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Simulation modelling is 50! Do we need a reality check?

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Simulation modelling is a fascinating research field. The techniques and tools of simulation modelling have been used to research and investigate the behaviour of various systems in a wide range of areas such as commerce, computer networks, defence, health, manufacturing and transportation. Indeed, the study of the use of these techniques and tools, and the development of new forms of these, are a rich source of research in their own right. Simulation modelling is about to reach the 50th anniversary of the development of GSP (General Simulation Program), the first simulation modelling language (Tocher and Owen, 1960). There have been several historical accounts of simulation modelling research. To complement these, we have performed a review of the recent history of simulation modelling. This study targeted three leading journals dedicated to this field. These are the *ACM Transactions of Modeling and Computer Simulation, Simulation: Transactions of The Society for Modeling and Simulation International* and *Simulation Modelling Practice and Theory* (formerly *Simulation Practice and Theory*). The study covered the first 6 years of this century (2000–2005) and included 576 papers. The key observation of this work was the relative lack of 'real world' involvement in simulation modelling research and an even greater lack of evidence of 'real world' benefit, arguably very alarming outcomes for an applied field. To further investigate this observation two additional surveys were carried out, one to study if real world papers appeared in the more widely known OR/MS literature (837 papers in 12 journals) and one to study if such papers appeared in Manufacturing and Logistics, an application area closely associated with simulation modelling (1077 papers in 10 journals). The results of these surveys confirmed our observations. We ask if this is the natural evolution of a field that has existed for half a century or an indication of a worrying problem? This paper reports on our findings and discusses whether or not simulation modelling research urgently needs to face a 'reality check.'

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1. Introduction

Simulation modelling, or modeling & simulation, is a fascinating multi-disciplinary field that draws on a wide range of techniques and tools. Simulation modelling is used to research the behaviour of real-world systems in a wide range of areas such as communication, defence, health, manufacturing and transportation. The study of the use of the techniques and tools of simulation modelling, and the development of new forms of these, is a rich source of research in their own right. Simulation modelling has almost reached its 50th anniversary marked by the development of General Simulation Program (GSP), the first simulation modelling language and the first published work in simulation modelling (Tocher and Owen, 1960). Today, many researchers and practitioners are involved in the progress and application of the field.

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Where are we now? There have been many reviews of simulation modelling research (eg Nance and Sargent, 2002; Robinson, 2005) and reports from experts (eg Taylor and Robinson, 2006; Goldsman *et al*, 2007; Lendermann *et al*, 2007). These present simulation modelling as a thriving area with much research still to do. However, none of these concentrate on what might be argued as the core output of the field, that is journals specifically dedicated to publishing peer-reviewed articles in simulation modelling. These are the *ACM Transactions of Modeling and Computer Simulation, Simulation: Transactions of The Society for Modeling and Simulation International* and *Simulation Modelling Practice and Theory* (formerly *Simulation Practice and Theory*). To reflect on the recent focus of this field, we examine the literature from the first 6 years of this century (2000–2005) (576 papers). As we will see, this examination reveals a lack of simulation modelling publications describing 'real-world' systems and an even greater lack of evidence of 'real-world' benefit; arguably very alarming outcomes for an applied field. To further investigate this, we carry out two additional surveys, one to study if

real-world papers appear in the more widely known OR/MS literature (837 papers in 12 journals) and one to study if such papers appear in Manufacturing and Logistics, an application area closely associated with simulation modelling (1077 papers in 10 journals). The results of these surveys confirm our observations. We reflect on the role of the real world in academic publishing and ask if this is the natural evolution of a field that has existed for half a century or an indication of a worrying divergence between theory and practice? Here we report on our findings and discuss whether or not published simulation modelling research urgently needs a reality check.

The paper is structured as follows. In Section 2, we present a review of studies of simulation modelling literature. In Section 3, we present our review approach that attempts to bring together aspects of previous reviews and adds a quantitative dimension. Section 4 presents the detailed results of our study. Section 5 analyses these results and presents some initial observations. The discussion of Section 6 presents the results of two further surveys and a comment on the nature of OR/MS publishing. The discussion continues by debating if simulation modelling does need a 'reality check' and what opportunities exist. Section 7 brings the paper to a close and suggests future survey work that might be carried out.

2. Studies of simulation modelling literature

There are essentially three different types of simulation modelling literature studies. These are *historical reviews, methodology reviews* and *application reviews*. Historical reviews typically cast the widest net across the literature in order to 'look back to look forward'. In these, authors identify key papers that they consider important to the historical development of simulation modelling. Methodology reviews address articles that are again key to the historical development of simulation modelling but consider specific topics, such as output analysis and simulation software. Both historical reviews and methodology reviews tend to be carried out by authors from within the simulation modelling field. Application reviews tend to be carried out by a mixture of authors that are either within the simulation modelling field or outside of it (ie 'champions' of simulation modelling in different disciplines). All are important as they represent important summaries of simulation modelling and give researchers the opportunity to take stock of their own discipline and area. We now present examples of each to give motivation to our own review approach.

