shading suggests why these columns are not marked. This representation scheme enables us to assign more designations in a confined space.

Table A.1 Summary of illustrative classifications of the first 70 articles (attributes 1–3.12)

	Article	1.	1.1.	1.1.1.	1.1.2.	1.1.3.	1.2.	1.2.1.	1.2.2.	1.3.	1.3.1.	1.3.2.	2.	2.1.	2.2.	2.3.	2.4.	2.5.	2.6.	2.7.	2.8.	3.	3.1.	3.2.	3.3.	3.4.	3.5.	3.6.	3.7.	3.8.	3.9.	3.10.	3.11.	3.12.
1	2000. Beaulieu et al.			x				x				x					x							x									
2	2000. Flessa			x				x			x							x						x									
3	2000. Rossetti et al.			x					x			x			x										x								
4	2000. Siddharthan et al.			x				x			x				x											x							
5	2001. Björkgren et al.			x				x			x				x			x								x							
6	2001. Congdon				x				x			x							x						x						x		
7	2001. Jacobs					x			x		x				x											x			x				
8	2001. Marshall et al.				x			x			x					x		x													x		
9	2001. Ratcliffe et al.		x						x		x							x	x						x								
10	2001. Swisher et al.				x				x		x			x											x								
11	2001. Vasilakis and El-Darzi		x						x		x					x			x						x								
12	2002. Chan et al.				x				x			x						x					x		x								
13	2002. Everett		x						x		x							x							x								
14	2002. Hofmarcher et al.		x					x			x				x											x							
15	2002. Kommer		x						x			x							x						x								
16	2002. Marshall et al.				x			x			x					x			x													x	
17	2002. Rauner		x						x		x			x				x							x								
18	2002. Rohleder and Klassen		x						x		x						x								x								
19	2002. Swisher and Jacobson		x						x			x		x	x										x								
20	2002. Verter and Lapierre		x					x				x								x			x										
21	2003. Chu et al.		x					x				x			x											x							
22	2003. De Angelis et al.				x				x		x			x									x		x								
23	2003. Flessa		x					x				x						x					x										
24	2003. Lane et al.		x					x			x								x									x					
25	2003. Mikkola et al.		x					x			x									x					x								
26	2003. Mullen					x						x					x		x														x
27	2003. Rauner and Bajmoczy				x			x				x			x								x										x
28	2003. Sendi and Al				x				x			x						x					x										
29	2004. Acid et al.					x			x		x				x																	x	
30	2004. Akkerman and Knip				x			x			x					x			x						x				x				
31	2004. Chang et al.		x					x				x			x											x							
32	2004. Grunow et al.		x					x				x					x	x					x										
33	2004. Gupta and Li		x						x			x								x			x										
34	2004. Hougaard et al.				x			x			x							x								x							
35	2004. Masterson et al.		x					x						x		x									x								
36	2004. Sibbritt and Gibberd				x				x		x										x												x
37	2004. Stummer et al.		x					x				x		x					x				x										
38	2005. Bard and Purnomo		x					x				x					x						x										
39	2005. Beynon and Kitchener				x				x			x			x															x			
40	2005. Harrison et al.				x				x		x					x									x				x				
41	2005. Koizumi et al.				x				x			x							x								x						
42	2005. Kontodimopoulos et al.		x					x			x				x											x							
43	2005. Marshall et al.					x						x				x			x						x				x				
44	2006. Aaby et. al				x				x			x		x		x									x		x						
45	2006. Akcali et al.		x						x			x				x							x										
46	2006. Bard and Purnomo				x				x			x					x						x										
47	2006. Cayirli et al.		x						x			x					x								x								
48	2006. Cochran and Bharti				x				x			x				x			x						x		x						
49	2006. Mitropoulos et al.		x						x			x								x				x									
50	2007. Aktas et al.		x						x		x							x														x	
51	2007. Anderson et al.		x						x		x										x				x								
52	2007. Cipriano et al.				x				x		x							x	x						x		x						
53	2007. de Bruin et al.		x						x		x					x			x								x						
54	2007. Denton et al.				x				x			x						x					x							x				
55	2007. Earnshaw et al.		x							x		x						x					x											
56	2007. Kopach et al.		x						x		x							x							x									
57	2007. Matta and Patterson		x					x			x				x										x									
58	2007. Molema et al.		x						x			x		x				x							x									
59	2007. Rohleder et al.		x						x			x		x														x						
60	2007. Santibáñez et al.		x					x				x					x		x				x											
61	2007. Testi et al.				x				x			x					x								x									
62	2007. VanBerkel and Blake		x						x		x					x			x						x									
63	2007. Vos et al.		x						x		x			x											x									
64	2008. Barros et al.				x				x		x				x								x											x
65	2008. Brasted		x					x				x							x						x									
66	2008. Clement et al.		x						x		x				x											x								
67	2008. Desai et al.		x						x			x		x													x						
68	2008. Dexter et al.				x				x		x										x					x								
69	2008. Goodson and Jang		x						x		x				x																	x		
70	2008. Ingolfsson et al.		x						x			x								x			x											

Table A.2 Summary of illustrative classifications of the first 70 articles (attributes 4–5.4)

