Can Management Science methods do more to improve healthcare?

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***Abstract*— In recent years healthcare has recognised the potential of management science methods (mainly from industry) to address challenging issues which are still unresolved, and continually posing huge problems and incurring massive costs. This paper is an attempt to investigate the gap between the application of management science in healthcare and in other industries. Adopting a novel review methodology, we carried out an extensive scientific survey of the published (academic), grey and patent literature in different areas of management and planning in an attempt to identify where there has already been a substantial contribution from management science methods to healthcare problems and where there is a clear potential for more work to be done. The focus is on the read-across to the healthcare domain from such approaches applied generally to management and planning, how the methods are currently being used to improve patient care and how academics and practitioners can contribute to improve these methods and developing new approaches so as to incorporate the complexities of healthcare, and fully exploit the potential for improvement.**

***Index Terms*— Management science, operational research, application of management science to healthcare, healthcare management and planning decisions, operations management and healthcare.**

I. Introduction

SELF-REPORT Healthcare is one of the largest and most complex industries in the developed world. Healthcare issues continue to pose huge problems and incur massive costs. In the UK alone, £48 billion was spent by the National Health Service (NHS) on healthcare in 2008/2009 [1]. Expenditure in healthcare remains a huge priority, and is closely related to aging of the population, increased patient/consumer expectations about services and outcomes, and workforce issues. In the operating framework 2009/2009 [1] the Department of Health resolved to reduce hospital related infections, improve access to care (for example to reduce waiting lists), improve health, improve patient experience and satisfaction and treat emergencies.

Because of its specific nature and the fact that, in many cases, it is mostly a non-profit and government owned industry there has traditionally been limited interest in innovation for the management of healthcare resources. Additionally, healthcare workers have been reluctant to adopt technologies that may take over their jobs. However, in recent years healthcare has recognised the potential of management science methods (mainly from industry) to address problematic issues. That these methods have increasingly been adopted is reflected by the inclusion of healthcare streams in many management science (or operational research) conferences and the introduction of a journal: Health Care Management Science (HCMS) devoted to this area [2]. To quote the journal homepage, HCMS "*publishes important articles that promote systems thinking, offer rigorous scientific approaches for solving tough health care problems, and address policy implications. The journal uses an interdisciplinary approach, covering such topics as productivity and operations analysis, information systems, financial management, strategic management, managed care, and systems dynamics.*" [2]. Within the NHS, such ideas have been championed by such bodies as the NHS Institute for Innovation and Improvement.

This paper is an attempt to investigate the gap between the application of management science in healthcare and in other industries. We carried out an extensive scientific survey of different areas of management and planning in an attempt to identify where there has already been a substantial contribution from management science methods to healthcare problems and where there is a clear potential for more work to be done. The focus will be on the read-across to the healthcare domain from such approaches applied generally to management and planning and how the methods can be used to improvement patient care. In particular, we will look at three main areas – (1) human resource planning methods, (2) material management and demand forecasting, (3) inventory planning and supply chain management, and (4) planning, process and quality control and consider the differences between healthcare and other industries in regard to the overall proportion of papers published, the proportion of papers published in regard to the various methodologies, and the most popular methods in healthcare and other industries. These questions will be considered within the academic, grey and patent literature.

This literature survey is a part of an extremely large, cross-sector survey [3-5] carried out in 2008 with in the RIGHT (Research Into Global Healthcare Tools) project with the aim to build an evidence base to establish whether there are any useful insights from other sectors that may be transferred across and applied towards implementing improvements on various functional areas in the healthcare sector.

We analyse the role and potential improvement for management science methods to facilitate the decision and planning process, improve the quality of care and ensure the optimum utilization of scarce healthcare resources. We conclude that, since the healthcare domain significantly differs from traditional areas of management and planning, in some cases there is a need to modify the approaches so as to incorporate the complexities of healthcare, and fully exploit the potential for improvement.

II. The Approach

Our approach is based on an extensive survey of management science methods that have been used to improve healthcare and other industries. There is no universally agreed classification of management science methods available. Therefore we developed our own classification scheme such as it should cover most of the healthcare areas where management science methods can be used. Having developed a classification scheme, the most popular management science methods were categorised as (1) human resource planning methods, (2) material management and demand forecasting, (3) inventory planning and supply chain management, and (4) planning, process improvement and quality control. In healthcare organizations, human resource planning methods should be quite similar to other service industries, however, unique issues in healthcare organizations is to take care of professional aspects of human resource and in many cases planning should be done at regional or national level. Similarly in healthcare organizations, there are a lot of material management (i.e., healthcare resource management and/or facility management) and demand forecasting similar issues (seasonality, demographic, innovation led) and approaches similar to those which has successfully been used in other industries can be adopted with little or no modifications. Supply chain management and inventory control issues are very critical in medical industry to ensure the availability and quality of health care and minimize the cost of healthcare delivery. However, these are not properly addressed and there is an urgent need to develop new methods or adopting methods from other industries to deal with such issues. Due to patient (experiential) aspects although some convergence with other service industries planning and process improvement methods are required to be customized towards the specific nature of healthcare delivery system. For instance costs can be measured as actual costs to the hospital (health service, insurer) but may also be measured as QALYs, i.e. Quality Adjusted Life Years [6].

Initially a number of databases were considered, including Scopus, Google Web, Google Scholar, Google book search, ACM Digital Library, IEEE Xplore, HighWire, JSTOR, Emerald, EBSCO, ISI web of knowledge, Financial Times Archive, KeyNote Market Reports, Mintel Reports, ebrary, Taylor and Francis Informaworld and Business Source Premier. We found a considerable overlap among these databases, therefore, we reduced our search to Scopus (mainly for academic literature), Google Web (mainly for the grey literature), and Scopus Patent database. For each of the four categories and management science methods the number of academic research articles available in healthcare and other industries was explored using Scopus, providing us with an insight into the academic interest in each case. Similarly the grey literature was explored using Google Web search and Scopus Patent database providing us with an insight into the interest from the non-academic community (mainly industry, government and the user community).