Several fascinating *historical reviews* have been written. As part of the anniversary issue of *Operations Research*, Nance and Sargent (2002) review the 'art and science' of simulation modelling and the bidirectional influence it has on, and by, the fields of computer science, probability and statistics, and mathematics. Robinson (2005) presents another historical perspective on simulation modelling and associated areas from the 1950s to the present day. The review discusses significant developments that occurred during this history and questions the need of following developments in computing without significant developments in simulation modelling methodology. An alternative historical review is by Hollocks (2006) who gives a personal account of the history and evolution of simulation modelling with a particular interest in software development up to 1992. He extrapolates from that history to comment on the continuing evolution of simulation modelling and its software. Shafer and Smunt (2004), however, take a different approach by studying trends in empirically based simulation modelling studies in 20 operations management journals from 1970 to 2000 (an area strongly related to manufacturing). Their study identified 85 papers of empirical work out of 600 simulation modelling studies performed from 1970 to 2000. They discovered that the majority of articles appeared in *Decision Sciences, Interfaces* and the *Journal of the Operational Research Society*. They also discovered that the topic of scheduling tended to dominate these articles and that there was a recent (in their collection period) increase in some areas of manufacturing (Capacity Planning, Cellular Manufacturing and Process Design). However, the main publishing trend indicated an overall slight increase in articles relating to empirical studies ($< 15\%$). The journals covered by their review did not include the three simulation modelling journals in our study.

There have been many examples of *methodology reviews* where authors present their account of relevant literature on an aspect of simulation modelling methodologies (and related techniques and/or technologies) in terms of simulation modelling as a discipline. The primary purpose of these reviews is to effectively establish a foundation of literature from which major observations of an area can be made. These papers are highly useful as they serve to summarize the state-of-the-art of the particular area and give the potential for the simulation modelling community to move forward as a whole. For example, Fu (1994) reviews techniques for optimizing stochastic discrete-event systems via simulation modelling. This was further updated in Fu (2005) which describes the main approaches and recent advances for optimization as well as summarizing supporting software. Andradottir (1998) also reviews optimization techniques with respect to continuous and discrete decision parameters. Swisher *et al* (2003) review these with respect to ranking, selection and multiple comparison techniques. In a related area, Kleijnen (2005) reviews approaches to sensitivity analysis and designs for experiments in simulation modelling. Alexopoulos (2006) presents a comprehensive review of methods for the analysis of outputs from simulation modelling experimentation. Müller and Schumann (2003) investigate methods for the visualization of time-dependent data that can be used to investigate aspects of simulation modelling and give an overview of dynamic presentation techniques and event-based visualization. Kuljis and Paul (2000) review the implications of the World Wide Web with respect to the development of simulation modelling software and applications. Finally, Swain (2003) continues his bi-annual review of software tools used in this area.

Rather than having a commentary on simulation modelling methodology as its focus, *application reviews* attempt to summarize literature in order to make observations on the impact that simulation modelling has had on an application area. There are many excellent and diverse examples of these and here we present a small selection. For many years simulation modelling has been used for the investigation and improvement of manufacturing and logistics systems. In this area, van der Zee (2003) reviews approaches to using simulation modelling to investigate scheduling of batch operations in manufacturing, Angerhofer and Angelides (2000) review the use of systems dynamics to investigate management issues in supply chains, and Kremer and Hancock (2006) review process modelling efforts which have been developed to investigate the fundamental physical processes underlying the manufacture and delivery of pharmaceutical dosage forms. In health care, Brailsford (2007) discusses issues relating to advances and challenges in simulation and health care, Eldabi *et al* (2007) consider the future of the area against past research, Cooper *et al* (2007) review the range of possible modelling techniques that can be used in this area, and Jun *et al* (1999) review discrete-event simulation in health care clinics. In a study of how organisms function on the molecular level in relation to gene expression, de Jong (2002) reviews formalisms that have been employed in mathematical biology and bioinformatics to describe genetic regulatory systems and how these formalisms have been used in the simulation modelling of the behavior of actual regulatory systems. Parker *et al* (2003) give an overview of how multi-agent system models have been used to investigate environmental issues in land-use and cover change. Similarly, Gotts *et al* (2003) review how agents in simulation modelling have been used to study social dilemmas. Mills (2002) reviews the impact that simulation modelling has had on the teaching of statistics in the classroom. Finally, Gwynne *et al* (1999) investigate how simulation modelling techniques can be used to analyse evacuation scenarios and reviews the capabilities of the models that have been developed to support this analysis.

