METHODOLOGY FOR PROFILING LITERATURE IN HEALTHCARE SIMULATION

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ABSTRACT:
The publications that relate to the application of simulation to healthcare have steadily increased over the years. These publications are scattered amongst various journals that belong to several subject categories, including Operational Research, Health Economics and Pharmacokinetics. The simulation techniques that are applied to the study of healthcare problems are also varied. The aim of this study is to present a methodology for profiling literature in healthcare simulation. In our methodology, we have considered papers on healthcare that have been published between 1970 and 2007 in journals with impact factors that belonging to various subject categories reporting on the application of four simulation techniques, namely, Monte Carlo Simulation, Discrete-Event Simulation, System Dynamics and Agent-Based Simulation. The methodology has the following objectives: (a) to categorise the papers under the different simulation techniques and identify the healthcare problems that each technique is employed to investigate; (b) to profile, within our dataset, variables such as authors, article citations, etc.; (c) to identify turning point (strategically important) papers and authors through co-citation analysis of references cited by the papers in our dataset. The focus of the paper is on the literature profiling methodology, and not the results that have been derived through the application of this methodology. The authors hope that the methodology presented here will be used to conduct similar work in not only healthcare but also other research domains.

Keywords: Simulation, Healthcare, Methodology, Profiling Research, Co-citation Analysis

1 INTRODUCTION

Over the years, healthcare requirements have grown and healthcare organisations have become larger, more complex and costly (Wang, 2009; Eveborn et al. 2005). The intrinsic uncertainty of healthcare demands and outcomes dictate that healthcare policy and management should be based on the evidence of its potential to tackle these stochastic problems. Computer modelling is valuable in providing evidence and insights in coping with these systems. They can be used to forecast the outcome of a change in strategy or predict and evaluate the implications of the implementation of an alternative policy (Wierzbicki, 2007). The use of modelling in healthcare is not limited to the management of activities necessary to deliver care alone. It is used for the study of several topics related to healthcare, for example, air pollution, pharmacokinetics and food poisoning. The methodology of this paper aims at profiling studies that have designed, applied, described, analysed or evaluated healthcare problems with the use of simulation modelling.

In the field of Operations Management, simulation is recognised as the second most widely used technique after 'modelling'(Pannirselvam et al, 1999; Amoako-Gympah and Meredith, 1989). So far, there have been a number of reviews in the literature on the applications of simulation to health. Fone et al (2003) have conducted a systematic review of the use and value of computer simulation methods in population health and healthcare. Eltabi et al (2007) reviewed the application of a diverse range of simulation techniques in healthcare settings. Brennan et al (2000) and Barrios et al

(2008) considered the application of simulation in the economic evaluation of health technologies and health products as well as a proposed method for the evaluation of pharmacoecomonic models (Hay, 2004). Dexter (1999) includes a review of computer simulation and patient appointment systems. A number of reviews have focused on the applications of discrete-event simulation in healthcare in general (England and Roberts, 1978), and more specifically in health clinics (Jun et al, 1999) and healthcare capacity management (Smith-Daniels et al, 1988). Hollocks (2006) gives a personal review of the use of Discrete-Event simulation in health among other fields.
However, most reviews limit themselves to either a single application area and/or a single simulation technique. Most of the current reviews lack the breadth of simulation techniques, the width of applications coverage and are published in outlets of different fields (e.g. medical, OR, health informatics journals, etc.), thus potentially hampering the widespread reference and use of such studies. Nonetheless, there is an excellent, very recent review (Brailsford et al, 2009) in healthcare simulation modelling which not only covers a very similar area of study but also uses comparable research methods. These research methods (particularly the use of ISI Web of Knowledge^{SM} and CiteSpace – please refer to section 3) have also been previously used in Eldabi et al. (2008) and Jahangirian et al. (2009) in the context of investigating the application of simulation techniques in *commerce & defence* and in *manufacturing & business* respectively; it has also been used in Dwivedi et al. (2009) to profile research published in a leading Information Systems journal (Information Systems Frontiers). With regard to Brailsford et al. (2009) and the research presented in our paper, a distinct difference in the approach is that our study identified papers according to the specific simulation technique applied from across general health related categories including, for example, pharmacological studies were appropriate. Moreover, a part of the methodology and the majority of the analysis and results are different in nature. The outcome of this research is a profiling study of when, where, from whom, how and with what impact research is conducted in this field; information equally useful to current and potential researchers.