Both hard and soft models were critically studied. We considered each management science method in terms of its potential application to healthcare management and policy design. Finally, popular articles (in terms of citation) were selected, using stratified random sampling to exemplify each management science method in order to provide a source of further information for those interested in knowing more about a particular method.

To obtain the full spread of articles published using each method we included all alternative keywords using a string search. For example, to find articles using constraint programming for human resource management in Scopus we used the search string *"(TITLE-ABS-KEY(("Constraint programming" OR "Constraint logic programming" OR "constraint satisfaction") AND ("Manpower planning" OR "Manpower Management" OR "Managing People" OR "Human Resource" OR staffing)))*. Similarly for articles from non-healthcare areas the search stream used was *(TITLE-ABS-KEY(("Constraint programming" OR "Constraint logic programming" OR "constraint satisfaction") AND ("Manpower planning" OR "Manpower Management" OR "Managing People" OR "Human Resource" OR staffing)) AND NOT TITLE-ABS-KEY(health OR medicine OR patient OR hospital OR medical OR nurse OR pharma OR clinic))*. The number of articles found for all years was recorded. To obtain results through Google and Scopus Patents we modified this search string accordingly. Each article was read to identify its application to healthcare and other industries. For each category we cite a few of the most popular papers so as to provide the reader with key references for the methods and areas under consideration.

The prevalence of each method within the academic and grey literature was reported. Having completed the search we were able to answer a numbers of questions, in respect of the four management science categories, as follows:

1. Have the methods as a whole been equally used within healthcare and other industries?
2. Are the methods used in equal proportions within healthcare and other industries?
3. What is the most popular method in healthcare and other industries?

III. Human Resource Planning Models (HRPM)

HRPM methods also known as personnel management methods or manpower planning methods are methods for effectively managing people to maximize performance. These include models for selection/ recruitment, rostering or scheduling (including job and resource allocation) of medical staff (physicians, specialists, nurses, managerial and other clinical and non-clinical staff), attracting and retaining quality healthcare professionals, improving workforce productivity, satisfaction and retention, models for performance appraisal, pay and incentives, training and development, models for developing healthy work environment ensuring effective communication, team working, security, career development, equal opportunities and work-life balance and models for budgetary analysis and allocation [7]. Some of the HRPM models are also being used for modelling patient flow through the care system including patient admission/ recruitment, scheduling and resource allocation. Based on underlying computing, mathematical or statistical concepts, HRPM models can be sub-divided into five categories i.e., (i) simple statistical models, (ii) simulation models, (iii) Stochastic models (iv) Mathematical programming models (v) Artificial Intelligence (AI) based models. In Appendix 1, we have provided provides details of each of these methods and their merits and limitations. The RIGHT workbook [8] gives a further detailed description of many of these methods.

A. *Literature review: Results and findings*

Our results indicate that human resource planning methods have been equally used within academic research in healthcare and other industries (Table 1). Using our search criteria, we found that 47.5% (n=688) of academic research papers were published in healthcare, and 52.5% (n=760) were published in other industries (Scopus). Within the grey literature (Google Web) more papers were published in healthcare than in other industries, with 70% (n=3,222,831) of papers being published in healthcare, and 30% (n=1,363,918) of papers being published in other industries. In Scopus Patents more papers were published from other industries than in healthcare with 41% (n=1,289) of papers published in healthcare and 59% (n=1,840) of papers published in other industries.

Of all papers published in healthcare and other industries (with the exception of Scopus Patents) simple statistics was used more in healthcare. For example, within the academic literature (Scopus), simple statistics accounted for 51% (n=348) of all papers published in healthcare and 18% (n=140) of papers in other industries. In Scopus Patents, simple statistics were used in equal proportions in both healthcare and other industries, specifically accounting for 14% (n=183) of all healthcare papers and 14.5% (n=266) of papers from other industries. Within the academic and the grey literature, AI methods were used less in healthcare than in other industries. For example, within the academic literature (Scopus), AI methods accounted for 8% (n=55) of healthcare papers and 14% (n=106) of papers from other industries. Simulation and mathematical programming methods were generally used in similar proportions across healthcare and other industries. For example, within the academic literature (Scopus), simulation approaches accounted for 27% (n=186) of papers in healthcare and 30% (n=227) of papers in other industries (Figure 1).

TABLE 1: HUMAN RESOURCE PLANNING METHODS IN HEALTHCARE AND OTHER INDUSTRIES

Method type	Industry	Scopus		Google Web		Scopus Patents	
Simple statistical	Healthcare	348	(50.58%)	675,200	(20.95%)	183	(14.20%)
	Other industries	140	(18.42%)	218,000	(15.98%)	266	(14.46%)
Simulation	Healthcare	186	(27.03%)	1,151,000	(35.71%)	282	(21.88%)
	Other industries	227	(29.87%)	449,000	(32.92%)	402	(21.85%)
Stochastic	Healthcare	56	(8.14%)	467,814	(14.52%)	285	(22.11%)
	Other industries	165	(21.71%)	132,335	(9.70%)	655	(35.60%)
AI based	Healthcare	55	(7.99%)	832,717	(25.84%)	525	(40.73%)
	Other industries	106	(13.95%)	534,683	(39.20%)	450	(24.46%)
Mathematical	Healthcare	43	(6.25%)	96,100	(2.98%)	14	(1.09%)
Programming	Other industries	122	(16.05%)	29,900	(2.19%)	67	(3.64%)
Total	All industries	1448		4,586,749		3,129	
	Healthcare	688	(47.51%)	3,222,831	(70.26%)	1,289	(41.20%)
	Other industries	760	(52.49%)	1,363,918	(29.74%)	1,840	(58.80%)