In summary, the three different review types help us understand what lessons the history of simulation modelling might have for the future or to establish a common foundation of the state-of-the-art of a particular aspect of simulation modelling methodology or application area. What these reviews do not give us is an idea of the relative breakdown of how much work is actually being published in what area. For example, a review might give a particular focus to work being performed in biology but it does not give an indication of how much work is being published when compared to, say, manufacturing. It is our observation that an area that has several reviews dedicated to it might appear a lot larger than one that has one or none. To complement these reviews we therefore wish to present an alternative approach for performing a review.

3. Review approach

The previous section served to identify three different types of review. In general, historical reviews tend to discuss the development of simulation modelling as a discipline, methodology reviews tend to summarize contributions made in an area of simulation modelling, and application reviews tend to summarize how simulation modelling has been applied to an area in terms of methodological advancements and how it has been used to investigate aspects of that area. The methodology of these reviews tends to be qualitative, that is, the author(s) form(s) a viewpoint on an aspect of simulation modelling by commenting on related articles. The viewpoints formed by the author(s) are extremely valuable in that they represent summaries of work in that area. Key articles and contributions are typically identified and areas and opportunity for future research are highlighted. Shafer and Smunt (2004) represent an exception to these where a quantitative approach is taken. Their studies allowed them to make observations on the journals, topics and trends of different aspects of simulation modelling (with respect to operational management) in terms of the numbers of published articles. The results led to different and useful conclusions about simulation modelling publishing that could not be demonstrated using a qualitative approach (such as the dominance of *scheduling* as a research topic). We therefore wish to add a quantitative dimension to our review.

We are interested in research as represented by journals publishing work on simulation modelling and the areas in which simulation modelling has been used to investigate or improve systems. We are also interested in research concerning the *methods* used to study these systems (methodology). In addition to this, for reasons outlined in the introduction, we are also interested in the extent to which this research is motivated by real-world problems. To summarize, we wish to find answers to the following questions:

- In what areas are the techniques and tools of simulation modelling being studied (Methodology)?
- In what areas is simulation modelling being used to study systems (Investigation)?
- To what extent are real-world systems involved in this research?
- What real-world benefit has simulation modelling research demonstrated?

To do this we classify papers on the basis of major contribution to the development of simulation modelling as a discipline and/or the use of simulation modelling as a tool to investigate a particular domain. We identify two main groupings, *Methodology* (and associated developments in technology or technique) or *Investigation*. For example, if the main contribution of a paper was the development of a novel optimization technique we would classify this as a Methodology paper. We would also classify advances in software tools, simulation modelling languages and parallel and

Table 1 Classification areas with notes

Area	*Notes*
Biology (Bio)	
Computing (Comp)	Including computer architecture, management, performance, high performance computing, logic, ubiquitous computing and distributed systems
Control (Cont)	Including electrical, hydro-electric, mechanical and real-time systems
Defence (Def)	
Education (EDu)	Including distance learning and technological support issues
Environmental (Env)	Including physical, water, energy, chemical and mining issues
General (Gen)	Including methodologies, tools and techniques such as those relating to discrete-event simulation modelling, system dynamics, Monte Carlo simulation modelling, mathematical modelling, languages, DEVS, component-based simulation modelling, agent-based simulation modelling, parallel and distributed simulation modelling, standards, Grid computing, visualization and statistics
Health Care (HC)	
Manufacturing and Logistics (ML)	
Networks and Communication (NC)	
Social Systems (SS)	
Transportation (Trans)	Including air, road, maritime and related issues
Other	Categories having one entry for all journals over review period (see results for specific areas)

distributed computing technologies as Methodology. Papers would be classified as being Investigation if, simply, simulation modelling techniques were used to investigate a given system. We also considered the problem of a paper having contributions involving both methodology and investigation, that is, a new simulation modelling technique was developed and was then used to investigate a system. If this was the case, then we would classify the paper as being both. Alternatively, if the paper had no contribution to methodology or did not perform an investigation, then we would classify the paper as being *Other*. This category includes descriptions of new languages and software tools, panel reports, opinion pieces and literature reviews. Note that we did not include articles such as editorials or book reviews in our survey.

For papers classified as either Methodology or Investigation, to further refine our survey we classified these papers by domain *area*. The identification of category areas was done iteratively. In the first iteration, each paper was effectively given its own area as we discovered that in 576 papers there was a remarkable amount of diversification. Table 1 shows these final categories with notes on the detail of each category.