In more detail, in this study we aim at presenting the methodology by which exploration of a sample of healthcare simulation literature, published in journals with impact factors within a well-defined timeframe (1970-2007), was targeted. The purpose of this methodology is to give a structured view on the "shape" of this literature to allow us to reflect on emerging trends and directions. The objectives of such a methodology were threefold: (1) to identify the different simulation methods which have been used over the years in addressing health issues and the classification of health issues according to the simulation technique employed; (2) to generate statistics regarding popular papers, authors, institutions, etc. that are involved in healthcare simulation research; and (3) to perform a co-citation analysis of references cited by the selected papers to identify the strategically important papers and authors.

Profiling of journal publications is considered to be an art of introspection (Palvia et al, 2007) that aims to benefit a specific audience. It is a useful activity as it helps the identification of major research issues and paradigms, especially in research areas which are in the emergent phase. Similar research has been undertaken in other fields and particularly in Information Systems and Electronic Commerce with great success (Avison et al, 2008; Claver et al, 2000; Dwivedi and Kuljis, 2008; Dwivedi et al, 2009). Moreover, citation analysis has been used to map the topical relatedness of clusters of authors, journals and articles (White and McCain, 1989). It was developed in information science as a tool to identify core sets of these variables within particular fields of study. Citation analysis can provide a mapping of the intellectual structure of a disciple, showing significant clustering of topically related authors (White and Griffith, 1981). This type of analysis has been shown to be effective in a broad range of disciplines (Bayer et al, 1990; McCain, 1991).

A profiling study, using the literature profiling methodology presented in this paper, is likely to help authors, reviewers and editors to better understand the discipline that this methodology is applied to. It will help upcoming researchers to develop an appreciation of the research area in question and the various topics considered worthy of research and publication in the stated area. With regard to the healthcare profiling study conducted in this paper by employing the proposed methodology, this study has complemented other studies in healthcare simulation such as those done by Jun et al (1999) and Fone et al (2003) towards gaining a better understanding and developing the area of healthcare through the use of simulation.

Since this paper mainly concerns with the approach rather than the results, the largest part of the paper is spent on explaining the method of research (section 2 and 3). Some indicative results are discussed in section 4. Finally, section

5 presents the limitations of the methodology and draws the main conclusion of this research.

2 SIMULATION SCOPE

Our literature review methodology is aimed at profiling literature in the subject area of healthcare simulation. The simulation modelling techniques that were found appropriate for the purposes of this study are Monte Carlo Simulation (MCS), Discrete-Event Simulation (DES), System Dynamics (SD) and Agent-Based Simulation (ABS). Journal papers included in this study have been selected based on the criteria that the papers report on the use of one or more of these simulation techniques in the healthcare settings. The choice of simulation techniques was made through interaction with experts in this area but was also backed by the review of Jahangirian et al (2009) of simulation in business and manufacturing. The latter identifies the following simulation techniques: DES, SD, ABS, MCS, Intelligent Simulation, Traffic Simulation, Distributed Simulation, Simulation Gaming, Petri-Nets and Virtual Simulation, excluding simulation for physical design. According to this study, the first five techniques were the most commonly presented/used in the selected papers for that review. Initially in our study we also considered papers that reported on the use of Intelligent Simulation and Parallel & Distributed Simulation (PADS). However, these categories were later dropped owing to the fact that only a few relevant papers pertaining to the aforementioned categories were found in our sample study (one or two for each category). Moreover, our choice of simulation techniques is further supported by the study conducted by Fone et al (2003), wherein DES, SD and MCS are discussed as popular simulation techniques in healthcare. For an introduction to the aforementioned techniques, the readers are referred to Rubinstein (1981) for MCS, Robinson (1994) for DES and Sterman (2001) for SD. ABS is the most recent of the four simulation methods and is used since mid-1990s.

3 RESEARCH PROFILING METHODOLOGY

The literature review methodology is divided into three distinct phases, whereby each phase realises one of the three objectives of our methodology. The three stages of our research profiling methodology are shown in Figure 1. It is to be noted that each phase comprises of two or more distinct stages. These are described next.

3.1 Phase one: Identification of relevant healthcare simulation papers

For the purpose of our research we wanted to identify publications with highest credibility and thus we looked only at the journal articles from the ISI Web of Science® database (ISI WoS), part of the ISI Web of Knowledge^{SM} (http://apps.isiknowledge.com) platform of quality research databases. The Web of Science® is one of the largest databases of high-quality academic journals (journals with an impact factor rating) and provides access to bibliographic information pertaining to research articles published from 1970 onwards. ISI WoS indexes approximately 10,000 high impact research journals that are spread across approximately 250 disciplines.