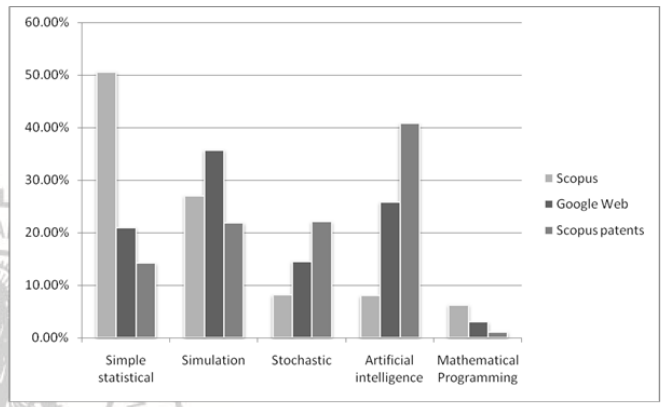

Figure 1: Proportion of human resource planning methods in healthcare

Within the academic literature (Scopus) and the grey literature (Google Web) the most popular methods in healthcare were simple statistical approaches and simulation techniques. For example in the academic literature (Scopus), simple statistical approaches and simulation techniques accounted for 51% (n=348) and 27% (n=140) respectively of all papers published in healthcare. In Scopus Patents the most popular approaches in healthcare were AI approaches (41%, n=525) and stochastic modelling (22%, n=285). Mathematical programming methods appear to have been of little interest to either healthcare or other industries, accounting for only 6% (n=430) of all academic papers published in healthcare.

Our results have indicated that human resource planning methods have been equally or more often used in healthcare than in other industries, particularly within the grey literature (Figure 1). Simple statistics are used more often in healthcare than in other industries and appear to be the most popular method in healthcare. A rather surprising result is that AI based approaches are used less in healthcare.

B. *Applications of human resource planning methods.*

Human resource modelling is clearly an important issue within healthcare and management science has contributed to various areas of interest. Needleman et al. [9] analyzed the effect of nurse staffing policy on the quality of care in a healthcare unit. Using our search criteria this paper was deemed to be the most popular paper published in healthcare. Ichniowski et al. [10] used regression analysis to help HR policy design and assessment in the steel production industry.

Simulation techniques have been very popular in solving staffing problems. For example, Gans [11] discusses the application of simulation techniques to manpower planning and scheduling in call centres. Stochastic modelling especially queuing models have been successfully used in manpower planning under uncertainty e.g., the queuing model used by Sze [12] to model telephone operator staff requirement planning. Borst et al. [13] also used such models for manpower requirement planning in a call centre.

Mathematical programming approaches comprise: linear programming, linear integer programming, non-linear programming, including quadratic programming, goal programming, dynamic programming etc. Within healthcare, Miller et al. [14] and Warner and Prawda [15] used mathematical programming approaches to configure nurse schedules in a large hospital.

AI based approaches have been very popular with both healthcare and industry and include the application of heuristic search techniques, constraint programming, expert systems, decision support systems, fuzzy logic and different meta heuristic techniques such as simulated annealing, tabu search, genetic algorithms (GA), problem space search, greedy random adaptive search procedure, artificial neural networks (ANN), machine learning, reinforcement learning, ant colony optimization, swap and interchange based neighbourhood and hyper-heuristics. AI methods are efficiently being used to develop solutions for complex staffing problems both in healthcare and non-healthcare industry. Brusco and Jacobs [16], for example, presented a simulated annealing based local search heuristic approach for workforce scheduling. Christou et al. [17] used GA based approach to solve the cabin crew scheduling problem in an airline. Verbeek [18] developed a decision support system to manpower requirement planning of airline pilots.

Constraint programming has not been so popular in healthcare manpower planning, although such methods may be used in efficiently solving many healthcare staffing problems as these are quite similar to the staffing problems in other industries but a bit more complex as there are large many specializations professionals. For example, Weil et al. [19] demonstrated the use of constraint programming for nurse scheduling. In an industrial setting, Lin et al. [20] developed a constraint programming application for the prediction of staff requirement and scheduling for a customer hotline service.

IV. Material Management and Demand Forecasting

Managing scarce health resources is a challenge to ensure the quality of care with constrained budget availability. Material management models include models for capacity planning, material requirement planning, ensuring optimum utilization and availability of medical equipments and other clinical items satisfying requirements and keeping pace with the rapidly changing product offerings and forecasting requirements and allocate budget accordingly. It also includes provisions for clinical waste management.

Based on underlying computing, mathematical or statistical concepts, Material management and demand forecasting models can be sub-divided into five categories i.e., (i) Artificial Intelligence (AI) based models (ii) Simulation models, (iii) Mathematical programming models (iv) Stochastic models (v) Game theoretic and economical models. In Appendix 1, we have provided provides details of each of these methods and their merits and limitations.

A. *Literature review: Results and findings*

With regard to material management and demand forecasting, the proportion of healthcare articles published varied in terms of which database was searched (Table 2). Using our search criteria, considerably fewer academic research papers were published in healthcare (2%, n=17) than in other industries (98%, n=939). Similarly in Scopus Patents 35% (n=663) of all papers were published in healthcare. Within the grey literature (Google Web), an equal number of papers were published in healthcare and other industries.

Within the grey literature (Google Web) all methods were used in similar proportion in healthcare and other industries. For example, 41% (n=23,590) of all healthcare papers and 40% (n=215,100) of papers from other industries used AI based approaches. In the academic literature (Scopus) and Scopus Patents the proportion of AI based approaches was greater in healthcare. All other approaches were proportionally less used in healthcare.