	Article	4.	4.1.	4.1.1.	4.1.2.	4.1.3.	4.1.4.	4.2.	4.2.1.	4.2.2.	4.2.3.	4.3.	4.3.1.	4.3.2.	4.3.3.	4.3.4.	4.3.5.	4.3.6.	4.3.7.	5.	5.1.	5.1.1.	5.1.2.	5.2.	5.2.1.	5.2.2.	5.3.	5.3.1.	5.3.2.	5.4.
1	2000. Beaulieu et al.				x				x					x											x					
2	2000. Flessa			x							x								x			x								
3	2000. Rossetti et al.			x					x				x																	x
4	2000. Siddharthan et al.			x						x									x					x						
5	2001. Björkgren et al.			x						x			x											x						
6	2001. Congdon						x				x			x										x						
7	2001. Jacobs			x					x				x											x						
8	2001. Marshall et al.			x					x										x									x		
9	2001. Ratcliffe et al.						x			x									x									x		
10	2001. Swisher et al.			x					x				x															x		
11	2001. Vasilakis and El-Darzi						x		x									x										x		
12	2002. Chan et al.					x			x										x									x		
13	2002. Everett						x		x						x															x
14	2002. Hofmarcher et al.			x					x				x														x			
15	2002. Kommer						x				x								x					x						
16	2002. Marshall et al.			x			x		x									x										x		
17	2002. Rauner			x							x																x			
18	2002. Rohleder and Klassen						x		x										x											x
19	2002. Swisher and Jacobson			x					x				x															x		
20	2002. Verter and Lapierre			x					x				x															x		
21	2003. Chu et al.				x				x															x						
22	2003. De Angelis et al.			x					x				x											x						
23	2003. Flessa			x							x														x					
24	2003. Lane et al.						x		x					x														x		
25	2003. Mikkola et al.										x													x						
26	2003. Mullen																													x
27	2003. Rauner and Bajmoczy			x						x									x					x						
28	2003. Sendi and Al			x																										x
29	2004. Acid et al.			x					x					x														x		
30	2004. Akkerman and Knip						x		x						x									x						
31	2004. Chang et al.			x					x				x											x						
32	2004. Grunow et al.				x					x									x											x
33	2004. Gupta and Li						x			x														x						
34	2004. Hougaard et al.						x				x						x		x					x						
35	2004. Masterson et al.			x						x									x					x						
36	2004. Sibbritt and Gibberd			x					x										x									x		
37	2004. Stummer et al.			x					x				x														x			
38	2005. Bard and Purnomo					x			x				x															x		
39	2005. Beynon and Kitchener									x														x						
40	2005. Harrison et al.						x		x									x										x		
41	2005. Koizumi et al.						x		x																x					
42	2005. Kontodimopoulos et al.			x					x				x											x						
43	2005. Marshall et al.						x		x									x												x
44	2006. Aaby et. al			x							x			x													x			
45	2006. Akcali et al.						x		x									x												x
46	2006. Bard and Purnomo					x			x																					x
47	2006. Cayirli et al.				x		x		x										x									x		
48	2006. Cochran and Bharti						x		x									x						x						
49	2006. Mitropoulos et al.			x					x																x					
50	2007. Aktas et al.			x					x										x									x		
51	2007. Anderson et al.			x							x										x									
52	2007. Cipriano et al.						x		x						x										x					
53	2007. de Bruin et al.						x		x					x														x		
54	2007. Denton et al.								x						x													x		
55	2007. Earnshaw et al.			x							x														x					
56	2007. Kopach et al.				x		x		x																					x
57	2007. Matta and Patterson			x					x				x															x		
58	2007. Molema et al.			x	x				x						x				x									x		
59	2007. Rohleder et al.			x						x																		x		
60	2007. Santibáñez et al.				x		x		x						x													x		
61	2007. Testi et al.								x						x													x		
62	2007. VanBerkel and Blake						x		x						x													x		
63	2007. Vos et al.			x					x				x															x		
64	2008. Barros et al.			x					x				x											x						
65	2008. Brasted						x		x										x									x		
66	2008. Clement et al.			x					x				x											x						
67	2008. Desai et al.						x				x						x										x			
68	2008. Dexter et al.				x				x						x															x
69	2008. Goodson and Jang									x							x							x						
70	2008. Ingolfsson et al.									x						x											x			

Table A.3 Summary of illustrative classifications of the last 72 articles (attributes 1–3.12)