To investigate the level of 'real-world' involvement, we attempted to identify any evidence that the contribution of a paper was motivated by a real-world problem. For example, if a paper presented the results of an investigation of a new production line, it would clearly have a real-world involvement. Similarly, if a paper outlined a problem that had been encountered in the real world; for example, that end users find simulation difficult to use, and then presented a novel approach to deskilling simulation, then we would class this as having 'real-world' involvement. We then divided this involvement into three 'cumulative' categories: papers that solve problems with a clearly identifiable real-world problem or papers that are clearly motivated by such a problem; papers with evidence of a solution to that problem; and papers with some evidence of the benefit that this solution presented to the real world. For example, a paper reports on the production problems of a semiconductor manufacturer. The solution is based around the use of simulation modelling to better schedule production. If the paper identified the problem, gave a solution and then demonstrated the system improvements made by the new technique, the paper would be classified as 'investigation' and then as having real-world involvement, a solution and a real-world benefit. Similarly, a paper could observe that health practitioners find it difficult to use simulation modelling. The paper then proposes a new tool that is aimed at making simulation modelling easier. If in this case the paper then shows the successful use of the tool then it would be classified as 'methodology' with real-world involvement, solution and benefit. Figure 1 shows this classification. We now present the results of this work.

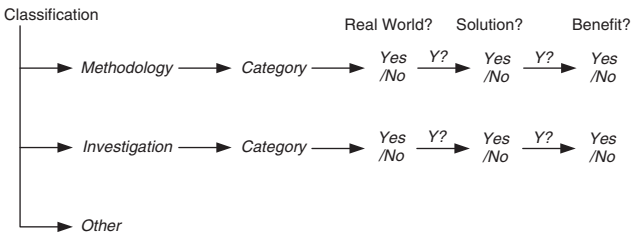

Figure 1 Real world involvement classification.

4. Results

A total of 576 papers from the simulation modelling journals *ACM Transactions of Modeling and Computer Simulation, Simulation: Transactions of the Society for Modeling and*

Table 2 Classification by type and year

Year	*Meth*	*Inv*	*Oth*	*Total*	*Meth %*	*Inv %*	*Oth %*
2000	64	26	5	95	67.37	27.37	5.26
2001	49	16	6	71	69.01	22.54	8.45
2002	53	40	4	97	54.64	41.24	4.12
2003	71	29	4	104	68.27	27.88	3.85
2004	62	31	4	97	63.92	31.96	4.12
2005	79	31	2	112	70.54	27.68	1.79
Total (ALL)	378	173	25	576	65.63	30.03	4.34

Table 3 Classification by type and area

Area	*Methodology*		*Investigation*		*Total*			
	#	*%*	*#*	*%*	*#*	*%*	*%M*	*%I*
Bio	11	2.91	0	0	11	2	100.0	0.00
Comp	18	4.76	9	5.2	27	4.9	66.67	33.33
Cont	14	3.7	5	2.89	19	3.45	73.68	26.32
Def	16	4.23	2	1.16	18	3.27	88.89	11.11
Edu	7	1.85	0	0	7	1.27	100.0	0.00
Env	20	5.29	12	6.94	32	5.81	62.50	37.50
Gen	158	41.8	23	13.29	181	32.85	87.29	12.71
HC	15	3.97	15	8.67	30	5.44	50.00	50.00
ML	43	11.38	38	21.97	81	14.7	53.09	46.91
NC	45	11.9	33	19.08	78	14.16	57.69	42.31
SS	2	0.53	18	10.4	20	3.63	10.00	90.00
Tran	24	6.35	14	8.09	38	6.9	63.16	36.84
Oth	5	1.32	4	2.31	9	1.63	55.56	44.44
Total	378	100	173	100	551	100	68.60	31.40

Table 4 Classification by real world involvement (RW), solution (So) and benefit (B)

Area	*Methodology*		*So?*	*B?*	*Investigation*		*Total*					
	#	*RW?*			*#*	*RW?*	*So?*	*B?*	*#*	*RW?*	*So?*	*B?*
Bio	11	0	0	0	0	0	0	0	11	0	0	0
Comp	18	0	0	0	9	0	0	0	27	0	0	0
Cont	14	5	5	1	5	2	2	0	19	7	7	1
Def	16	1	1	0	2	0	0	0	18	1	1	0
Edu	7	5	5	2	0	0	0	0	7	5	5	2
Env	20	10	10	3	12	4	4	0	32	14	14	3
Gen	158	1	1	1	23	1	1	0	181	2	2	1
HC	15	11	11	2	15	10	10	2	30	21	21	4
ML	43	8	8	2	38	20	20	11	81	28	28	13
NC	45	3	2	0	33	4	4	1	78	7	6	1
SS	2	1	1	1	18	3	3	1	20	4	4	2
Tran	24	2	2	1	14	1	1	1	38	3	3	2
Oth	5	0	0	0	4	0	0	0	9	0	0	0
Total	378	47	46	13	173	45	45	16	551	92	91	29