In an increasingly metric-driven world, the impact factor of a journal is arguably a significant factor in determining quality of research. The overall set of papers with impact factors are subject to rules of inclusion by the ISI WoS. As such, some factors may therefore not be taken into account when basing quality on impact factors. We merely wish to provide an analysis of literature within the scope of journals with impact factors and therefore provide some reflection as to the "health" of healthcare simulation within a potentially metric-driven world. The readers should also note that this research is not a systematic review of publications in healthcare simulation and, as such, other abstract, citation and bibliographic databases have not included in our study. Moreover, there is a vast 'grey literature' in healthcare simulation but this paper focuses only on the academic literature as described above.

As can be seen from Figure 1, three different stages constitute phase one of our methodology. Stage 1 is primarily concerned with structuring an ISI WoS query that will return articles that have used at least one of the simulation techniques (MCS, DES, SD, ABS) in the healthcare context. To identify articles which would be incorporated in our study's dataset the following criteria were used: inclusion of the words, *"simulat*"* OR *"health*"* in the article's title and both of the words/phrases (*"Monte SAME Carlo"* AND *"health*"*) OR (*"Discrete SAME Event *"* AND *"health*"*) OR (*"System* SAME Dynamics"* AND *"health*"*) OR (*"Agent SAME Based"* AND *"health*"*) in the abstract or keywords of the published paper. The SAME operator returns records where the terms separated by the operator

appear in the same sentence. The use of the asterisk "*" in the Boolean keywords combination, allowed for the inclusion of keyword derivatives in the search options. It should be noted that the search identified only documents written in the English language from 1970 until 2007 (inclusive). Only articles and review papers were included in the search. The same search was repeated for DES, SD and ABS.