	Article	1.	1.1.	1.1.1.	1.1.2.	1.1.3.	1.2.	1.2.1.	1.2.2.	1.3.	1.3.1.	1.3.2.	2.	2.1.	2.2.	2.3.	2.4.	2.5.	2.6.	2.7.	2.8.	3.	3.1.	3.2.	3.3.	3.4.	3.5.	3.6.	3.7.	3.8.	3.9.	3.10.	3.11.	3.12.
71	2008. Jiang and Giachetti					x		x				x							x						x		x						
72	2008. Lim and Kirikoshi				x			x			x									x												x	
73	2008. Little and Coughlan			x				x				x						x						x									
74	2008. Mayhew and Smith			x					x		x								x								x						
75	2008. Mazur and Chen				x			x				x		x																			x
76	2008. Puenpatom and Rosenman			x				x			x				x											x							
77	2008. Sobolev et al.				x				x		x								x						x								
78	2008. Utley et al.				x			x				x				x												x					
79	2008. van de Klundert et al.				x				x			x		x									x										x
80	2009. Adan et al.				x			x				x					x	x					x					x					
81	2009. Augusto and Xie				x			x				x		x						x			x		x								
82	2009. Brunner et al.		x					x				x					x						x										
83	2009. Chand et al.				x			x				x							x						x								x
84	2009. De Grano et al.				x			x				x					x							x									
85	2009. Hare et al.				x				x		x					x												x					
86	2009. Lavieri and Puterman			x				x				x		x			x						x										
87	2009. Marjamaa et al.			x					x			x		x			x							x									
88	2009. Restrepo et al.				x				x			x						x		x			x										
89	2009. Santibáñez et al.			x				x				x						x	x						x									
90	2009. Sharma			x				x			x							x	x										x				
91	2009. Sundaramoorthi et al.				x				x		x						x								x				x				
92	2009. Testi and Tànfani			x					x			x		x									x										
93	2009. Tiwari and Heese			x					x			x		x																x			
94	2010. Blank and Valdmanis				x			x			x				x											x							
95	2010. Garg et al.				x				x		x								x									x					
96	2010. Joustra et al.				x			x				x							x				x		x								
97	2010. Kristensen et al.			x				x			x				x											x							
98	2010. Linna et al.			x				x			x				x											x							
99	2010. Mukherjee et al.			x				x			x				x											x							
100	2010. Persson and Persson			x				x				x						x		x					x								
101	2010. Rönnberg and Larsson			x				x				x						x					x										
102	2010. Sundaramoorthi et al.					x		x				x						x							x								
103	2010. Varela et al.			x				x			x				x											x							
104	2010. Yaesoubi and Roberts				x				x		x							x			x									x			
105	2010. Zhang et al.				x			x				x		x						x				x									
106	2010. Zonderland et al.				x				x			x					x		x								x		x				
107	2011a. Büyüközkan et al.				x				x			x			x														x				
108	2011. Carpenter et al.				x			x				x					x	x					x										
109	2011. Conforti et al.		x					x				x					x						x										
110	2011. Dursun et al				x			x				x		x															x				
111	2011. Garavaglia et al.				x			x			x				x											x							
112	2011. Kreng and Young		x					x				x						x															x
113	2011. Lasry et al.					x			x		x							x					x										x
114	2011. Rohleder et al.				x			x				x							x						x								
115	2012. Büyüközkan and Çifçi				x				x			x			x															x				
116	2012. Defechereux at al		x						x		x			x															x				
117	2012. Goetghebeur et al		x					x			x										x								x				
118	2012. Grigoroudis et al.		x						x			x			x															x				
119	2012. Kuo et al				x			x				x		x																			x
120	2012. Thokala and Duenas					x			x			x									x									x			
121	2012. Zhang and Huang				x				x		x			x																	x			x
122	2013. Abo-Hamad and Arisha				x			x			x				x				x						x								
123	2013. Chen et al				x				x			x									x									x			x
124	2013. Hulshof et al		x						x			x							x				x										
125	2013. Marsh et al		x						x			x		x																x			
126	2013. Özkan					x			x			x									x									x			
127	2013. Toro-Díaz et al				x				x			x						x		x												x	
128	2013. Zeng et al				x			x				x		x																x			
129	2014. Akdag et al					x			x		x				x															x			
130	2014. Amaral and Costa		x						x			x							x											x			
131	2014. Choi and Wilhelm				x				x			x					x							x									
132	2014. Lashgari et al					x			x			x				x														x			
133	2014. Mitton et al				x						x							x															x
134	2014. Robinson et al		x						x		x				x										x								
135	2014. Sun et al				x			x				x						x						x									
136	2015. Khaki et al				x				x			x								x										x			x
137	2015. Hernandez et al				x				x			x					x							x	x								
138	2015. Kanuganti et al				x				x		x									x										x			x
139	2015. Girginer et al				x				x		x				x											x								x
140	2015. Rashwan et al		x					x			x					x											x						
141	2015. McCormack and Coates				x			x				x						x							x							x	
142	2015. Xu et al					x			x		x				x											x			x				x

Table A.4 Summary of illustrative classifications of the last 72 articles (attributes 4–5.4)

	Article	4.	4.1.	4.1.1.	4.1.2.	4.1.3.	4.1.4.	4.2.	4.2.1.	4.2.2.	4.2.3.	4.3.	4.3.1.	4.3.2.	4.3.3.	4.3.4.	4.3.5.	4.3.6.	4.3.7.	5.	5.1.	5.1.1.	5.1.2.	5.2.	5.2.1.	5.2.2.	5.3.	5.3.1.	5.3.2.	5.4.
71	2008. Jiang and Giachetti						x			x									x										x
72	2008. Lim and Kirikoshi				x					x									x					x					
73	2008. Little and Coughlan			x					x										x									x	
74	2008. Mayhew and Smith			x							x			x										x					
75	2008. Mazur and Chen			x					x										x									x	
76	2008. Puenpatom and Rosenman			x					x		x		x											x					
77	2008. Sobolev et al.						x		x						x									x					
78	2008. Utley et al.			x						x								x						x					
79	2008. van de Klundert et al.			x					x						x				x										x
80	2009. Adan et al.			x					x						x													x	
81	2009. Augusto and Xie					x				x									x									x	
82	2009. Brunner et al.				x				x																			x	
83	2009. Chand et al.						x		x																			x	
84	2009. De Grano et al.								x					x														x	
85	2009. Hare et al.						x			x							x								x				
86	2009. Lavieri and Puterman					x					x														x				
87	2009. Marjamaa et al.			x	x	x			x						x													x	
88	2009. Restrepo et al.			x						x						x											x		
89	2009. Santibáñez et al.			x			x			x			x															x	
90	2009. Sharma						x		x						x									x					
91	2009. Sundaramoorthi et al.					x	x		x				x															x	
92	2009. Testi and Tànfani			x					x						x													x	
93	2009. Tiwari and Heese			x					x				x																x
94	2010. Blank and Valdmanis			x					x				x											x					
95	2010. Garg et al.						x																						x
96	2010. Joustra et al.						x		x										x									x	
97	2010. Kristensen et al.			x					x															x					
98	2010. Linna et al.			x					x		x		x									x							
99	2010. Mukherjee et al.			x							x													x					
100	2010. Persson and Persson				x		x		x						x													x	
101	2010. Rönnberg and Larsson					x			x										x									x	
102	2010. Sundaramoorthi et al.					x	x		x									x										x	
103	2010. Varela et al.			x							x														x				
104	2010. Yaesoubi and Roberts						x		x	x														x					
105	2010. Zhang et al.			x						x			x												x				
106	2010. Zonderland et al.			x			x		x						x													x	
107	2011a. Büyüközkan et al.			x					x				x														x		
108	2011. Carpenter et al.					x			x										x									x	
109	2011. Conforti et al.						x		x				x															x	
110	2011. Dursun et al			x						x									x								x		
111	2011. Garavaglia et al.			x						x						x								x					
112	2011. Kreng and Young			x							x													x					
113	2011. Lasry et al.			x						x														x					
114	2011. Rohleder et al.						x		x				x															x	
115	2012. Büyüközkan and Çifçi			x					x										x										x
116	2012. Defechereux at al			x							x													x					
117	2012. Goetghebeur et al			x						x														x					
118	2012. Grigoroudis et al.			x					x		x		x															x	
119	2012. Kuo et al						x				x						x							x					
120	2012. Thokala and Duenas			x							x													x					
121	2012. Zhang and Huang			x							x																x		
122	2013. Abo-Hamad and Arisha			x					x					x															x
123	2013. Chen et al				x				x										x									x	
124	2013. Hulshof et al			x					x				x																x
125	2013. Marsh et al			x							x													x					
126	2013. Özkan			x						x									x					x					
127	2013. Toro-Díaz et al			x					x					x															x
128	2013. Zeng et al			x							x													x					
129	2014. Akdag et al								x				x											x					
130	2014. Amaral and Costa			x					x					x														x	
131	2014. Choi and Wilhelm			x					x						x														x
132	2014. Lashgari et al			x						x			x															x	
133	2014. Mitton et al			x							x										x								
134	2014. Robinson et al			x					x				x															x	
135	2014. Sun et al						x		x					x											x				
136	2015. Khaki et al										x			x											x				
137	2015. Hernandez et al				x	x					x			x													x		
138	2015. Kanuganti et al						x		x				x												x				
139	2015. Girginer et al			x					x						x												x		
140	2015. Rashwan et al			x							x			x										x					
141	2015. McCormack and Coates						x									x											x		
142	2015. Xu et al			x					x				x														x		

