APPLICATION OF OPERATIONS RESEARCH WITHIN THE UK HEALTHCARE CONTEXT

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ABSTRACT

Operations Research (OR) techniques enable decision makers and stakeholders to analyse and evaluate strategies for effective operations management of sophisticated systems. Healthcare systems are an example of such complex systems, and therefore it comes as no surprise that an increasing number of healthcare-focussed OR studies have been reported in literature over the years. Although several studies have profiled literature in healthcare modelling and simulation (Katsaliaki and Mustafee, 2011; Brailsford et al., 2009; Jun et al., 1999), there is currently no study that has methodologically reviewed the application of OR in healthcare. The objective of this paper, therefore, is to synthesise extant literature in healthcare OR by classifying papers based on OR technique, application category, healthcare speciality, among others. The scope of this review paper is limited to OR studies undertaken in the UK. One interesting finding of this study is that the application of OR in the UK healthcare system does not cover a wide range of OR techniques and methods; from among 70 papers that are included in this review, about 80% discuss simulation techniques. Our review also reveals that approx. 37% of the studies have employed multiple OR techniques for realising the stated objectives and that simulation is one of the methods included in these studies.

Keywords: Operations Research, Healthcare, Literature Review

1 INTRODUCTION

The application of Operations Research (OR) techniques like Simulation, Scheduling, Forecasting, Data Envelopment Analysis, Linear Programming, Statistical Quality Control Techniques, Just-In-Time, Decision Trees, Markov Chains and Soft OR (Beasley, 2011), enable stakeholders to make better and more informed decisions. The discipline of OR originated in the UK in late 1930s and ever since it has been applied for decision making in various sectors of the UK economy, including, military and industry (Rosenhead, 2009). OR has a notable and sustained contribution in UK healthcare (Royston, 2009), and indeed, “from an international perspective, unique selling points of significant strength within the British OR research agenda are so-called ‘soft OR’ and applications in healthcare” (EPSRC, 2004).

In the last three decades, OR techniques have been considered to be one of the most popular decision making and analysis tools in healthcare (Sainfort et al., 2005). Consequently, the number of published studies that have applied OR in healthcare has significantly increased over the years. Since OR is an amalgamation of several decision making techniques, a technique-based classification of this literature will serve several purposes - it will demonstrate the popularity of OR techniques as applied to healthcare, it will inform the selection of techniques based on problem context, etc. The aim of this research, therefore, is to undertake a methodological study of the extant healthcare OR literature and to present a classified, technique-based review of the existing studies. It is expected that this research will inform decision makers, academics and researchers, practitioners and all other problem stakeholders and will contribute to an increase in the awareness of the applicability of OR techniques for solving specific problems related to healthcare operations management. The scope of this study is
however limited to the UK healthcare sector. Although this can be viewed as a drawback of this study, and we acknowledge that this is indeed a limitation, we would like to present an argument that, as noted by the joint EPSRC/ESRC/ORS “Review of Research Status of OR in the UK” (EPSRC, 2004), UK has significant strengths in the application of OR in healthcare; and therefore we would expect that researchers from the UK have continued to lead this field. Thus, the studies conducted here in the UK provide us a good reference point for undertaking a review of OR in healthcare.

The rest of the paper is structured as follows. Section 2 will summarise existing studies that have reviewed literature in healthcare OR/Simulation. This is followed by a description of the research methodology (Section 3). Section 4 presents the results. This section has several sub-sections, each of which presents a categorised view of the literature, for example, Section 4.1 classifies OR studies based on OR methods, Section 4.2 presents categorisation based on application area. Section 5 is the concluding section of this paper; it reflects on the data, summarises the contribution of the paper and presents future research directions.

2 EXISTING REVIEWS ON OR APPLIED TO HEALTHCARE

The majority of literature reviews on the application of OR focus on one particular method, namely simulation. This includes the reviews by Fone et al. (2003) and Jun et al. (1999) on the application of computer simulation in modelling health care delivery; the study by Barrios et al (2008) and Brennan and Akehurst (2000) on the application of simulation techniques for analysis of the economic effectiveness of health-related products and technologies; the review of simulation in pharmacoeconomic model development conducted by Hay (2004); the review conducted by Katsaliaki and Mustafee (2011) that focused on four different simulation techniques (Agent-Based Simulation, Discrete-Event Simulation, Monte-Carlo Simulation and System Dynamics) and its application in healthcare; the review by Brailsford et al. (2009) that analysed academic literature on healthcare modelling and simulation; the review of computer simulation and patient survey studies by Dexter (1999). While some reviews focus specifically on one simulation technique, e.g., the reviews by England and Roberts (1978), Jun et al. (1999) and Barrios et al. (2008) all relate to Discrete-Event Simulation, reviews such as those by Katsaliaki and Mustafee (2011) and Brailsford et al. (2009) focus on multiple simulation techniques.