TABLE 2: MATERIAL MANAGEMENT AND DEMAND FORECASTING IN HEALTHCARE AND OTHER INDUSTRIES

Method type	Industry	Google Web		Scopus		Scopus Patents	
AI based	Healthcare	235,900	(41.00%)	12	(70.59%)	355	(53.54%)
	Other industries	215,100	(40.22%)	398	(42.39%)	588	(47.92%)
Simulation	Healthcare	178,000	(30.94%)	4	(23.53%)	193	(29.11%)
	Other industries	182,000	(34.03%)	328	(34.93%)	295	(24.04%)
Mathematical programming	Healthcare	63,200	(10.99%)	0	(0.00%)	52	(7.84%)
	Other industries	63,800	(11.93%)	104	(11.08%)	231	(18.83%)
Stochastic	Healthcare	66,000	(11.47%)	1	(5.88%)	38	(5.73%)
	Other industries	59,000	(11.03%)	98	(10.44%)	103	(8.39%)
Game theory	Healthcare	32,200	(5.60%)	0	(0.00%)	25	(3.77%)
	Other industries	14,900	(2.79%)	11	(1.17%)	10	(0.81%)
Total	All industries	1,110,100		956		1890	
	Healthcare	575,300	(51.82%)	17	(1.78%)	663	(35.08%)
	Other industries	534,800	(48.18%)	939	(98.22%)	1227	(64.92%)

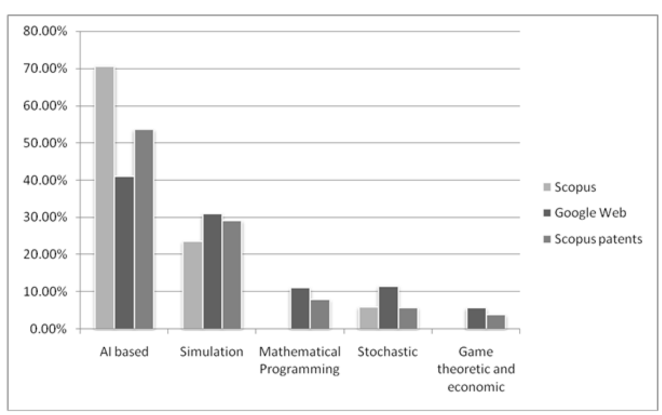

Figure 2: Proportion of material management and demand forecasting models in healthcare

Overall, AI based methods and simulation techniques were the most popular choices for both healthcare and other industries. Within the academic literature (Scopus) 71% (n=12) of all healthcare papers used AI methods. Within the grey literature (Google Web) 41% (n=235,900) of all papers published in healthcare used AI based methods. Simulation techniques were used in 23.5% (n=4) of healthcare papers within the academic literature (Scopus) and in 31% (n=178,000) of healthcare papers within the grey literature (Figure 2).

Our results indicate that, within academic research, material management and demand forecasting modes are used less in healthcare than in other industries. In the grey literature an opposite trend is apparent. All methods are generally used in similar proportions in healthcare and other industries. The most popular methods in both healthcare and other industries are AI approaches and simple statistical approaches.

B. Applications of material management and demand forecasting models

AI based approaches were found to be equally used in healthcare and industry. For example, Blackburn and Millen [21] proposed a heuristic search technique for material requirement planning while Srinivasan et al. [22] used a hybrid technique based on Fuzzy-Neural Networks (FNN) for demand forecasting for power generation system.

Among mathematical programming approaches, mixed integer linear programming (MILP) is most popular. For example, Bard and Golany [23] used MILP method for materials requirements planning systems (MRP) in manufacturing industry. Spearman et al. [24] used a simulation method to compare the performance of CONWIP (CONstant Work In Progress) based MRP system over Push systems. Stochastic models have also been popular to describe MRP systems under demand uncertainty; for example Buzacott [25] proposed a queueing model for MRP for a production system. Alternatively, Bogataj and Horvat [26] proposed the application of game theory to MRP.

V. Inventory planning and supply chain management

Inventory planning and supply chain management include standardizing purchases (both stock and non-stock), price negotiation, order placement, confirmation, distribution, receipt and payment, identifying and eliminating supply chain waste ensuring secure procurement of clinical equipments, medicines and other items. It also includes models to improve relationship between hospitals (customers), suppliers, channel intermediaries and manufacturers to optimally align the end-to-end supply, improve cash flow and develop better products and services.

When demand exceeds supply a phenomenon known as market failure occurs. Market failure is particularly frequent within the healthcare industry that relies on several critical inputs, for example human resources and drugs, to function properly [27]. In many countries insufficient and inefficient spending disrupt the supply and demand of such inputs thus compromising the performance of the health care system and their ability to meet targets [28]. To achieve equilibrium, reliable information in regards to the costs and benefits of a product or service is critical to decision making within industry. Inventory planning and supply chain management models can be very useful tools for helping such decision making and to avoid market failure.

Based on underlying computing, mathematical or statistical concepts, inventory planning and supply chain models can be sub-divided into five categories i.e., (i) Artificial Intelligence (AI) based models (ii) Simulation models, (iii) Mathematical programming models (iv) Stochastic models (v) Game theoretic and economical models. In Appendix 1, we have provided provides details of each of these methods and their merits and limitations.

A. Literature review: Results and findings

Inventory planning and supply chain management methods have been used more in other industries than in healthcare (Table 3). Using our search criteria only 1% (n=108) of all academic research papers were published in healthcare while 99% (n=8,325) were published in other industries (Scopus). This trend continues within the grey literature (Google Web) with 35% (n=2,253,000) of papers published in healthcare and 63% (n=2,391) in other industries. Scopus Patents also suggest that less work is carried out in healthcare (32%, n=1,108).

Of all papers published in healthcare and in other industries, AI based approaches are used in a higher proportion in healthcare. Within the academic literature (Scopus), 39% (n=42) of all healthcare papers and 29.5% (n=2,457) of papers from other industries used AI based approaches. Similarly in the grey literature (Google Web), 40% (n=89,990) used AI based approaches. The Scopus Patents search suggest an opposite trend with 9% (n=101) of papers from healthcare and 12% (n=293) from other industries.

In regard to simulation approaches, mathematical programming, and stochastic modelling, the results vary according to whether the academic or grey literature is searched. In the academic literature, simulation approaches account for a higher proportion of papers published in healthcare (39%, n=42) than in other industries (34%, n=2,808) (Scopus).