Simulation International and *Simulation Modelling Practice and Theory* (formerly *Simulation Modelling Practice and Theory*) were classified in the 6-year period from 2000 to 2005. Table 2 shows the classification of the number of papers published each year over the period of the survey by Methodology, Investigation and Other. Table 3 expands Methodology and Investigation over each area identified in Table 1. The table shows the relative percentage of each type of paper for each area overall and the split by area. For example, the area biology accounts for 2.91% of the

Methodology papers and 0% of the Investigation papers. The split for biology is therefore 100% Methodology papers and 0% Investigation papers. Table 4 shows the real-world involvement of a paper by type and area. For example, the area environment has 20 methodology papers of which 10 were clearly motivated by real-world problems, 10 had some solution and three demonstrated some real-world benefit.

To summarize the main findings, of 576 papers 378 were Methodology (65.62%), 173 (30.03%) were Investigation and 25 (4.34%) were Other. Of these 92 were clearly motivated by a real-world problem, 91 presented some solution to that problem and 29 demonstrated the benefit of that solution. This means that around 16% of the surveyed papers involved a real-world problem and solution but only 5% demonstrated some kind of benefit. In the next section we analyse our results to determine if further light can be thrown on these initial results.

5. Analysis

To analyse our results, let us return to our review questions.

- In what areas are the techniques and tools of simulation modelling being studied (Methodology)?
- In what areas is simulation modelling being used to study systems (Investigation)?

In terms of research on the techniques and tools of simulation modelling (ie Methodology) about two-thirds of the total number of papers surveyed fall into this category. Figure 2 shows the ranked distribution of Methodology papers by area. As can be seen, General is by far the leading area with 41.8% of papers. Networks and Communication and Manufacturing and Logistics are ranked second and third with 11.9 and 11.38% of papers, respectively. The remaining 10 Methodology areas represent 39.41% of papers with Transport being the highest percentage (6.35%) of papers. Papers on the use of simulation modelling to research and investigate systems (ie Investigation) represent slightly less than one-third of papers in our review. Figure 3 shows the ranked distribution of investigation papers by area. Manufacturing and logistics is the leading area with 21.97% of papers. Networks and Communication and General are the next highest ranked with 19.08 and 13.29%, respectively. The remaining eight Investigation areas represent 45.66% of papers with social systems being the highest of these with 10.4%. Figure 4 shows a comparison of the percentage of Methodology and Investigation papers by area. As can be seen in all cases apart from Social Systems and Health Care there are more Methodology papers than Investigation papers. General and Defence have significantly more Methodology papers than the average. Biology and Education only have Methodology papers. Social Systems has significantly more Investigation papers than Methodology.

What does this tell us about the 'shape' of simulation modelling research? Within the bounds of our survey, there appears to be more effort in the development of techniques and tools (Methodology) than the use of simulation modelling to investigate systems (Investigation). It appears there is much work still to be done in simulation modelling Methodology with the leading area being General. This is potentially due to the wide range of research topics covered by General. It is interesting to note that a field that is almost 50 years old continues to be a major focus of research effort in itself. In specific areas, it is perhaps unsurprising that methodological research is focussed in the 'traditional' areas of Networks and Communication, and Manufacturing and Logistics. However, it is interesting to note that almost two-fifths of Methodology papers come from a wide range of research in 10 areas covering a very wide range of topics. Although there are relatively fewer papers in Investigation, a similar picture emerges. Again, the 'traditional' areas of Manufacturing and Logistics and Networks and Communication appear to be the main focus of simulation modelling used to investigate systems. General is also highly ranked indicating that simulation modelling is being used to study phenomena in simulation modelling itself (such as the performance of different Parallel and Distributed Simulation protocols or optimisation techniques). The remaining eight Investigation areas account for almost half the overall papers in this category indicating a 'healthy' spread of systems being studied. It is perhaps unsurprising that Biology and Education only have Methodology papers as it is perhaps inappropriate to use simulation modelling to investigate systems in the sense of other areas (ie Biology papers typically discuss methodological advancements to study *in vitro* systems and Education papers typically study the improvement of methods of simulation education). On the other hand, it is interesting to note that simulation modelling was almost exclusively used to investigate Social Systems, rather than work on the methodology developments in social systems simulation, and possibly reflects the relative novelty of the use of simulation modelling in this area (ie the use of new agent-based modelling and simulation techniques to study social systems to attempt to understand emergent behaviour). Given this 'shape', to what extent has this research been motivated by real world problems? Our review questions ask

- To what extent are real-world systems involved in this research?
- What real-world benefit has simulation modelling research demonstrated?