References

Aaby K, Herrmann JW, Jordan CS, Treadwell M, Wood K (2006) Montgomery county's public health service uses operations research to plan emergency mass dispensing and vaccination clinics. Interfaces 36:569–579

Abo-Hamad W, Arisha A (2013) Simulation-based framework to improve patient experience in an emergency department. Eur J Oper Res 224:154–166

Acid S, de Campos LM, Fernandez-Luna JM, Rodriguez S, Rodriguez JM, Salcedo JL (2004) A comparison of learning algorithms for Bayesian networks: a case study based on data from an emergency medical service. Artif Intell Med 30:215–232

Adan I, Bekkers J, Dellaert N, Vissers J, Yu X (2009) Patient mix optimisation and stochastic resource requirements: a case study in cardiothoracic surgery planning. Health Care Manag Sci 12:129–141

Akcali E, Cote MJ, Lin C (2006) A network flow approach to optimizing hospital bed capacity decisions. Health Care Manag Sci 9:391–404

Akdag H, Kalaycı T, Karagöz S, Zülfikar H, Giz D (2014) The evaluation of hospital service quality by fuzzy MCDM. Appl Soft Comput 23:239–248

Akkerman R, Knip M (2004) Reallocation of beds to reduce waiting time for cardiac surgery. Health Care Manag Sci 7:119–126

Aktas E, Ulengin F, Sahin SO (2007) A decision support system to improve the efficiency of resource allocation in healthcare management. Socio Econ Plan Sci 41:130–146

Amaral TM, Costa APC (2014) Improving decision-making and management of hospital resources: an application of the PROMETHEE II method in an emergency department. Oper Res Health Care 3:1–6

Anderson J, Chaturvedi A, Cibulskis M (2007) Simulation tools for developing policies for complex systems: modeling the health and safety of refugee communities. Health Care Manag Sci 10:331–339

Augusto V, Xie X (2009) Redesigning pharmacy delivery processes of a health care complex. Health Care Manag Sci 12:166–178

Bard JF, Purnomo HW (2006) Incremental changes in the workforce to accommodate changes in demand. Health Care Manag Sci 9:71–85

Barros CP, de Menezes AG, Peypoch N, Solonandrasana B, Vieira JC (2008) An analysis of hospital efficiency and productivity growth using the Luenberger indicator. Health Care Manag Sci 11:373–381

Beaulieu H, Ferland JA, Gendron B, Michelon P (2000) A mathematical programming approach for scheduling physicians in emergency room. Health Care Manag Sci 3:193–200

Björkgren MA, Häkkinen U, Linna M (2001) Measuring efficiency of long-term care units in Finland. Health Care Manag Sci 4:193–200

Blank JLT, Valdmanis VG (2010) Environmental factors and productivity on Dutch hospitals: a semi-parametric approach. Health Care Manag Sci 13:27–34

Brasted C (2008) Ultrasound waiting lists: rational queue or extended capacity? Health Care Manag Sci 11:196–207

Brunner JO, Bard JF, Kolisch R (2009) Flexible shift scheduling of physicians. Health Care Manag Sci 12:285–305

Buyukozkan G, Çifçi G (2012) A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry. Expert Syst Appl 39(3):2341–2354

Büyüközkan G, Çiftçi G, Güleryüz S (2011) Strategic analysis of healthcare service quality using fuzzy AHP methodology. Expert Syst Appl 38:9407–9424

Carpenter AP, Leemis LM, Papir AS, Phillips DJ, Phillips GS (2011) Managing magnetic resonance imaging machines: support tools for scheduling and planning. Health Care Manag Sci 14:158–173

Carter M (2002) Diagnosis: mismanagement of resources. OR/MS Today 29:26–33

Cayirli T, Veral E (2003) Outpatient scheduling in health care: a review of literature. Prod Oper Manag 12:519–549

Cayirli T, Veral E, Rosen H (2006) Designing appointment scheduling systems for ambulatory care services. Health Care Manag Sci 9:47–58

Chan SY, Ohlmann J, Dunbar S, Dunbar C, Ryan S, Savory P (2002) Operations research methods applied to workflow in a medical records department. Health Care Manag Sci 5:191–199