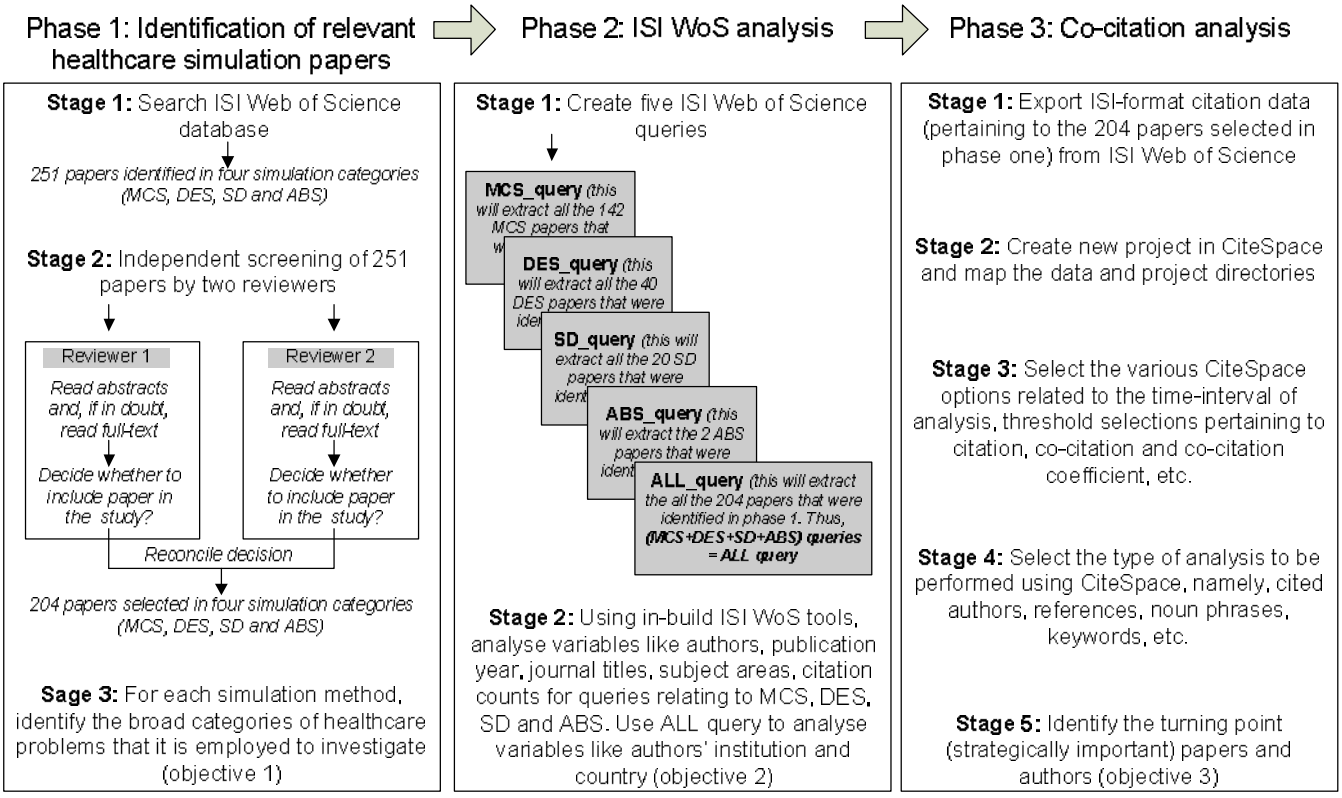

Figure 1: The Literature Profiling Methodology

The second stage of phase one involved the screening of these papers. Two authors independently and critically reviewed all papers by reading their abstracts and, if in doubt, reading the whole article. The appraisal was carried out based on certain paper-inclusion criteria, (a) selected papers should evidently demonstrate strong relation with the healthcare sector or have an impact on healthcare and use the chosen simulation method to describe, analyse or assess the phenomenon, and (b) the paper should spend at least one paragraph describing the applied simulation method that was used in the research.. Thus, physics simulations and human systems simulations did not fulfil the inclusion criteria. However, the boundaries between health-related papers and non health-related papers were not always straightforward. In many papers the impact on human healthcare is provided by a less direct relationship. In such cases the reviewers took a flexible approach by including papers which one could clearly relate the problem described with some kind of health impact. Thus, simulation papers related to pollution and contamination, food poisoning, drug dosage and pharmacokinetics, etc. have been included in this study as these topics have a health impact. Each of the reviewers assessed all abstracts independently and results were compared. In cases of discrepancies, the conservative route was taken and the full-text of the paper was examined. This was followed by a discussion between the reviewers, subsequent to which a decision was reached for the paper's inclusion or exclusion in the study. The full-text of the papers which fulfilled the inclusion criteria were downloaded and those not available online were requested via inter-library loan services. Table 1 shows the results of the search strategy (stage 1) and the screening (stage 2).

Table 1: *No. of identified and selected papers*

Simulation Methods	Identified papers (Stage 1)	Percent	Selected papers (Stage 2)	Percent
Monte Carlo Simulation	163	64.9%	139	69.15%
Discrete-Event Simulation	51	20.3%	38	18.91%
System Dynamics	31	12.4%	17	8.46%

Agent-Based Simulation	5	2.4%	2	1.00%
Multiple simulation methods	0	0.0%	5	2.49%
SUM	**251**	**100.0%**	**201**	**100.00%**

Of the selected papers, MCS seems to be by far (142 papers) the most applied method dealing with health issues. It is followed by DES (40 papers) and SD (17 papers). Finally, the method with the least number of papers is ABS (2 papers) - this is not a surprise since it is the most recently developed simulation technique. The reader should note that some of the papers incorporated more than one simulation techniques and were thus entitled to fit into more than one simulation category. However, these results cannot be generalised because we have not undertaken a systematic review. Nonetheless, we believe that the statistics in Table 1 provide the readers with a sense of the current "state-of-play" in this research area.

The third stage of phase 1 of our literature profiling methodology concentrated on the content of the papers. The aim was to gain a better understanding of how extensively simulation methods have been used to address health problems and to identify health applications pertinent to each simulation method applied. As can be seen in Figure 1, stage three realises objective one of our methodology, namely, to identify the broad categories of healthcare problems that each of the identified simulation methods is employed to investigate. The readers should take note that these results are not presented here since the objective of this paper is to propose a methodology for profiling literature in healthcare simulation. These results have been presented in a paper submitted to a journal (presently under review).