Figure 5 shows the number of papers by area motivated by real-world problems and those demonstrating some real-world benefit. Note that as all but one paper give some solution to the problem, 'solution' is not shown separately (three Networks and Communication papers in Methodology were linked to a real-world problem but only two proposed a solution). A total of 92 papers represent 16% of the total papers with approximately 12% of Methodology papers and 26% of Investigation papers. It might be argued that General requires

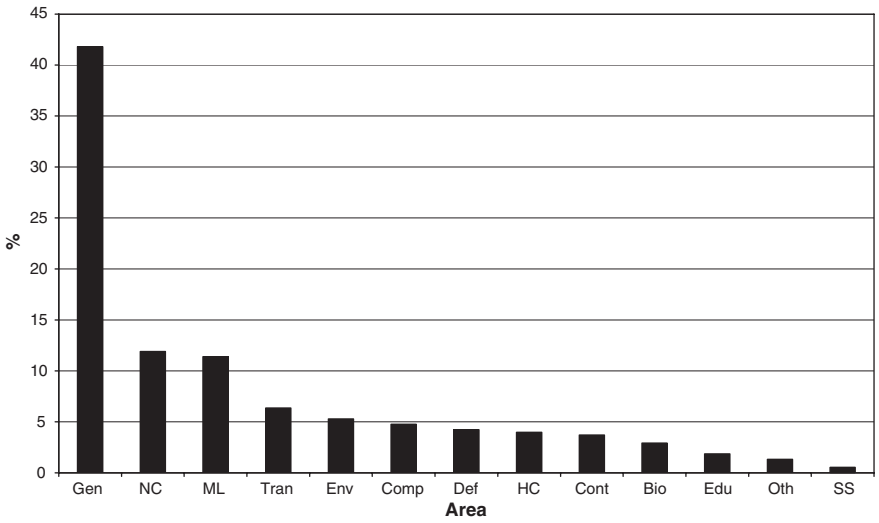

Figure 2 Ranked distribution of methodology papers by area.

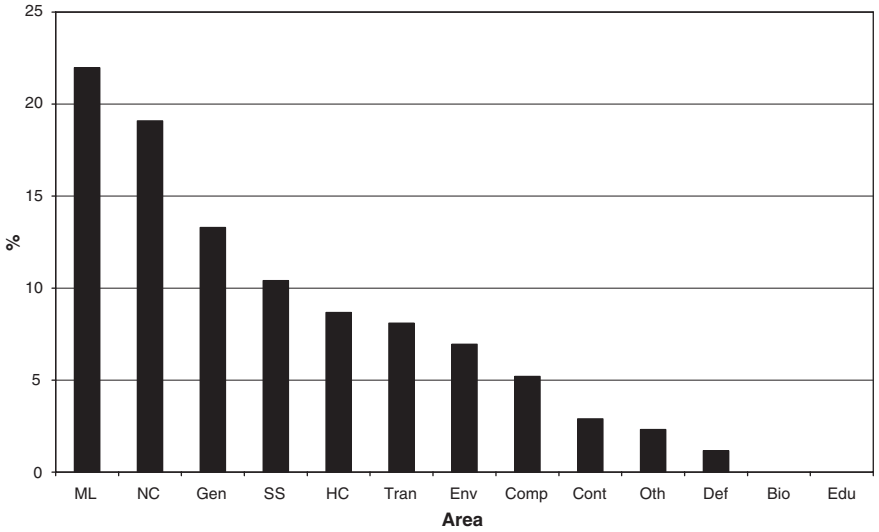

Figure 3 Ranked distribution of investigation papers by area.

no specific real-world motivation as it involves furthering the field in its own right. Factoring General out of the results improves the figures somewhat to approximately 25% overall with 21% being Methodology papers and 30% being Investigation papers. Figures 6 and 7 show a weighted ranking of real world motivated papers by area for Methodology and Investigation, respectively (without General). The weighting has been calculated to show the percentage of papers that have the real-world link as a proportion of the total number of papers in that area. This has been done to remove an obvious bias (ie if an area had two papers, one of which had a real-world link, then an unweighted percentage would be 50%). The weight has been calculated on the basis of a maximum of an 'idealized' 50 papers in an area. These figures show that Manufacturing and Logistics have the most real-world motivated papers in both categories (6.8 and 15.2%, respectively). Environment and Health Care are the next ranked in Methodology. Health Care and Networks and Communication are the next ranked in Investigation. However, the percentages involved are very small indeed.