One study that closely relates to the work presented in this paper is the survey of OR in healthcare by Rais and Viana (2011). In their paper the authors present “selected” OR studies under four major categories, namely, healthcare planning, healthcare management and logistics, healthcare practice, and specialised and preventive healthcare. However, unlike our study which has an underlying literature review methodology, there is no such methodological approach in the study by Rais and Viana (2011). Our research methodology is described next.

3 RESEARCH METHODOLOGY

We have reviewed a total of 70 papers on the application of OR within the UK healthcare context. The majority of these papers are journal papers (the dataset includes only 8 conference papers) and were published between 1992 and 2011. The database that was selected for the selection of the aforementioned papers was the “ISI Web of Science®” (ISI WoS). ISI WoS is one of the largest academic databases and it includes more than 8000 international research journals with impact factors covering around 200 different categories. Figure 1 illustrates the research methodology process that has been followed in this research.
The methodology we employed for searching the ISI WoS involved two steps – (a) the search for OR papers, and (b) the search for papers related to simulation. The search included papers written in the English language within the time span of 1971 to 2011 (till August). The specific criterion (including keywords and wildcard characters) used to conduct these searches were as follows: (a) Inclusion of the words, (“health*” OR “healthcare”*) AND (“operation* research”) AND (“NHS” OR "National Health Service" OR “UK” OR “England” OR “Wales” OR “Scotland” OR “Northern Irland”) in any of the following fields - title, abstract, authors’ keywords and keywords plus; (b) Inclusion of the words, (“health*” OR “healthcare”*) AND (“simulation*”) AND (“NHS” OR "National Health Service" OR “UK” OR “England” OR “Wales” OR “Scotland” OR "Northern Irland") in any of the following fields - title, abstract, authors’ keywords and keywords plus. This two-step search process retrieved approx. 387 papers and we had to methodologically read the abstracts (in some cases we had to skim through the full-text) so as to select papers relevant for the purposes of this study. The papers were selected based on certain inclusion criterion. These were broadly similar to those used by Katsalaiki and Mustafee (2011), albeit the selection criterion in the current study related to OR and its application in the UK healthcare. Thus, for a paper to be included in our final dataset, the relationship between the selected article and the UK healthcare sector had to be clear; it had to use one or more OR techniques to describe, investigate, and examine the problem context; and it had to include a discussion on at least one OR technique that was used in the study. Following this selection process we were left with a total of 70 papers. These papers were relevant to our study since they fulfilled the aforementioned selection criterion.

The next stage involved reading the full-text of the papers with the objective of categorising the studies based on, (a) the OR methods discussed/employed, and (b) the application area. With regard to (a), the studies were classified into the following nine groups: Discrete-Event Simulation (DES); Monte Carlo Simulation (MCS); Modelling Systems (MOD); Cohort Simulation (CS); Statistical Quality Control Techniques (SQC); Scheduling (SCH); System Dynamics (SD); Forecasting (FC); and Multiple OR Techniques (MTP). In case of (b), the studies were classified under three main areas: Cost-effective and economic evaluation in healthcare (37 papers); Improving healthcare clinical and administrative performances (23 papers); and Literature and methodology review (10 papers).
Appendix-1 lists the papers categorised under OR methods. The papers have identifiers associated with them, for example, a paper under Discrete-Event Simulation category will have an identifier prefix of DES and a number (e.g., DES1). All papers are numbered in an ascending order based on their year of publication. The identifiers will be used throughout the remaining text of this paper so as to guide the readers to the appropriate study.

Our research methodology also included the design of an “Information Capture” template. The purpose of the template was to capture specific information pertaining to each of the 70 papers that were selected for the purposes of this study. The design of this template was influenced by the “RIGHT Information Template (RIT)” (Brailsford et al., 2009); however the specific fields of our template are different from RIT. Our “Information Capture” template captures eight pieces of information for each paper in this study. The descriptions of the fields are presented in Table 1 below.