3.2 Phase two: ISI WoS analysis

The second phase of our literature profiling methodology consists of two stages. The objective of this phase is to use inbuilt ISI WoS tools to profile some key variables (such as authors, publication year, etc.) associated with the papers that were selected in phase one. It would be interesting to know, for example, the authors who have published the most papers in each of the four simulation categories. Since we were interested in (a) analysing variables based on each simulation technique, and (b) utilising ISI WoS tools for this purpose, therefore we created four ISI WoS queries (*MCS_query, DES_query, SD_query, ABS_query*), each of which would retrieve articles pertaining to MCS, DES, SD and ABS respectively. Thus, query *MCS_query* would retrieve 142 MCS-specific records from ISI WoS, *DES_query* would retrieve 40 records, and so on and so forth (please refer to Figure 1 [phase two-stage 1] and Table 1). Furthermore, in order to retrieve aggregate results, we created a fifth query (called *ALL_query*), which when executed on ISI WoS would return all the 201 records that we selected for inclusion in phase one of our methodology. Each query used the title of the paper (the variable *"TI"* in ISI WoS advance search options) to conduct the search. Thus, the most complex query was *ALL_query*, in which the search string consisted of the titles of all the 201 papers which were logically joined by merging together 21 individual queries.

The second stage of this phase involved analyses of variables like authorship, institution/territory, publication year, citation count, etc. The analysis was conducted using tools inbuilt in ISI WoS database. Again, since the focus of this paper is only on the methodology, these metrics are not presented in this paper. They have been included in a paper submitted to a journal and which is presently undergoing review.

3.3 Phase three: Co-citation analysis

Phase three of this literature profiling methodology is concerned with the co-citation analysis of references that have been cited by the 201 papers that were included in our study. It is important to distinguish between citation analysis and co-citation analysis. In a citation-based analysis the significance of an article is often measured on the basis of the number of citations it has had. However it can be argued that there may exist certain articles that can be considered high-impact even thought the number of citations it has received is comparatively less (for example, papers that have been cited a few times *but* across domains/years or papers that have been published recently). The opposite of this may also be true (for example, self-citations or a group of authors citing each others' work will usually increase the number of citations for a paper). Furthermore, it usually takes at least 5-6 years for a paper to build up its citation count. Using only citation metrics to identify important papers would risk excluding articles that hold promise, but have only been published recently. Co-citation analysis has the potential to identify important articles, which would otherwise have been overlooked if only conventional citation analysis techniques were used. Co-citation analysis and visualisation software such as CiteSpace (Chen, 2004) can identify strategically important papers by employing data-mining techniques and

visualisation algorithms to citation data downloaded from the ISI WoS.

We have used CiteSpace in our research in order to identify strategically important papers and authors through co-citation analysis of the approximately 6350 non-unique references included in our dataset of 201 healthcare simulation journal papers. CiteSpace identifies potentially significant articles/authors (also called strategically important or turning point articles/authors) in a co-citation network through *landmark nodes* (a node with extraordinary attributes), *hub nodes* (widely co-cited article) and *pivot nodes* (common nodes that are shared between two co-citation network or gateway nodes that are interconnected by inter-network links), and by enhancing the visual features of such nodes it makes it easier to detect them through visual inspection (Chen, 2004). In this analysis we are interested in the identification of potentially significant articles (through visualisation of document co-citation network) and significant authors (through visualisation of author co-citation network) irrespective of their citation count.

As can be seen from Figure 1, the third phase of our methodology is divided into five stages. These stages are listed in Table 2. It is to be noted that these five stages realize objective three of this paper, namely, identification of strategically important papers and authors in the subject area of healthcare simulation.

Table 1: *The five stages in phase three of our methodology*

Stages	Description
Stage 1	In this stage we downloaded ISI-format citation data pertaining to our dataset of 201 healthcare simulation articles from the ISI Web of Science database. In ISI-format data, meta-data tags are appended to qualify citation-specific fields. For example, tags "AU", "TI", "SO" and "CR" are used to qualify the author(s), the title, the journal and the cited references respectively. Citespace is programmed to process ISI format data.
Stage 2	We created a new project in CiteSpace and mapped the project and data directories. The data directory contains citation data downloaded from stage 1.
Stage 3	We selected CiteSpace options related to the time interval of analysis (e.g., 1970-2007); the unit of analysis (e.g., 5 years); threshold selection pertaining to citation counts *(C)*, co-citation counts *(CC)*, and co-citation co-efficients *(CCV)* and applied to the earliest, the middle and the last time slice (interpolated thresholds for the remaining time slices); pruning and merging; and visualisation (Chen, 2006).
Stage 4	We performed two types of analysis using CiteSpace, namely, *references* and *cited authors*. This co-citation analysis identifies important papers (through the "document co-citation network") and authors (through the "author co-citation network") that have been referred to by the 204 journal publications in our healthcare simulation dataset.
Stage 5	This stage involves the analysis of the results/visualisation generated by CiteSpace.