Of the 92 papers only 29 demonstrated the benefit of the solution provided by the paper. Overall this represents 5% of the total number of papers and around 3% of Methodology papers and 9% of Investigation papers. Returning to Figure 5, a visual inspection of the chart clearly shows Manufacturing and Logistics Investigation papers have by far the largest number of papers showing benefit. However, at 11 papers overall this represents 2% of the total papers. The other areas

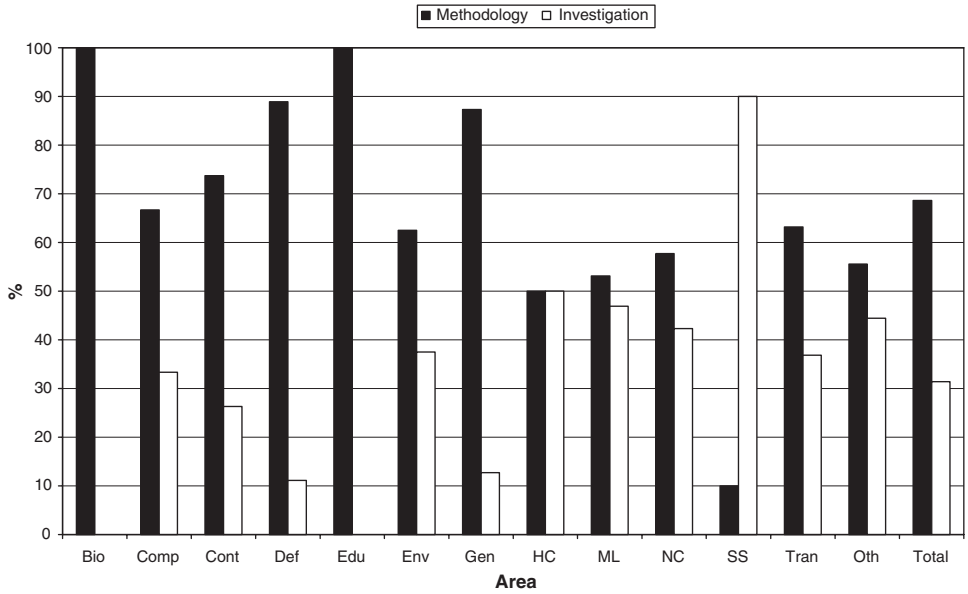

Figure 4 Percentage of methodology and investigation papers by area.

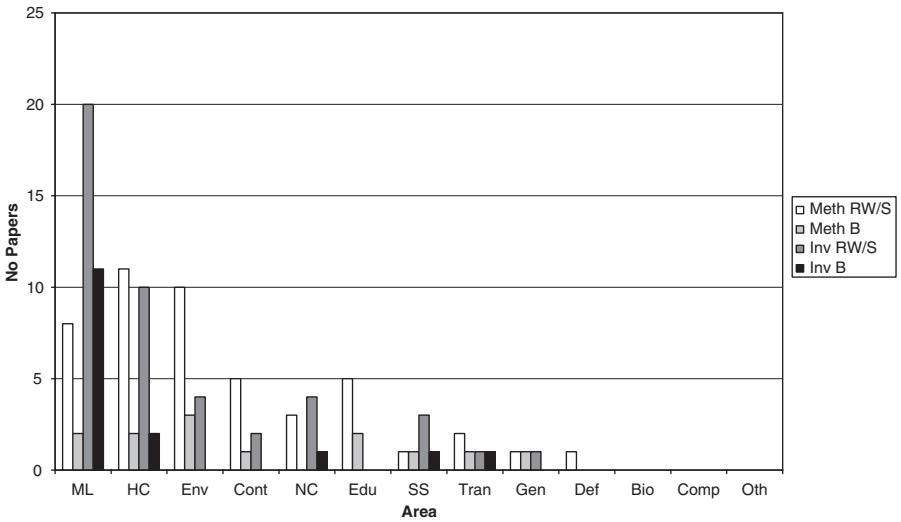

Figure 5 Total papers with real world involvement, solution and benefit by area ranked by total.

are very marginal indeed with some areas having no beneficiaries at all.

From the above, it might be argued that the number of papers with a real-world motivation appear to be oddly low, with only 1 in 6 of all papers having a link (1 in 8 Methodology papers and 1 in 4 Investigation papers). Factoring out the General area improved matters a little moving from 1 in 6 papers to 1 in 4 papers. At best this gave 1 in 5 Methodology papers and 1 in 3 Investigation papers. Looking at Methodology first, is it reasonable to expect every paper to have a real-world motivation? One might take the stance that simulation modelling is a well-known field and that the real-world link does not need to be made clear as those researching in the field implicitly know what the links are. This arguably might be the case for General Methodology and Investigation papers but could this be claimed for all Methodology areas? The picture for Investigation papers appears much better. However, since Investigation papers report on research involved in the use of simulation modelling to study a system, one could reasonably argue that this figure should be a lot higher, especially for each area. One might make the case that areas such as Networks and Communication and Computer System papers do not always need a real-world motivation for research as theoretical protocols or architectures might be investigated to