<table>
<thead>
<tr>
<th>Indicator of paper (e.g., DES1)</th>
<th>Reference</th>
<th>Category</th>
<th>Healthcare specialty</th>
<th>Data</th>
<th>Region</th>
<th>Funding sources</th>
<th>Software</th>
<th>Publication year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides the reference (e.g., Smith, P. 1995. Large scale models and large scale thinking: The case of the health services. Omega, 23(2): 145-157).</td>
<td>Indicates the application area (e.g., Improving healthcare clinical and administrative performance)</td>
<td>Indicates the target areas, unit, department, patients group, and disease or treatment type (e.g., Emergency and Accident Department)</td>
<td>Source of data (e.g., Data has been collected from approximately 600 patient cards from 83 A&amp;E departments which were selected randomly over a two month period).</td>
<td>Region where the study was conducted (e.g., England, Wales, Scotland or Northern Ireland).</td>
<td>Source of funding (e.g., Research Council UK).</td>
<td>OR software used for the study (e.g., Simul8).</td>
<td>The year of publication (e.g., 2010).</td>
<td></td>
</tr>
</tbody>
</table>

4 RESULTS

In this section we present the results of our literature review. As has been mentioned earlier, we have read the full-text of the 70 articles in our dataset and have categorised them according to the OR methods employed (Section 4.1); the application areas (Section 4.2); Sources of funding (Section 4.3); UK regions (Section 4.4); Publication trends (Section 4.5); and Software packages used (Section 4.7).

4.1 OR Techniques

Nine OR techniques have been referred or used in the 70 studies included in this literature review. The list of the techniques, in order of popularity, is as follows - MTP, DES, MCS, MOD, CS, SQC, SCH, SD, and FC (see Table 2). As can be seen from the table, approx. 37% of the studies have referred to multiple OR techniques in order to achieve the stated objectives of the OR study. Combining different OR methods enables stakeholders to reduce the limitations and increase the capabilities of each technique. The findings indicate that simulation is one of the methods included in most MTP studies. One reason for this is, the stakeholders prefer to create a model and simulate the case prior to taking any decisions and making changes in their organisation. Simulation provides a cost-effective means to experiment with the system and therefore the decision makers would rather have one of the simulation techniques in addition to other OR methods in their MTP tool box.
Table 2 List of the OR techniques and the number of related papers

<table>
<thead>
<tr>
<th>OR Techniques</th>
<th>Number of Papers</th>
<th>Initial title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Multiple OR Techniques</td>
<td>26</td>
<td>MTP</td>
</tr>
<tr>
<td>2 Discrete-Event Simulation</td>
<td>18</td>
<td>DES</td>
</tr>
<tr>
<td>3 Monte-Carlo Simulation</td>
<td>11</td>
<td>MCS</td>
</tr>
<tr>
<td>4 Modelling Systems</td>
<td>10</td>
<td>MOD</td>
</tr>
<tr>
<td>5 Cohort Simulation</td>
<td>1</td>
<td>CS</td>
</tr>
<tr>
<td>6 Statistical Quality Control Techniques</td>
<td>1</td>
<td>SQC</td>
</tr>
<tr>
<td>7 Scheduling</td>
<td>1</td>
<td>SCH</td>
</tr>
<tr>
<td>8 System Dynamic</td>
<td>1</td>
<td>SD</td>
</tr>
<tr>
<td>9 Forecasting</td>
<td>1</td>
<td>FC</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>70</strong></td>
<td></td>
</tr>
</tbody>
</table>

4.2 Application areas

The data related to application area is presented under three main categories: (a) Cost-effective and economic evaluation in healthcare (27 papers), (b) Improving clinical and administrative performance (23 papers), and (c) Literature and methodology review (10 papers). Analysis of economic efficiency is a common theme among the studies, about 52% of articles refer to it directly and most of the other studies refer to it indirectly. This is expected since it can be argued that the stakeholders are always looking for cost-effective ways to solve problems related to healthcare operations management. Another important point which is noticeable in most papers is the focus of recent studies on patient/client centeredness and attendant performance approaches.