TABLE 3: INVENTORY PLANNING AND SUPPLY CHAIN MANAGEMENT IN HEALTHCARE AND OTHER INDUSTRIES

Method type		Google Web		Scopus		Scopus Patents	
AI based	Healthcare	899,000	(39.90%)	42	(38.89%)	101	(9.12%)
	Other industries	1,170,000	(28.25%)	2,457	(29.51%)	293	(12.2%)
Simulation	Healthcare	220,000	(9.76%)	42	(38.89%)	162	(14.62%)
	Other industries	1,820,000	(43.94%)	2,808	(33.73%)	133	(5.56%)
Mathematical programming	Healthcare	315,000	(13.98%)	12	(11.11%)	27	(2.44%)
	Other industries	415,000	(10.02%)	1,612	(19.36%)	60	(2.51%)
Stochastic	Healthcare	605,000	(26.85%)	8	(7.41%)	781	(70.49%)
	Other industries	575,000	(13.88%)	1,207	(14.50%)	1,849	(77.33%)
Game theory	Healthcare	214,000	(9.50%)	4	(3.70%)	37	(3.34%)
	Other industries	162,000	(3.91%)	241	(2.89%)	56	(2.34%)
Total	All industries	6,395,000		8,433		3,499	
	Healthcare	2,253,000	(35.23%)	108	(1.28%)	1,108	(31.67%)
	Other industries	4,142,000	(64.77%)	8,325	(98.72%)	2,391	(68.33%)

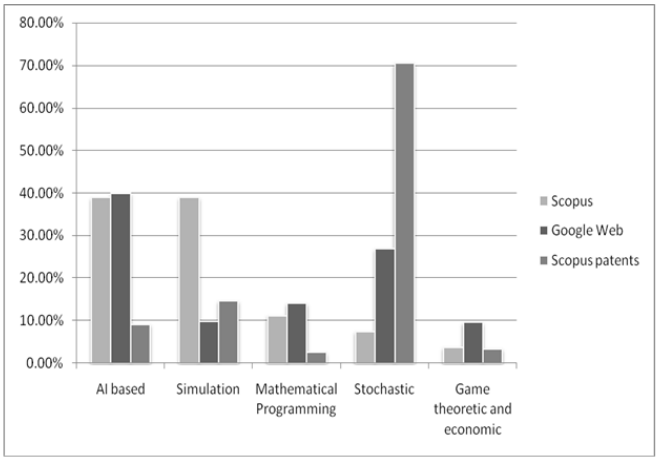

Figure 3: Proportion of inventory planning and supply change management in healthcare

In the grey literature, the picture is reversed. According to the Google Web search 44% (n=182,000) of papers from other industries used simulation approaches, while 10% (n=220,000) of papers from healthcare used simulation approaches.

Stochastic modelling and mathematical programming accounted for a lower proportion of academic research papers published in healthcare than in other industries. For example, stochastic approaches account for 7% (n=8) of all healthcare papers and 14% (n=1,207) of papers from other industries (Scopus). Within the grey literature (Google Web), stochastic modelling and mathematical programming account for a higher proportion of papers published in healthcare than in other industries. For example, 27% (n=605,000) of healthcare papers used stochastic modelling, while 14% (n=575,000) of papers from other industries used stochastic approaches. In Scopus Patents, simulation approaches and stochastic approaches account for a higher proportion of all articles published in healthcare than in other industries while mathematical programming accounts for a lower proportion of all articles published in healthcare than in other industries. For example, 14% (n=162) of healthcare papers and 5.5% (n=133) of papers from other industries used simulation approaches.

In regard to game theory, the results were similar in healthcare papers and in other industries. For example, in the academic literature, 4% (n=4) of all academic research papers were from healthcare and 3% (n=241) from other industries. Generally usage of game theory was very low in both healthcare papers and papers from other industries.

Within the academic literature and the grey literature, the most popular method used in healthcare and other industries were AI based methods For example, in the academic literature (Scopus), AI based methods accounted for 39% (n=42) of all healthcare papers and 29.5% (n=2,457) of papers from other industries. In Scopus Patents the most popular method in healthcare papers and papers published in other industries were stochastic approaches (Figure 3).

Our results indicate that methods from inventory planning and supply chain management are used much less in healthcare than in other industries. AI methods are used more in healthcare. Within the academic literature, simulation approaches are used more in healthcare than in other industries and stochastic modelling is used less in healthcare. An opposite trend is noted in the grey literature. Mathematical programming and game theory are rarely used either by healthcare or other industries. The most popular methods used in healthcare were AI based approaches.

B. Applications of inventory planning and supply change management methods

Simulation based approaches have been popular within healthcare and other industries (Table 4). Cachon and Fisher [29] proposed a simulation based approach to evaluate an information sharing policy in a supply chain management system. Swaminathan et al. [30] used a multi-agent simulation approach to supply chain dynamics. Stochastic models are also an attractive choice for modelling supply chains with stochastic demand. For example, Akella and Kumar [31] modelled the production system as a continuous time Markov chain for designing an inventory control system. Also, Karmarkar [32] used queuing models to understand and model the inventory system dynamics.

An alternative AI-based approach was that of Cohen and Lee [33] who proposed a heuristic optimization based method to model supply chain performance decision making. Gallego and van Ryzin [34] proposed a heuristic approach of dynamically pricing the items to optimize inventory and maximizing the total expected profit. Jain and Meeran [35] used a Hopfield neural network to solve a job-shop scheduling problem. Gupta et al. [36] proposed a hybrid constraint programming and stochastic programming model for supply chain planning and inventory management.

Mathematical programming approaches were among the earliest methods used for inventory planning. Akella and Kumar [31] proposed a combination of mathematical programming methods and stochastic methods for inventory control in a manufacturing system. Federgruen and Michal [37] proposed a dynamic programming approach for dynamic lot size inventory planning model.

Cachon and Zipkin [38] used game theory to model inventory policy design in two stage supply chain. Cachon and Lariviere [39] also used game theory to analyse the effect of demand forecasting among manufacturer and supplier, and design a model to assure supply chain performance in such an environment.