Chand S, Moskowitz H, Norris JB, Shade S, Willis DR (2009) Improving patient flow at an outpatient clinic: study of sources of variability and improvement factors. Health Care Manag Sci 12:325–340

Chang H, Cheng MA, Das S (2004) Hospital ownership and operating efficiency: evidence from Taiwan. Eur J Oper Res 159:513–527

Chen T-Y, Chang C-H, Lu JF (2013) The extended QUALIFLEX method for multiple criteria decision analysis based on interval type-2 fuzzy sets and applications to medical decision making. Eur J Oper Res 226:615–625

Choi S, Wilhelm WE (2014) An approach to optimize block surgical schedules. Eur J Oper Res 235:138–148

Chu HL, Liu SZ, Romeis JC, Yaung CL (2003) The initial effects of physician compensation programs in Taiwan hospitals: implications for staff model HMOs. Health Care Manag Sci 6:17–26

Cipriano LE, Chesworth BM, Anderson CK, Zaric GS (2007) Predicting joint replacement waiting times. Health Care Manag Sci 10:195–215

Clement JP, Valdmanis VG, Bazzoli GJ, Zhao M, Chukmaitov A (2008) Is more better? An analysis of hospital outcomes and efficiency with a DEA model of output congestion. Health Care Manag Sci 11:67–77

Cochran JK, Bharti A (2006) Stochastic bed balancing of an obstetrics hospital. Health Care Manag Sci 9:31–45

Congdon P (2001) The development of gravity models for hospital patient flows under system change: a Bayesian modelling approach. Health Care Manag Sci 4:289–304

Conforti D, Guerriero F, Guido R, Cerinic MM, Conforti ML (2011) An optimal decision making model for supporting week hospital management. Health Care Manag Sci 14:74–88

Corner JL, Kirkwood CW (1991) Decision analysis applications in the operations research literature. Oper Res 39:206–219

De Angelis V, Felici G, Impelluso P (2003) Integrating simulation and optimisation in health care centre management. Eur J Oper Res 150:101–114

de Bruin AM, van Rossum AC, Visser MC, Koole GM (2007) Modeling the emergency cardiac in-patient flow: application of queuing theory. Health Care Manag Sci 10:125–137

De Grano ML, Medeiros DJ, Eitel D (2009) Accommodating individual preferences in nurse scheduling via auctions and optimization. Health Care Manag Sci 12:228–242

Defechereux T, Paolucci F, Mirelman A, Youngkong S, Botten G, Hagen TP, Niessen LW. Health care priority setting in Norway a multicriteria decision analysis. BMC Health Serv Res. 2012;12(39), viewed 26 Feb 2016. https://bmchealthservres.biomedcentral.com/articles/10.1186/1472-6963-12-39.

Denton B, Viapiano J, Vogl A (2007) Optimization of surgery sequencing and scheduling decisions under uncertainty. Health Care Manag Sci 10:13–24

Desai MS, Penn ML, Brailsford S, Chipulu M (2008) Modelling of Hampshire Adult Services—gearing up for future demands. Health Care Manag Sci 11:167–176

Dexter F, O'Neill L, Xin L, Ledolter J (2008) Sensitivity of super-efficient data envelopment analysis results to individual decision-making units: an example of surgical workload by specialty. Health Care Manag Sci 11:307–318

Dursun M, Karsak EE, Almula Karadayi M (2011) A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives. Expert Syst Appl 38(9):11453–11462

Earnshaw SR, Hicks K, Richter A, Honeycutt A (2007) A linear programming model for allocating HIV prevention funds with state agencies: a pilot study. Health Care Manag Sci 10:239–252

Eksioglu B, Vural V, Reisman A (2009) The vehicle routing problem: a taxonomic review. Comput Ind Eng 57:1472–1483
Everett JE (2002) A decision support simulation model for the management of an elective surgery waiting system. Health Care Manag Sci 5:89–95
Fries BE (1976) Bibliography of operations research. Oper Res 24:801–814
Fries BE (1981) Applications of operations research to health care delivery systems: a complete review of periodical literature. Springer-Verlag, Berlin
Flagle CD (1962) Operations research in the health services. The Johns Hopkins University and Hospital, Baltimore
Flessa S (2000) Where efficiency saves lives: a linear programme for optimal allocation of health care resources in developing countries. Health Care Manag Sci 3:249–267
Flessa S (2003) Priorities and allocation of health care resources in developing countries: a case-study from the Mtwara region, Tanzania. Eur J Oper Res 150:67–80
Garg L, McClean S, Meenan B, Millard P (2010) A non-homogeneous discrete time Markov model for admission scheduling and resource planning in a cost or capacity constrained healthcare system. Health Care Manag Sci 13:155–169
Garavaglia G, Lettieri E, Agasisti T, Lopez S (2011) Efficiency and quality of care in nursing homes: an Italian case study. Health Care Manag Sci 14:22–35
Gattoufi S, Oral M, Reisman A (2009) A taxonomy for data envelopment analysis. Socio Econ Plan Sci 38:141–158
Girginer N, Köse T, Uçkun N (2015) Efficiency analysis of surgical services by combined use of data envelopment analysis and gray relational analysis. J Med Syst 39:56
Goetghebeur MM, Wagner M, Khoury H, Levitt RJ, Erickson LJ, Rindress D (2012) Bridging health technology assessment (HTA) and efficient health care decision making with multicriteria decision analysis (MCDA): applying the EVIDEM framework to medicines appraisal. Med Decis Making 32:376–388
Goodson J, Jang W (2008) Assessing nursing home care quality through Bayesian networks. Health Care Manag Sci 11:382–392
Grigoroudis E, Orfanoudaki E, Zopounidis E (2012) Strategic performance measurement in a healthcare organisation: a multiple criteria approach based on balanced scorecard. Omega 40:104–119
Grunow M, Günther HO, Yang G (2004) Development of a decision support model for scheduling clinical studies and assigning medical personnel. Health Care Manag Sci 7:305–317
Gupta A, Li L (2004) A modeling framework for optimal long-term care insurance purchase decisions in retirement planning. Health Care Manag Sci 7:105–117
Hare WL, Alimadad A, Dodd H, Ferguson R, Rutherford A (2009) A deterministic model of home and community care client counts in British Columbia. Health Care Manag Sci 12:80–98
Harrison GW, Shafer A, Mackay M (2005) Modelling variability in hospital bed occupancy. Health Care Manag Sci 8:325–334
Hernandez I, Ramirez-Marquez JE, Starr D, McKay R, Guthartz S, Motherwell M, Barcellona J (2015) Optimal staffing strategies for points of dispensing. Comput Ind Eng 83:172–183
Hillier FS, Lieberman GJ (2005) Introduction to operations research, 8th. (International) edn. McGraw-Hill, Boston
Hofmarcher MM, Paterson I, Riedel M (2002) Measuring hospital efficiency in Austria – a DEA approach. Health Care Manag Sci 5:7–14
Hougaard JL, Kronborg D, Overgard C (2004) Improvement potential in Danish elderly care. Health Care Manag Sci 7:225–235
Hulshof PJH, Kortbeek N, Boucherie RJ, Hans EW, Bakker PJM (2012) Taxonomic classification of planning decisions in health care: a structured review of the state of the art in OR/MS. Health Syst 1:129–175
Hulshof PJH, Boucherie RJ, Hans EW, Hurink JL (2013) Tactical resource allocation and elective patient admission planning in care processes. Health Care Manag Sci 16:152–166
Ingolfsson A, Budge S, Erkut E (2008) Optimal ambulance location with random delays and travel times. Health Care Manag Sci 11:262–274