The three main categories are presented is Section 4.2.1, 4.2.2 and 4.2.3 with reference to the specific OR techniques that have been outlined in Section 4.1. So as to guide the readers to the related study, all the references used are numbered (e.g., MTP1). The list of references, together with the identifier, is included as Appendix 1.

4.2.1 Cost-effective and economic evaluation

According to our findings, 37 papers (52%) have applied OR techniques in order to form an economic evaluation and cost utility analysis in the UK healthcare system. These studies are presented below in relation to the OR technique used.

*Multiple OR Techniques (MTP)*

MTP studies under this category have mostly used OR techniques in order to evaluate the economic efficiency of new forms of treatment, to compare the cost-effectiveness of using different systems of treatment, and to analyse costs and benefits related to social health issues such as infection and communicable disease.

With respect to this category, the studies have used MTP to compare the cost-effectiveness of two kinds of treatments for attaining clinical pregnancy with assisted reproduction by incorporating the Markov decision framework and Monte-Carlo Simulation (MTP1); to compare cost effectiveness of two kinds of treatments for heavy menstrual bleeding by using Monte-Carlo Simulation and the Markov model (MTP3); to evaluate the costs and benefits of fluvastatin used for the prevention of cardiac events by applying Monte-Carlo Simulation to assess uncertainty and a Markov model (MTP4); to estimate the cost effectiveness of two different therapies for Alzheimer by using Monte-Carlo Simulation and a Markov model (MTP5); to estimate the cost-effectiveness and also clinical benefits of drotrecogin alfa for adults with severe sepsis with Markov modelling and Monte-Carlo Simulation (MTP7); for economic analysis of fluvastatin for diabetes by developing a probabilistic Markov model and estimating distributions of costs using Monte-Carlo Simulation (MTP8, 2005); for clinical and economic evaluation of endoscopic surveillance of barrett's esophagus using Monte-Carlo Simulation and Markov modelling (MTP9); to compare the cost-utility of two kinds of treatment for [more content]
atopic eczema by developing Markov state transition model and conducting probabilistic sensitivity analysis using Monte-Carlo Simulation (MTP10); for economic and clinical analysis of docetaxel for cancer treatment using Markov framework and Monte-Carlo Simulation (MTP11); for developing a life-time model and comparing the costs and benefits of two types of treatments for type 2 diabetes patients by developing a decision-analytic model by using Monte-Carlo Simulation and Markov analysis model (MTP12); to estimate the economic and cost-effectiveness of buprenorphine maintenance therapy (BMT) and methadone maintenance therapy (MMT) for managing opioid-dependents patients by Markov modelling framework and Monte-Carlo Simulation (MTP13); to evaluate cost and clinical-effectiveness of gemcitabine for breast cancer patients applying Decision Analytical Modelling technique and Markov framework (MTP14); for comparing the evaluation of cost and clinical effectiveness between two types of oral anticoagulation treatment with Markov modelling and Monte-Carlo Simulation (MTP15); for comparative evaluation of CRT clinical and cost-effectiveness for patients with heart failure using Discrete-Event Simulation and Markov modelling (MTP16); to compare new and traditional types of treatment for children with ADHD using a Markov model and Monte-Carlo Simulation (MTP19); to compare the economic efficiency of using different types of treatments for patients with heart failure using Markov Chain and Monte-Carlo Simulation (MTP20); to estimate the costs and benefits of treatment for patients with saphenous varicose vein using a Markov framework and Monte-Carlo Simulation (MTP24); for cost-effective analysis and modelling of occupancy time in the NHS using Forecasting and Length of stay (LOS) modelling techniques (MTP25); and to evaluate the economic efficiency of using new types of treatment for patients with heart failure using Markov modelling and Monte-Carlo Simulation (MTP26).

Discrete-Event Simulation (DES)
With respect to this category, studies have used DES to evaluate the direct and indirect societal costs of schizophrenia patients in the UK (DES1); for comparative study on cost-effectiveness of two types of treatments for women diagnosed with breast cancer (DES3); to estimate the cost-effectiveness and cost utility of two different postsurgical methods for renal transplant recipients (DES6); for comparative evaluation of cost utility between two rejected prevention methods for renal transplantation patients (DES9); to estimate the cost-effectiveness of two types of treatments for diabetes patients (DES14); and to evaluate the donepezil’s cost effectiveness for Alzheimer’s disease in UK (DES16).