VI. PLANNING, PROCESS IMPROVEMENT AND QUALITY CONTROL

These are the methods which (are part of organization's strategy and) used to improve overall care system, its quality, safety and delivery with satisfying some objectives such as reducing waiting times for patients, reducing wasted times for employees, improving employee performance, reducing cost or serving more patients in same budget, improving patient satisfaction or achieving optimal outcomes etc.

In appendix 1 we have provided the details of each of the popular planning, process improvement and quality control methods.

A. *Literature review: Results and findings*

Our results indicate that the extent to which planning, process and quality control methods are used in healthcare and other industries also varies across databases (Table 4). Using our search criteria, there was less academic interest in planning, process improvement, and quality control methods in healthcare than in other industries. Specifically, 4% (n=1,038) of all academic papers published were in healthcare while 96% (n=24,446) were in other industries (Scopus). These results are supported in Scopus Patents where 37.8% (n=182) of all papers published related to healthcare and 62% (n=299) to other industries. Within the grey literature (Google Web), more papers are published in healthcare than in other industries (60%, n=22,330,900 and 41%, n=15,428,100 respectively).

Table 4: Planning, process improvement and quality control methods in healthcare and other industries

Method type		Google Web		Scopus		Scopus Patents	
Agile	Healthcare	17,710,000	(79.31%)	32	(3.08%)	13	(7.14%)
	Other industries	3,490,000	(22.62%)	3,217	(13.16%)	82	(27.42%)
Six Sigma	Healthcare	30,000	(0.13%)	46	(4.43%)	102	(56.04%)
	Other industries	2,030,000	(13.16%)	858	(3.51%)	9	(3.01%)
Total Quality	Healthcare	390,000	(1.75%)	540	(52.02%)	3	(1.65%)
Management	Other industries	1,630,000	(10.57%)	4,422	(18.09%)	1	(0.33%)
Lean Manufacturing	Healthcare	30,000	(0.13%)	43	(4.14%)	4	(2.20%)
	Other industries	2,050,000	(13.29%)	1,055	(4.32%)	18	(6.02%)
Continuous	Healthcare	2,070,000	(9.27%)	116	(11.18%)	23	(12.64%)
Improvement	Other industries	2,250,000	(14.58%)	2,373	(9.71%)	38	(12.71%)
Concurrent	Healthcare	190,000	(0.85%)	37	(3.56%)	1	(0.55%)
Engineering	Other industries	552,000	(3.58%)	4,549	(18.61%)	11	(3.68%)
Re-engineering/	Healthcare	1,330,000	(5.96%)	153	(14.74%)	32	(17.58%)
BPR	Other industries	2,340,000	(15.17%)	3,855	(15.77%)	116	(38.80%)
Theory of	Healthcare	130,000	(0.58%)	9	(0.87%)	2	(1.10%)
Constraints	Other industries	374,000	(2.42%)	345	(1.41%)	4	(1.34%)
Statistical Process	Healthcare	383,000	(1.72%)	57	(5.49%)	2	(1.10%)
Control	Other industries	627,000	(4.06%)	3,677	(15.04%)	20	(6.69%)
IPT/ Integrated	Healthcare	67,900	(0.30%)	5	(0.48%)	0	(0.00%)
Product Teams	Other industries	85,100	(0.55%)	95	(0.39%)	0	(0.00%)
Total	All industries	37,453,000		25,584		481	
	Healthcare	22,330,900	(59.62%)	1,038	(4.11%)	182	(37.84%)
	Other industries	15,428,100	(41.19%)	24,446	(95.89%)	299	(62.16%)

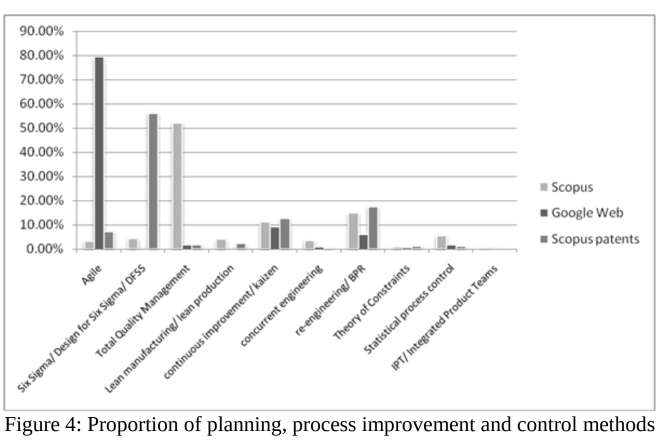

Figure 4: Proportion of planning, process improvement and control methods in healthcare.

Within the academic literature (Scopus), Six Sigma, lean manufacturing methods, continuous improvement, business process re-engineering (BPR), theory of constraints (TOC), and integrated product teams (IPT) were used in fairly equal proportions within healthcare and other industries. The remaining methods, with the exception of total quality management (TQM) were proportionally less used in healthcare than in other industries. TQM was used in 52% (n=540) of healthcare papers and 18% (n=44,212) of papers from other industries. In the grey literature (Google Web), concurrent engineering, TOC, statistical process control, and IPT were used in similar proportions within healthcare and in other industries. The remaining methods, with the exception of agile methods, were proportionally less used in healthcare than in other industries. Agile methods were used in 79% (n=17,710,000) of healthcare papers and 23% (n=3,490,000) of other industries. In Scopus Patents most methods, with the exception of agile, Six Sigma and BPR, were used in equal proportions in healthcare and other industries. Six Sigma was used more in healthcare (60%, n=102) than in other industries (3%, n=9), while agile and BPR were more often used in other industries (See Figure 4). In the academic literature (Scopus) the most popular method, in both healthcare and other industries, was TQM. TQM accounted for 52% (n=540) of all healthcare papers and 18% (n=4,422) of papers from other industries. In the grey literature (Google Web), the most popular method was agile, accounting for 79% (n=17,710,000) of healthcare papers and 23% (n=3,490,000) of papers from other industries. In Scopus Patents the most popular method used in healthcare was Six Sigma. Little interest was shown, within the academic literature, for lean manufacturing (2% in healthcare and 5% in other industries according to Google Scholar), theory of constraints (1% in both healthcare and other industries according to Google Scholar), and statistical process control (3% and 6% in healthcare and other industries respectively).