Jacobs R (2001) Alternative methods to examine hospital efficiency: data envelopment analysis and stochastic frontier analysis. Health Care Manag Sci 4:103–115
Jiang L, Giachetti RE (2008) A queueing network model to analyze the impact of parallelization of care on patient cycle time. Health Care Manag Sci 11:248–261
Joustra PE, de Wit J, Struben VMD, Overbeek BJH, Fockens P, Elkhuizen SG (2010) Reducing access times for an endoscopy department by an iterative combination of computer simulation and linear programming. Health Care Manag Sci 13:17–26
Jun JB, Jacobson SH, Swisher JR (1999) Application of discrete-event simulation in health care clinics: a survey. J Oper Res Soc 50:109–123
Kanuganti S, Sarkar AK, Singh AP, Arkatkar SS (2015) Quantification of accessibility to health facilities in rural areas. Case Stud Transp Policy 3:311–320
Khaki AM, Mojaradi B, Ghobadipour B, Maghsoudy S, Naghibi F (2015) Integration of GIS and analytical hierarchy process method for locating road emergency medical services station. Geosyst Eng 18(2):92–103
Kirby MW (2003) Operational research in war and peace: the British experience from the 1930s to 1970. Imperial College Press, London
Koizumo N, Kuno E, Smith TE (2005) Modeling patient flows using a queuing network with blocking. Health Care Manag Sci 8:49–60
Kommer GJ (2002) A waiting list model for residential care for the mentally disabled in the Netherlands. Health Care Manag Sci 5:285–290
Kontodimopoulos N, Nanos P, Niakas D (2006) Balancing efficiency of health services and equity of access in remote areas in Greece. Health Policy 76:49–57
Kopach R, DeLaurentis P, Lawley M, Muthuraman K, Ozsen L, Rardin R, Wan H, Intrevado P, Qu X, Willis D (2007) Effects of clinical characteristics on successful open access scheduling. Health Care Manag Sci 10:111–124
Kreng VB, Yang C-T (2011) The equality of resource allocation in health care under the National Health Insurance System in Taiwan. Health Policy 100(2):203–210
Kristensen T, Bogetoft P, Pedersen KM (2010) Potential gains from hospital mergers in Denmark. Health Care Manag Sci 13:334–345
Kuo R-J, Wu Y-H, Hsu T-S (2012) Integration of fuzzy set theory and TOPSIS into HFMEA to improve outpatient service for elderly patients in Taiwan. J Chin Med Assoc 75:341–348
Lane DC, Monefeldt C, Husemann E (2003) Client involvement in simulation model building: hints and insights from a case study in a London hospital. Health Care Manag Sci 6:105–116
Langabeer J (2007) Health care operations management: a quantitative approach to business and logistics, 1st edn. Jones and Bartlett Publishers, Sudbury
Lashgari S, Antuchevičienė J, Delavari A, Kheirkhah O (2014) Using QSPM and WASPAS methods for determining outsourcing strategies. J Bus Econ Manag 15(4):729–743
Lasry A, Sansom SL, Hicks KA, Uzunangelov V (2011) A model for allocating CDC's HIV prevention resources in the United States. Health Care Manag Sci 14:115–124
Lavieri MS, Puterman ML (2009) Optimizing nursing human resource planning in British Columbia. Health Care Manag Sci 12:119–128
Lim CW, Kirikoshi T (2008) Understanding the effects of pharmaceutical promotion: a neural network approach guided by genetic algorithm-partial least squares. Health Care Manag Sci 11:359–372
Linna M, Häkkinen U, Peltola M, Magnussen J, Anthun KJ, Kittelsen S, Roed A, Olsen K, Medin E, Rehnberg C (2010) Measuring cost efficiency in the Nordic Hospitals—a cross-sectional comparison of public hospitals in 2002. Health Care Manag Sci 13:346–357
Little J, Coughlan B (2008) Optimal inventory policy within hospital space constraints. Health Care Manag Sci 11:177–183
Lowery JC (1996) Introduction to simulation in health care. Proceedings of the 1996 Winter Simulation Conference, pp 78–84
Luss H, Rosenwein M (1997) Operations research applications: opportunities and accomplishments. Eur J Oper Res 97:220–244