Monte Carlo Simulation (MCS)
In this category, studies have mostly used MCS in order to evaluate the economic efficiency of a new method or technology for treatment, for undertaking an economic comparative study between two different systems or ways of treatments, or for performing cost-effective analysis of infection and communicable disease. MCS has been applied to compare and analyse the cost utility of two way of treatments or using new treatment methods for patients with breast cancer (MCS1;MCS4;MCS6); to evaluate the most economical way for coping with public health issues, such as the administration of universal vaccination or influenza infection (MCS2;MCS5); to estimate the cost-effectiveness of using new treatments for patients with metabolism disorders, and for diabetes and rheumatoid arthritis (MCS3;MCS7;MCS9;MCS10). The results show that about 70% of MTP studies have used or discussed MCS and Markov modelling frameworks, so it can be argued that Monte-Carlo Simulation is the most referred OR technique for economic evaluation cases.

Modelling Systems (MOD)
The nature of the studies in this category is based on developing models including: Mathematical or logical models, and Physical scheme. According to the findings, the papers included in the present research have applied MOD in order to develop a model to evaluate the cost and medical effectiveness of using new treatments for different diseases (MOD7;MOD10).
Cohort Simulation (CS)
Cohort Simulation (CS) is used in clinical and social studies for groups of individuals. CS helps to find correlations among the risk factors, assuming that the conformation of the population target under survey does not change over time (Doll, 2001). One paper has been found that used CS in order to evaluate the clinical, cost and system effectiveness of using a new type of treatment for osteoarthritis of the knee (CS1).

There are no studies under this category that have applied Statistical Quality Control Techniques (SQC), Scheduling (SCH), System Dynamics (SD) or Forecasting (FC).

4.2.2 Improving clinical and administrative performance

The aim of the papers under this category is to improve the clinical or administrative issues in healthcare through use of OR techniques. According to the findings, 23 papers (32%) have applied these techniques instil such improvements in the UK healthcare system. The studies related to this category can be categorised into two broad groups; (a) studies that have used OR techniques for medical and clinical improvements; and (b) the studies that have applied these techniques for managerial and administrative improvements. These studies are presented below with reference to the OR technique used.

Multiple OR Techniques (MTP)
Studies related to this category have used MTP for improvements in patient care (this involves the application of new treatment methods or technologies) and for investigating managerial issues (through use of scheduling, forecasting, quality control and process improvement). More specifically, these studies have applied MTP tools to improve the appointment system and reduce the waiting time using scheduling and virtual interactive simulation (MTP2); to improve and accommodate all healthcare services in order to increasing the efficiency and whole performance of the hospital by using Discrete-Event Simulation and scheduling (MTP6); to develop a model for a waiting list system and appointment system using statistical analysis and Discrete-Event Simulation (MTP21); and to develop a predictive model for embryo transfers using Monte-Carlo Simulation and Markov modelling frameworks (MTP23).

Discrete-Event Simulation (DES)
The papers related to this category have discussed the application of DES in healthcare systems with the purpose of improvements in medical or administrative areas. According to the findings, DES has been used to develop a model for planning the bed capacities for different departments (DES4;DES7); to predict and analyse the factors affecting performance targets for the accident and emergency department (DES8); to analyse the resource requirements, to improve patient flow and to minimise bottlenecks in the systems in order to improve clinical processes (DES10); to develop a model for reducing the waiting time and to improve and accelerate all processes (discharge, transfer or admission) of accident and emergency departments (DES11;DES18); to analyse the improvement scenarios for hospitals using the District General Hospital Performance Simulation, or DGHPSim in short (DES12); for developing a model a model to improve the waiting list and appointment system of the hospital (DES13); to predict the outputs of different improvement plans and then compare them with the actual results after implementation (DES15); to develop a model to investigate the impact of health care services, and to find the areas in the hospital that require improvement (DES17).

Monte Carlo Simulation (MCS)
MCS has been applied to develop a model in order to illustrate the likelihood of random clustering of different cases arising in healthcare units (MCS8); and to examine breast cancer tumour detection speed between two different methods using MCS and a numerical simulation technique (MCS12).