Our results indicate that, in general, planning, process improvement and quality control methods are used less in healthcare than in other industries (Figure 4). All methods are used in similar or lower proportions in healthcare than in other industries, with the exception of agile (in the grey literature) and TQM (in the academic literature). The most popular methods in both healthcare and other industries are agile approaches and business process re-engineering.

B. *Applications of planning, process improvement and quality control methods*

Naylor et al. [40] and Christopher [41] discuss how agile methods can be integrated with total supply chain and the advantages. Gunasekaran [42] and Yusuf et al. [43] provide a good explanation of agile manufacturing while Linderman et al. [44], Hahn et al. [45], Hoerl [46] and Harry [47] provide a useful discussion of Six Sigma implementation.

Hendricks and Singhal [48] and Zbaracki [49] critically analyse total quality management and its impact on organization efficiency. Shah and Ward [50] review the impact of lean manufacturing on organizational performance and Naylor et al. [40] and Lamming [51] discuss how lean manufacturing can be integrated into the supply chain. Garvin [52] proposed how a learning organization can gain competitive advantages by continuous improvement. Sohlenius [53] is an excellent reference to learn more about concurrent engineering. Georgakopoulos et al. [54] discuss the need for business process reengineering (BPR) and how it can help organizations to lead in global competition.

VII. Discussion

The Health Service is a human activity system where humans work together to achieve a common purpose. A systems approach to the planning of healthcare is therefore essential to facilitate understanding of the process and develop a holistic method for improvement. Management science methods can be used alongside a systems approach to facilitate healthcare improvement. Such methods were typically developed to improve processes in business and other industries but as our survey has shown, in many cases, they have proven very applicable to healthcare applications. However there is significant difference between healthcare and other industries. The most important difference is the product of healthcare industry is patient and purpose is to cure their diseases. Patient cannot be considered similar to other products as s/he experiences the process and provides feedback at each step of the production process (throughout the patient pathway). Therefore healthcare system is far more complex than any other production system. One should be very cautious while applying a method developed for other industry. It needs to be customized to suits to healthcare processes.

The aim of the survey was to attempt to identify where there has already been a contribution from management science methods to healthcare and where there is clear potential for more work to be done. Generally speaking our survey has found high proportions of publications in the healthcare area across a range of different methods, with some notable exceptions.

In general, human resource methods are used in equal or more proportions in healthcare than in other industries. Arguably human resource management is the driving force within any organisation and is critical to the provision of a high quality level of healthcare. It is accepted that HRPM is a fundamental element of quality control methods, such as Total Quality Methods [55]; hence there has been much interest in the relationship between, and the integration of, HRPM and TQM [56].

Relatively little interest was shown for material management and demand forecasting methods by either healthcare or other industries. Within healthcare it is reasonable to assume that healthcare managers would have little responsibility for the procurement of raw material. However, the success of most industries is thought to often hinge on the accuracy of their forecast of demand. Hamel and Prahalad [57] argue that implementation failures are, in reality, due to lack of demand forecasting. Forecasting issues in healthcare include the prediction of number of beds required in the future. Such is the problem of bed usage; Marshall et al. [58] proposed a conditional phase-type distribution (C-Ph) to model patient length of stay. The authors commented that a hospital ward could be more efficiently managed and beds and resources better allocated if the duration of length of stay could be estimated. Patient demand modelling can be based on seasonal, or even daily, patterns. Vasilaskis and El Darzi [59], for example, predicted bed numbers for winter crisis demands.

Demand forecasting is logically connected with supply chain management. For example, correct prediction of the demand for the flu vaccine, and hence supply, will help alleviate a winter bed crisis, particularly among the elderly and frail that are most prone to influenza related complications such as respiratory infections [60].

Uptake has been slow in these areas, particularly for demand forecasting. As in Eom and Kim's [61] literature survey, inter-organisational decisions such as supply chain management represent a small proportion of methods used in this survey. The read-across literature may be problematic as demand in healthcare is in some ways more predictable (e.g. demographically based) and in other ways less predictable (e.g. due to stochastic nature of demand, the development of new diseases, uncertainty of disease progression, inaccurate projections of length of stay due to lack of comprehensive databases [62]). In order to fully understand the usefulness of these approaches to healthcare and to develop a holistic approach to healthcare there is an urgency to integrate these methods. There is clearly scope for more work in this area.

Our findings indicate that, of all management science methods, planning, process improvement and quality control methods would appear to be of the most interest to both healthcare and other industries. TQM and re-engineering have shown potential for enabling dramatic improvements in quality and cost, although found to be quite difficult to implement [63], probably due to the involvement, motivation and commitment from staff at all levels. It is encouraging that this survey has found these methods to be increasing in popularity within the healthcare industry. However, our results do indicate that planning, process improvement and quality methods have not been as popular in healthcare as in other industries. It is therefore suggested that more work could be done to integrate these methods into healthcare.

Simple statistical methods, AI based approaches and agile approaches are identified in our survey to be the most deeply embedded methods. Overall, they are used in similar proportions in both healthcare and other industries. The use of stochastic approaches, mathematical programming and game theory is fairly sparse in both healthcare and other industries. Usage of deterministic models and stochastic models in decisions support systems have been found to be on the decrease [61]. Complex process improvement methods such as Six Sigma, theory of constraints and IPR were of little interest to either industry or healthcare. The most popular approaches in both healthcare and other industries were simple statistical approaches, AI based methods, simulation approaches and agile approaches. This study reveals that healthcare and other industries are generally more likely to opt for simple approaches, and reject more complex methods.