Marjamaa RA, Torkki PM, Hirvensalo EJ, Kirvelä OA (2009) What is the best workflow for an operating room? A simulation study of five scenarios. Health Care Manag Sci 12:142–146
Marsh K, Dolan P, Kempster J, Lugon M (2013) Prioritizing investments in public health: a multi-criteria decision analysis. J Public Health 35(3):460–466
Marshall A, Vasilakis C, El-Darzi E (2005) Length of stay-based patient flow models: recent developments and future directions. Health Care Manag Sci 8:213–220
Marshall AH, McClean SI, Shapcott CM, Hastie IR, Millard PH (2001) Developing a Bayesian belief network for the management of geriatric hospital care. Health Care Manag Sci 4:25–30
Marshall AH, McClean SI, Shapcott CM, Millard PH (2002) Modelling patient duration of stay to facilitate resource management of geriatric hospitals. Health Care Manag Sci 5:313–319
Masterson BJ, Mihara TG, Miller G, Randolph SC, Forkner ME, Crouter AL (2004) Using models and data to support optimization of the military health system: a case study in an intensive care unit. Health Care Manag Sci 7:217–224
Matta ME, Patterson SS (2007) Evaluating multiple performance measures across several dimensions at a multi-facility outpatient center. Health Care Manag Sci 10:173–194
Mayhew L, Smith D (2008) Using queuing theory to analyse the government's 4-h completion time target in accident and emergency departments. Health Care Manag Sci 11:11–21
Mazur LM, Chen SJ (2008) Understanding and reducing the medication delivery waste via systems mapping and analysis. Health Care Manag Sci 11:55–65
McCormack R, Coates G (2015) A simulation model to enable the optimization of ambulance fleet allocation and base station location for increased patient survival. Eur J Oper Res 247:294–309
Mclaughlin DB, Hays JM (2008) Healthcare operations management. Health Administration Press, Chicago
Mikkola H, Sund R, Linna M, Häkkinen U (2003) Comparing the financial risk of bed-day and DRG based pricing types using parametric and simulation methods. Health Care Manag Sci 6:67–74
Mitropoulos P, Mitropoulos I, Giannikos I, Sissouras A (2006) A biobjective model for the locational planning of hospitals and health centers. Health Care Manag Sci 9:171–179
Mitton C, Dionne F, Donaldson C (2014) Managing healthcare budgets in times of austerity: the role of program budgeting and marginal analysis. Appl Health Econ Health Policy 12:95–102
Molema JJW, Groothuis S, Baars IJ, Kleinschiphorst M, Leers EGE, Hasman A, van Merode GG (2007) Healthcare system design and parttime working doctors. Health Care Manag Sci 10:365–371
Mukherjee K, Santerre RE, Zhang NJ (2010) Explaining the efficiency of local health departments in the U.S.: an exploratory analysis. Health Care Manag Sci 13:378–387
Mullen PM (2003) Prioritising waiting lists: how and why? Eur J Oper Res 150:32–45
Özkan A (2013) Evaluation of healthcare waste treatment/disposal alternatives by using multi-criteria decision-making techniques. Waste Manag Res 31(2):141–149
Persson MJ, Persson JA (2010) Analysing management policies for operating room planning using simulation. Health Care Manag Sci 13:182–191
Pierskalla WP, Brailer D (1994) Applications of operations research in health care delivery. In: Pollock S, Barnett A, Rothkopf M (eds) Beyond the profit motive: public sector applications and methodology, Handbooks in OR&MS, vol 6. Elsevier, North Holland, pp 469–505
Preater J (2002) Queues in health. Health Care Manag Sci 5:283
Puenpatom RA, Rosenman R (2008) Efficiency of Thai provincial public hospitals during the introduction of universal health coverage using capitation. Health Care Manag Sci 11:319–338
Rashwan W, Abo-Hamad W, Arisha A (2015) A system dynamics view of the acute bed blockage problem in the Irish healthcare system. Eur J Oper Res 247:276–293
Ratcliffe J, Young T, Buxton M, Eldabi T, Paul R, Burroughs A, Papatheodoridis G, Rolles K (2001) A simulation modelling approach to evaluating alternative policies for the management of the waiting list for liver transplantation. Health Care Manag Sci 4:117–124
Rauner MS (2002) Using simulation for AIDS policy modeling: benefits for HIV/AIDS prevention policy makers in Vienna. Health Care Manag Sci 5:121–134