Modelling Systems (MOD)
The papers included in the present research have applied MOD to develop a model in order to improve patient flow in the hospital (MOD3); to evaluate the role of system modelling in change
management and its relation to organisational strategy, processes and systems (MOD4); to develop a model using IT tools to improve the processes of healthcare organisation (MOD5); and to develop a model in order to analyse different variables in relation to efficiency of using a new treatment technique (MOD9).

**Statistical Quality Control (SQC)**
One paper included in the present research has applied SQC to improve the quality of care using a controlling system such as AHRQ (Agency for Healthcare Research and Quality) patient safety indicators (SQC1).

**Scheduling (SCH)**
One paper has applied SCH to analyse the nurse rostering system, such as assigning tasks and shift types by using a scheduling technique (SCH1);

**Forecasting (FC)**
One paper included in the present research has applied FC to forecast and estimate hospital admission during pressure times, such as influenza cases during winter (FC1).
There are no studies under this category that have applied System Dynamics (SD) or Cohort Simulation (CS).

4.2.3 Literature and Methodology Review

A number of review studies have been identified among the papers included in this research. These discuss the application of OR methods for solving problems in the context of the UK healthcare system. According to the findings, 10 papers, or 14%, of the studies have reviewed the literature or have discussed different methodologies for the application of OR techniques. These studies are presented below.

**Multiple OR Techniques (MTP)**
Review papers have referred to MTP and have discussed the economic efficiency of new healthcare methodologies using Markov models, DES and decision analysis tools (MTP17). There are papers that argue about the application of specific OR methodology like Hybrid simulation (integrating the System Dynamic and Discrete-Event Simulation) for improving the efficiency of the decisions (MTP18) and those that discuss cost-effectiveness and health-related quality of life analysis of treatment models by using a Markov modelling framework and MCS (MTP22).

**Discrete-Event Simulation (DES)**
This research has identified two DES methodology reviews in the UK healthcare literature. These articles refer to DES for reviewing the research opportunities in IT and computing to improve the efficiency of OR techniques; one paper discusses the application of DES for improving and developing healthcare policies (DES5).

**Modelling Systems (MOD)**
This research has identified a number of MOD review articles in the UK healthcare literature. These refer to MOD to develop a model and formula in order to improve the allocation of resources (MOD1); to explain large scale models and large scale thinking considering three important initiatives in the NHS (MOD2); analyse the role of modelling techniques in leading innovations in an effective way (MOD6); and investigate the role of healthcare stakeholders in developing simulation models (MOD8).

**System Dynamics (SD)**
One of the review articles found in this research refers to SD. The paper analyses the application of SD for developing and implementing healthcare programmes and policies (SD1).
There are no studies under this category that have applied Monte-Carlo Simulation (MCS), Cohort Simulation (CS), Statistical Quality Control (SQC), Scheduling (SCH) and Forecasting (FC).

4.3 Funding sources

According to the findings, 35% of the studies included in the underlying dataset are directly and indirectly funded by the government; 7% are financially supported by industry and stakeholders; 5% receive funding from research centres and NGOs, and only 1% studies are directly funded by academic institutes and universities. Funding sources for the remaining 52% of the studies are not mentioned in the papers.

By looking at the publication trends, it can be realised that over the years (especially since the last 5 years) studies supported by government have been increasing year by year. NHS has also been increasing its support for OR studies, and it can be argued that this is especially because of its effectiveness of OR techniques in conducting cost-utility and cost-effectiveness analysis. However, financial support from the stakeholders is not considerable in monetary terms (this excludes opportunity costs); the stakeholders usually support the projects by providing them with data and through sharing of knowledge and experience of their experts.

4.4 UK Regions

According to the findings, from the 70 papers included in this review, 45 papers or about 64%, discuss healthcare issues in the context of UK as a whole, whereas others focus on specific regions (Table 3).

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>45</td>
</tr>
<tr>
<td>England</td>
<td>14</td>
</tr>
<tr>
<td>Wales</td>
<td>3</td>
</tr>
<tr>
<td>Scotland</td>
<td>2</td>
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<tr>
<td>Northern Ireland</td>
<td>-</td>
</tr>
<tr>
<td>England and Wales</td>
<td>6</td>
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</tbody>
</table>

4.5 Publication trends

Over the last three decades, the application of OR methods for solving healthcare problems has improved significantly. This research represents 41 (1970-2011) years of applying OR techniques in the UK healthcare system.