This following discussion pertains to stage 4 (see Table 2). In our study we have performed the following two analyses, (a) articles that may be considered as turning-point/strategically important, and (b) authors that may be considered as turning-point/strategically important. Nodes and links are the building blocks of a co-citation network. CiteSpace supports a total of eight different node types. For the purpose of our analysis we use the following two node types (NTs) - *NT References* and *NT Cited authors* (see Figure 2). For each of the above mentioned NTs, the citation (C), the co-citation (CC) and the co-citation co-efficient (CCV) thresholds determine the nodes that will ultimately be selected for subsequent processing and will thus be included in the CiteSpace-generated sequence of co-citation networks. Figure 3 shows the CiteSpace-generated "document co-citation network" that identifies potentially significant articles. As has been mentioned earlier, we are not presenting the results derived by employing our profiling methodology in this paper, since the focus of this paper is only on the methodology.

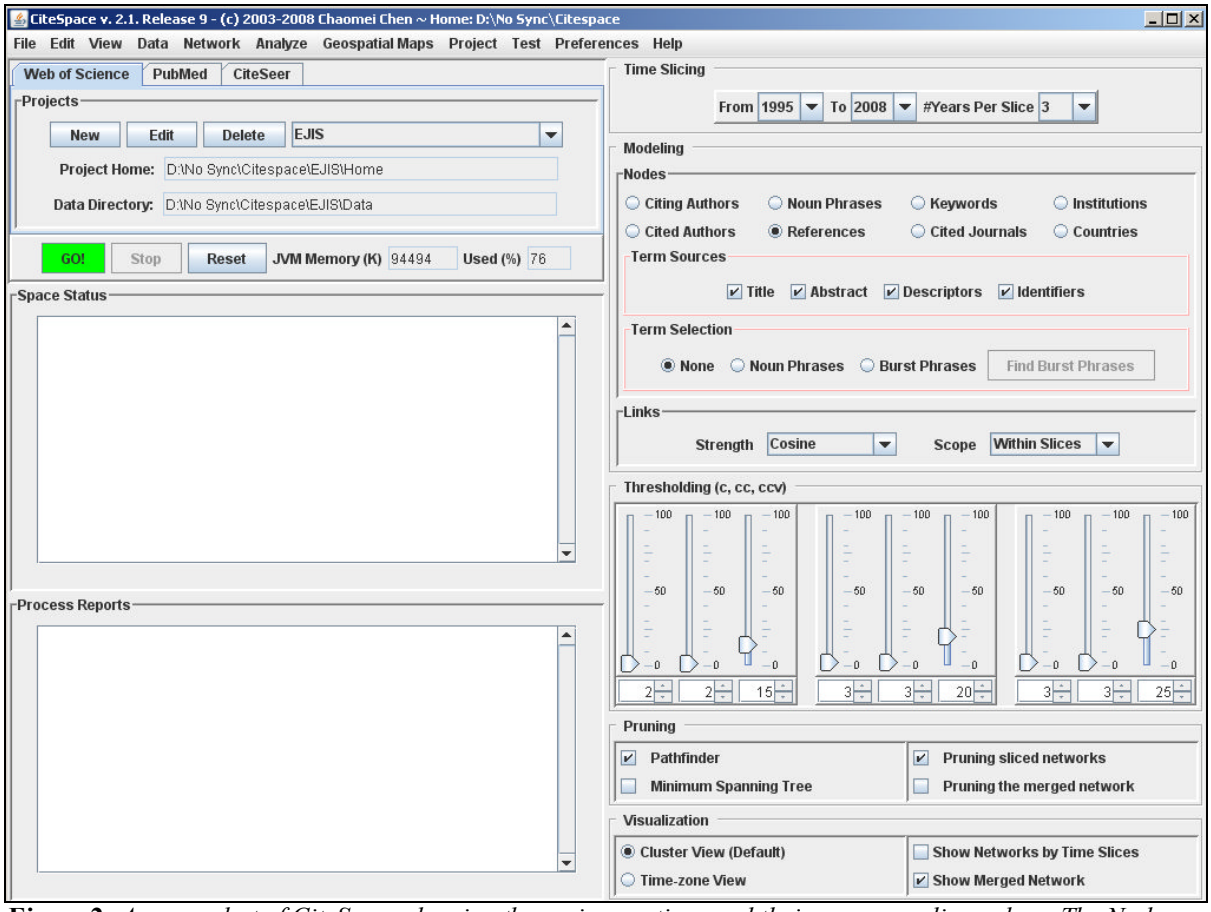

Figure 2: *A screenshot of CiteSpace showing the various options and their corresponding values. The Node Type (NT) selection panel is shown on the top right and the C, CC and CCV thresholds are shown in the middle (right hand side).*