In a paper [64] we have focused on the take-up of lean thinking within healthcare and the extent to which the methods are being optimally imported into healthcare areas. Our conclusion was that there are three key themes, or dimensions, to value in healthcare: the clinical, the operational, and the experiential and for lean, the absence of a single customer with a clear concept of value is perhaps the most important issue for the successful adoption of these methods for healthcare. We concluded that, in order to fully incorporate lean thinking into healthcare we must engage with these multi-dimensions of value and modify the concepts accordingly. Such arguments may explain why our study found evidence that process improvement methods such as Six Sigma and lean have been less evident in healthcare than for other areas.

Our literature review has revealed many areas of management and planning where management science approaches have been successfully imported into healthcare and usefully applied. In addition, there are other areas, such as lean engineering where, although there have been some applications to healthcare; more methodological work is needed in order to achieve the full potential of such approaches. Future work will focus on such developments.

Our survey has found high proportions of publications in the healthcare area across a range of different methods, with some notable exceptions. In particular, more complex methods (stochastic models and mathematical programming) are less common in the academic healthcare literature than grey literature. This is a rather surprising finding which may indicate that practitioners can learn from academics that simple approaches may be adequate and complexity is not always necessary. Also significant improvements may be made by academics focusing more on complex approaches with corresponding knowledge transfer to healthcare practitioners.

VIII. Conclusion and Future work

The results of this survey demonstrate that there are areas where healthcare practitioners and academic researchers are using management science approaches in a similar way to other service and manufacturing industries. However, there is still there is a gap in some areas which require urgent attention to help improve healthcare service management and planning decisions. Given than healthcare poses a massive economic problem in the UK, it is imperative that steps are taken to find a solution to the problem. Academic researchers can hugely contribute to such developments by properly identifying the concepts and need for improvement and suitably adapting the management science methods for healthcare problems.

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APPENDIX I

Simple statistical methods: Simple statistical methods are simple and straight forward (can be implemented as a automated process), easy to use and understand and have better explain ability than other complex methods and can usually be implemented as basic spreadsheet operations. However such methods are not much useful for modelling sophisticated non-deterministic systems or much complex problem scenarios. Some complex problems (deterministic only) can also be divided in to a set of simple problems and can effectively model by using simple statistical methods. Popular simple statistical methods are qualitative analysis or expert analysis, statistical analysis and regression analysis.

Simulation techniques: Simulation techniques are useful tools to model a wide range of problems including both deterministic and non-deterministic problems. Popular simulation techniques are agent based simulation, contact dynamic simulation, discrete event simulation, distributed simulation, Monte-Carlo simulation, numerical simulation, real-time simulation, system dynamics and war gaming. Simulation techniques are flexible, easy to learn, easy to use and can also be used in scenarios where insufficient or no appropriate data is available. By using simulation techniques one can gain a level of detail about the problem and its dynamics. These techniques are very useful for 'what if' analysis. However, simulation techniques are expensive in terms of computing time and space requirements and sometimes it is difficult to interpret simulation results. Another limitation of simulation techniques is its randomness and in order to have credible results it is required to compare the results with experimental results or with the analytical model. Sometimes it is very difficult to gather experimental results.

Mathematical programming: Popular mathematical programming (also known as constrained optimization techniques or optimization models) are linear programming, linear integer programming, and non-linear programming including quadratic programming, goal programming, and dynamic programming. These are quick and easy to understand. However, these techniques are less flexible, require huge data processing resources and cannot model complex non-deterministic problems. Also it is very difficult to define a quantifiable objective function to design a mathematical programming based model.

Artificial intelligence based techniques: Artificial Intelligence based approaches includes the application of heuristic search techniques, constraint programming, expert systems, decision support systems, fuzzy logic and different meta heuristic techniques such as simulated annealing, tabu search, genetic algorithm, problem space search, greedy random adaptive search procedure, neural networks (ANN), machine learning, reinforcement learning, ant colony optimization, swap and interchange based neighbourhood and hyper-heuristics. These AI based techniques are useful tool to solve complex problems (both deterministic as well as nondeterministic) as these techniques mimic/ recreate human intelligence for problem solving. These techniques can also use domain expert knowledge and context-relevant information for problem solving. These techniques can also be used with faulty data, fuzzy and incomplete knowledge. The limitation of AI based approaches is that these provide a feasible solution however do not always guarantee an optimum solution.

Stochastic models: Stochastic models are very useful in modelling non-deterministic complex systems. Stochastic models are based on probability theory and popular examples are Markov chain, queuing models, direct search methods (such as Nelder-Mead method), stochastic approximation and stochastic programming. The limitation of such methods is their complexity and less explain-ability.

Lean manufacturing: Lean manufacturing originally developed by Toyota, stresses on achieving organization goals/ profit by reducing wastes. It using this methodology one can reduce the inventory cost, employee, resource and capital requirements by producing only what is needed and when it is needed (removing activities that don't add value) with no defects. When lean thinking is applied in healthcare by value stream redesign (redesigning end-to-end care process or patient journey or patient pathways and support streams), it is called lean healthcare.

Agile manufacturing: Agile manufacturing emphasizes on flexibility, adaptation and continuous learning to quickly respond to the customer needs and market changes while controlling quality and cost. Initially it was developed for managing software development projects however, it is becoming increasingly popular among manufacturing and service industry including healthcare.

Six Sigma: Originally developed by Motorola, Inc. Six Sigma is a measurement based strategy for process improvement by process variation reduction and defect elimination. It is implemented by statistically representing processes and measuring defects. A process is called Six Sigma compliant if it does not generate more than 3.4 defective parts per million opportunities. A part which does not satisfy customer specifications (requirements and timely execution) is measured as a defective part. There are two Six Sigma sub-methodologies. DMAIC (Define, Measure, Analyze, Improve, Control) is for existing processes and DMADV (define, measure, analyze, design, verify) is for new processes. Six Sigma has been demonstrated very useful in healthcare process improvement. However there are some limitations of Six Sigma especially for existing processes. To overcome these limitations Six Sigma is used with other process improvement strategies such as Lean Six Sigma.

Total Quality Management (TQM): TQM is strategy of ensuring long-term success by organization-wide management of quality and customer satisfaction.