According to the findings, 90% of the studies have been published from the year 2000 onwards; especially since 2007 the numbers of published papers have been significantly increasing. The latest paper included in this research was published in July 2011. The search strategy intended to find the papers published from 1970 onwards (Section 3), but the oldest paper retrieved was published in the year 1992. This gap of 22 years can perhaps be explained by the following: first of all, it is debateable that the application of OR in the UK healthcare context is comparatively new (especially when compared to its application in other industries like manufacturing and defence). This may especially be true in the case of published literature; thus, while these techniques may have been in sufficient use in the UK healthcare scene, the results were perhaps not published in scholarly outlets. Furthermore, the ISI web of science is an online database for journals, and it may be that after the internet revolution of the last two decades, new journals and papers have been published on-line, but older papers published in the 70s and 80s are not available in electronic format. The third reason is that the growth in funding for OR studies in last two decades has resulted in the increase in the number of researchers working in this field; this might not have been the case previously. Historical trends of published OR papers in the context of UK healthcare have been illustrated in Figure 2 (A and B).
4.6 Software package

The selection of appropriate software package(s) for the purposes of conducting an OR study is informed by (a) the OR method that is going to be used, and (b) the requirements of the project. According to the findings, “TreeAge” is one of the most popular OR software packages used in UK healthcare and it is using mostly for Cost-effectiveness models and Markov chain modelling. Our review has identified the high variety of software packages used or developed for conducting the OR studies. At least 27 different software packages were used for 70 studies. Table 4 lists the software packages that were used and the frequency of use.

Table 4 Software Packages

<table>
<thead>
<tr>
<th>List of the software packages were used in studies</th>
<th>MTP</th>
<th>DES</th>
<th>MCS</th>
<th>MOD</th>
<th>CS</th>
<th>SQC</th>
<th>SCH</th>
<th>SD</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Microsoft Excel (Spreadsheet)</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>2 TreeAge Software Inc (Markov, Decision three, MCS)</td>
<td>7</td>
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<td>2</td>
<td></td>
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<td></td>
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<tr>
<td>3 Micro Saint Sharp (DES, Commercial simulation packages)</td>
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<td>5</td>
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<td></td>
<td></td>
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<tr>
<td>4 Stata (Statistical programming language)</td>
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5 CONCLUSION

The aim of this research is to analyse, categorise, profile and synthesise academic literature with regard to the application of OR methods in the UK healthcare sector. The findings indicate that the application of OR techniques has been increasing in terms of the number of studies conducted and also the breadth of its application. Although the study focuses on the UK healthcare sector, it can be seen as representative of the wider OR-related healthcare literature since according to the review of research status of operational research conducted by EPSRC (EPSRC, 2004), UK has been identified as having significant strengths in the application of OR techniques in healthcare.
In this research, around 70 high-quality journal papers on application of OR in the UK, published between 1992 and 2011, have been reviewed and analysed. The outcome has been to present the categorised and classified healthcare OR articles based on: (a) the OR technique they applied or discussed, (b) the application category, (c) the report on presentation and application of the studies’ outcome, (d) UK regional location, (e) the sources of funding and the financial support, (f) Publication trend and (g) the software they used, and their impact.

Although this research has achieved its stated aim, there have been some inescapable limitations and deficiencies. The most important limitation is related to the use of only one underlying data source, namely, the ISI Web of Science. Another limitation is that only scholarly literature is considered in this study. However, there are numerous OR studies that are conducted for realising particular stakeholder objectives, but the results are not published.

This research is likely to benefit healthcare decision makers since it will provide them with an overview of the different studies that have utilised multiple OR techniques for investigating problems in the stated domain. Additionally, this work presents a methodological and up-to-date review of literature, and this, in turn, provides academics and researchers an opportunity to conduct further studies based on particular OR techniques and/or application areas in healthcare.

REFERENCES


AUTHOR BIOGRAPHIES

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APPENDIX

Multiple OR Techniques (MTP) papers:


Discrete event simulation (DES) papers:


Monte Carlo simulation (MCS) papers:

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Modelling techniques (MOD) papers:


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**Cohort simulation technique (CS) papers:**

**Statistical quality control (SQC) papers:**

**Scheduling techniques (SCH) papers:**

**System Dynamics (SD) papers:**

**Forecasting techniques (FC) papers:**