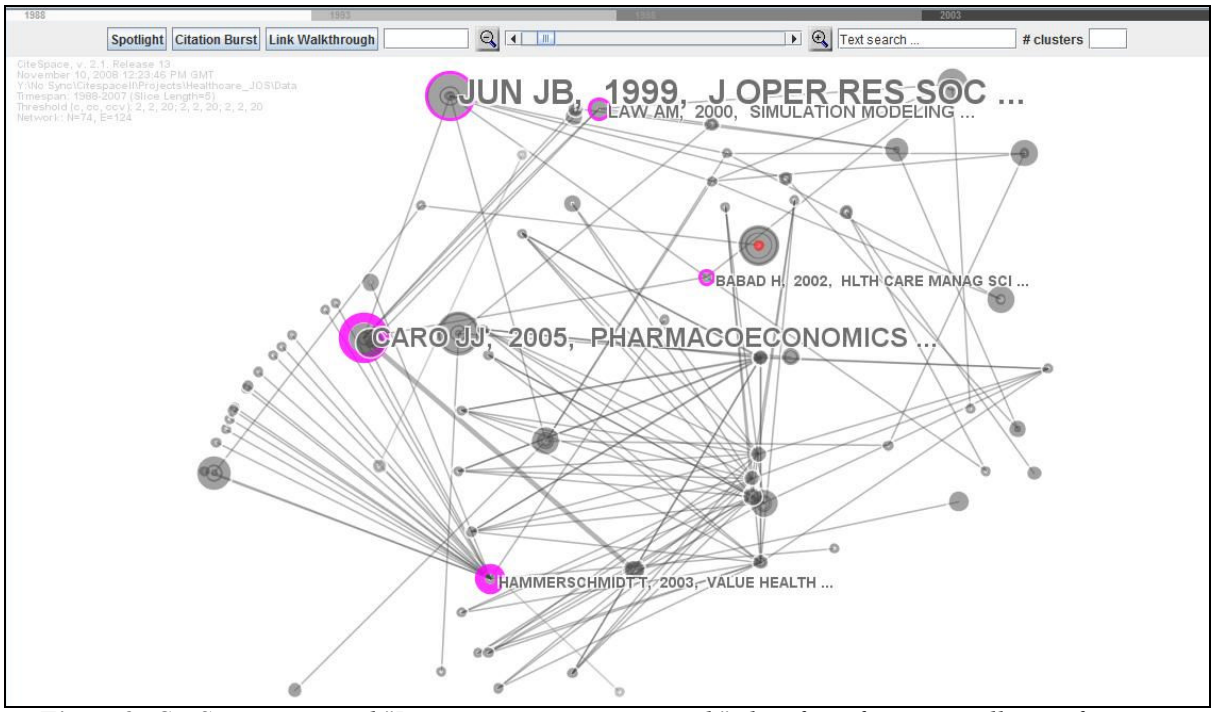

Figure 3: *CiteSpace generated "Document co-citation network" identifying five potentially significant articles articles*

4 RESULTS SUMMARY AND REFLECTIONS

As this paper concerns with the approach of profiling literature in healthcare simulation rather than the results, in this section we present only our main "headline" results from our identified dataset of 201 healthcare simulation papers and reflect on their usefulness. The full results of this survey can be found in (Mustafee et al, 2009).

A great number of health topics have been approached with simulation techniques which have offered greater insights with regards to: health risk assessment, health interventions, cost-benefit analysis of medical treatment and disease management programs, health policy evaluation, planning of healthcare services, contagious disease interventions, infrastructure systems and staff/students training. MCS seems to be the most popular simulation technique in health studies and the majority of papers fall within the health risk assessment category. Cost-benefit analyses health studies are also popular and hold the first positions in terms of research impact with high number of citations. Arguably, this demonstrates the importance attributed to researching new ways that would better utilise the finite budget available for various treatments.