Rauner MS, Bajmoczy N (2003) How many AEDs in which region? An economic decision model for the Austrian Red Cross. Eur J Oper Res 150:3–18
Reisman A (1992) Management science knowledge: it's creation generalization and consolidation. Quorum Books Publishing Company, Westport
Reisman A (1993) Operations management: time for meta research. Prospectives in operations management: essays in honor of Elwood S. Buffa. Springer, Boston, pp 471–482
Restrepo M, Henderson SG, Topaloglu H (2009) Erlang loss models for the static deployment of ambulances. Health Care Manag Sci 12:67–79
Robinson S, Worthington C, Burgess N, Radnor ZJ (2014) Facilitated modelling with discrete-event simulation: reality or myth? Eur J Oper Res 234:231–240
Rohleder TR, Bischak DP, Baskin LB (2007) Modeling patient service centers with simulation and system dynamics. Health Care Manag Sci 10:1–12
Rohleder TR, Lewkonia P, Bischak DP, Duffy P, Hendijani R (2011) Using simulation modeling to improve patient flow at an outpatient orthopedic clinic. Health Care Manag Sci 14:135–145
Rohleder TS, Klassen KJ (2002) Rolling horizon appointment scheduling: a simulation study. Health Care Manag Sci 5:201–209
Rossetti MD, Felder RA, Kumar A (2000) Simulation of robotic courier deliveries in hospital distribution services. Health Care Manag Sci 3:201–213
Rönnberg E, Larsson T (2010) Automating the self-scheduling process of nurses in Swedish healthcare: a pilot study. Health Care Manag Sci 13:35–53
Santibáñez P, Begen M, Atkins D (2007) Surgical block scheduling in a system of hospitals: an application to resource and wait list management in a British Columbia health authority. Health Care Manag Sci 10:269–282
Santibáñez P, Chow VS, French J, Puterman ML, Tyldesley S (2009) Reducing patient wait times and improving resource utilization at British Columbia Cancer Agency's ambulatory care unit through simulation. Health Care Manag Sci 12:392–407
Sendi P, Al MJ (2003) Revisiting the decision rule of cost–effectiveness analysis under certainty and uncertainty. Soc Sci Med 57:969–974
Sharma C (2009) Inter-DRG resource dynamics in a prospective payment system: a stochastic kernel approach. Health Care Manag Sci 12:38–55
Shuman J, Speas RD Jr, Young JP (1975) Operations research in health care: a critical analysis. Johns Hopkins University Press, Baltimore
Siddharthan K, Ahern M, Rosenman R (2000) Data envelopment analysis to determine efficiencies of health maintenance organizations. Health Care Manag Sci 3:23–29
Sibbritt D, Gibberd R (2004) The effective use of a summary table and decision tree methodology to analyze very large healthcare datasets. Health Care Manag Sci 7:163–171
Stimson DH, Stimson RH (1972) Operations research in hospitals: diagnosis and prognosis. Hospital Research and Educational Trust, Chicago
Sobolev B, Harel D, Vasilakis C, Levy A (2008) Using the Statecharts paradigm for simulation of patient flow in surgical care. Health Care Manag Sci 11:79–86
Stummer C, Doerner K, Focke A, Heidenberger K (2004) Determining location and size of medical departments in a hospital network: a multiobjective decision support approach. Health Care Manag Sci 7:63–71
Sun L, DePuy GW, Evans GW (2014) Multi-objective optimization models for patient allocation during a pandemic influenza outbreak. Comput Oper Res 51:350–359
Sundaramoorthi D, Chen VCP, Rosenberger JM, Kim SB, Buckley-Behan DF (2009) A data-integrated simulation model to evaluate nurse–patient assignments. Health Care Manag Sci 12:252–268
Sundaramoorthi D, Chen VCP, Rosenberger JM, Kim SB, Buckley-Behan DF (2010) A data-integrated simulation-based optimization for assigning nurses to patient admissions. Health Care Manag Sci 13:210–221
Swisher JR, Jacobson SH (2002) Evaluating the design of a family practice healthcare clinic using discrete-event simulation. Health Care Manag Sci 5:75–88

Swisher JR, Jacobson SH, Jun JB, Balci O (2001) Modeling and analyzing a physician clinic environment using discrete-event (visual) simulation. Comput Oper Res 28:105–125
Testi A, Tanfani E, Torre G (2007) A three-phase approach for operating theatre schedules. Health Care Manag Sci 10:163–172
Testi A, Tanfani E (2009) Tactical and operational decisions for operating room planning: efficiency and welfare implications. Health Care Manag Sci 12:363–373
Thokala P, Duenas A (2012) Multiple criteria decision analysis for health technology assessment. Value Health 15:1172–1181
Tiwari V, Heese HS (2009) Specialization and competition in healthcare delivery networks. Health Care Manag Sci 12:306–324
Toro-Díaz H, Mayorga ME, Chanta S, McLay LA (2013) Joint location and dispatching decisions for emergency medical services. Comput Ind Eng 64:917–928
Utley M, Jit M, Gallivan S (2008) Restructuring routine elective services to reduce overall capacity requirements within a local health economy. Health Care Manag Sci 11:240–247
van de Klundert J, Muls P, Schadd M (2008) Optimizing sterilization logistics in hospitals. Health Care Manag Sci 11:23–33
VanBerkel PT, Blake JT (2007) A comprehensive simulation for wait time reduction and capacity planning applied in general surgery. Health Care Manag Sci 10:373–385
Varela PS, de Andrade MG, Fávero LPL (2010) Production efficiency and financing of public health: an analysis of small municipalities in the state of São Paulo. Health Care Manag Sci 13:112–123
Vasilakis C, El-Darzi E (2001) A simulation study of the winter bed crisis. Health Care Manag Sci 4:31–36
Verter V, Lapierre SH (2002) Location of preventive health care facilities. Ann Oper Res 110:123–132
Vos L, Groothuis S, van Merode GG (2007) Evaluating hospital design from an operations management perspective. Health Care Manag Sci 10:357–364
Xu G-C, Zheng J, Zhou Z-J, Zhou C-K, Zhao Y (2015) Comparative study of three commonly used methods for hospital efficiency analysis in Beijing Tertiary Public Hospitals, China. Chin Med J 128(23):3185–3190
Yaesoubi R, Roberts SD (2010) A game-theoretic framework for estimating a health purchaser's willingness-to-pay for health and for expansion. Health Care Manag Sci 13:358–377
Zhang Q, Huang Y (2012) Early warning index selection and weight assignment for city significant emergency in uncertain environment. Adv Inf Sci Serv Sci 4(23):490–497
Zhang Y, Berman O, Marcotte P, Verter V (2010) A bilevel model for preventive healthcare facility network design with congestion. IIE Trans 42:865–880
Zeng Q-L, Li D-D, Yang Y-B (2013) VIKOR method with enhanced accuracy for multiple criteria decision making in healthcare management. J Med Syst 37:9908
Zonderland ME, Boucherie RJ, Litvak N, Vleggeert-Lankamp CLAM (2010) Planning and scheduling of semi-urgent surgeries. Health Care Manag Sci 13:256–267