The field of healthcare simulation has evolved significantly over the past 30 years and the proportion of papers published in the field have drastically increased, with more than three quarters published after 2000. Year-to-date figures suggest that this gradual upward trend will continue. A key factor for this may be that funding of research grants have increased in recent years (Murphy and Topel, 2003).

More than half of the identified MCS studies have been published with descending order under the a) Environmental Sciences, b) Public, Environmental & Occupational Health and c) Pharmacology & Pharmacy subject categories. A good number of DES studies have been published in a) Operations Research & Management Sciences and b) Management and the SD studies vice versa (Management first and secondly Operations Research & Management Sciences subject categories). The most popular journal that hosts such research is the *Journal of the Operational Research Society*, followed by *Risk Analysis* and *Health Economics*. The most productive authors in our dataset are Davies with 7 DES papers, followed by Brailsford (5 DES and 1 SD paper) and Ahmad, with 4 SD papers.

The University of Southampton (UK) has the highest number of publications (12). This is hardly surprising since two authors who were/are affiliated to The University of Southampton (Davies and Brailsford) were identified as the two most productive authors. The other institutions have few publications. The University of Michigan is second with 5 publications, Harvard and Sheffield have 4 and many other follows with 3 or fewer. One reason for this can be that healthcare simulation is still at its infancy and research is usually carried out by lone academics, who may collaborate with colleagues from other institutions. There are relatively few research centres that are dedicated to healthcare simulation. One example of such a centre is Clinical Operational Research Unit (CORU) at University College London.

Aggregate statistics pertaining to the countries in which the authors' affiliated institutions are based shows that the highest number of publications come from the USA (99 publications), the UK (39 publications) and Canada (21 publications). It is also interesting to note that four UK Universities (Southampton, Sheffield, Brunel and Bath) account for more than half of all UK's publications.

The most highly cited publication in MCS and overall comes from Chrischilles et al. (1994) in *Bone* focusing on the costs and health effects of osteoporosis. In DES, the most cited paper is again from the same year (Davies and Davies, 1994) in *Omega* which deals with the modelling of patient flows and resources in health systems. In SD, a most recent paper (Lane et al, 2000) in *JORS* looks at improvements in an accident and emergency department.

Hammerschmidt, et al. (2003) and Briggs is the first in the list of turning point articles and authors respectively identified by CiteSpace. The main theme linking these turning point articles is best practice or methodology and a significant subject area which raised public debate. It must also be noted that only two articles (out of 5) and seven authors (out of 23) that were identified by CiteSpace as turning point were present in our list of 201 papers. This also shows that turning-point papers and authors do not necessarily appear/publish in impact-factor journals.

5 CONCLUSIONS AND LIMITATIONS

The literature profiling methodology presented in this paper was developed for a sample review of healthcare simulation studies that aimed at identifying healthcare problems that are modelled using four popular simulation techniques, namely, MCS, DES, SD and ABS. The specific selection criteria for articles that were reviewed

in the course of this study would have inevitably left out a number of noble publications in the field (e.g. articles that do not mention health in their title-topic but refer to health problems with more specific terms such as hospitals, patients, etc.; articles that did not appear in journals indexed by ISI Web of Knowledge®). The implications of this are that there may be an unintentional bias introduced by the specific keywords search and by ISI WoS membership which leaves out newer journals that have not yet met the "duration of service" required by the ISI WoS and journals which editorial boards do not wish their journal to have an impact factor. These factors may therefore not be taken into account when basing quality on impact factors. However, the debate as to whether this is right or wrong is outside the scope of this article. We merely wish to provide an analysis of literature within the scope of journals with impact factors and therefore provide some reflection as to the "health" of healthcare simulation within a potentially metric-driven world. We hope that this study gives an indication of the pulse of research being conducted in the healthcare simulation field although generalisation of the results may not hold.

Future research could involve broadening the scope of our literature review (for example, profiling literature in OR/MS) and including other academic databases (for example, Scopus) to look at the relationships between impact factor journals and non-impact factor journals (especially as Scopus potentially contains a further 1,500 articles of relevance). Future research could also involve the use of the full feature-set of CiteSpace to discover not only the turning-points, but also identifying co-authorship networks, co-occurring phrases and keywords, journal co-citation networks, etc. Finally, we hope that in the future our methodology (or its derivatives) will be used by researchers to conduct similar literature reviews in other disciplines.

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