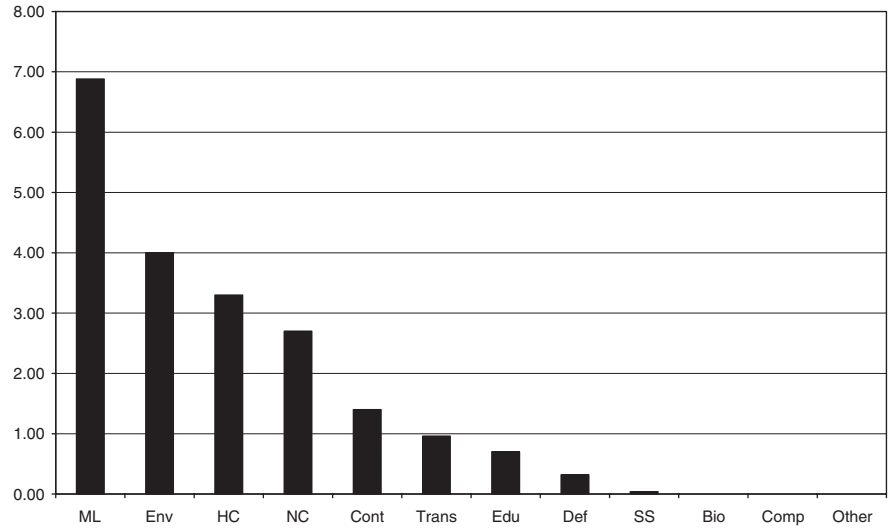

Figure 6 Ranked weighted real world methodology papers by area.

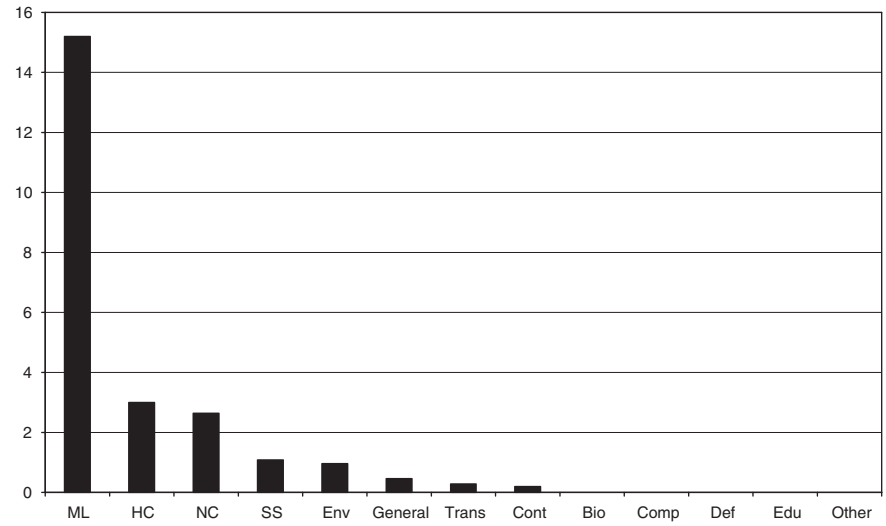

Figure 7 Ranked weighted real world investigation papers by area.

advance the state of knowledge in these areas. However, even discounting these fields there still appears to be relatively low levels of real-world involvement in Methodology and particularly in Investigation.

6. Discussion

We have identified in our sample of simulation modelling papers a lack of real-world involvement. Is this a worry? Does simulation modelling need a 'reality check' or is this 'normal'? The evidence of our survey is limited; so before advancing this argument, let us look to other journals to see if these real-world papers exist elsewhere. We begin by examining if real-world papers are being published in OR/MS journals and if real-world papers are being published in area-specific journals (in this case Manufacturing and Logistics). Following this we ask if the same real-world publishing problem exists in the wider area of OR/MS. We then discuss if this is actually a problem, possible underlying reasons and what opportunities might exist.

Are real-world papers being published in OR/MS journals?

As simulation modelling is an important part of OR/MS, a natural place to look is a cross-section of journals that publish in the area. Table 5 shows the results of a further survey we performed on well-known OR/MS journals in the same period. A total of 837 additional simulation papers were identified. This represents around 12% of OR/MS papers in the period. In this period, the 'leading' simulation

Table 5 Simulation publishing in representative OR/MS journals

Journal title	*Total papers*	*Simulation papers (% total)*	*RW?*	*So?*	*B?*
Annals of Operations Research	551	43 (7.8%)	2	2	0
European Journal of Operational Research	2050	244 (11.9%)	12	12	7
IIE Transactions	553	123 (22.4%)	12	12	4
INFORMS Journal on Computing	146	22 (15.1%)	0	0	0
Interfaces	278	33 (11.9%)	26	26	24
Journal of the Operational Research Society	803	157 (19.6%)	24	24	13
Management Science	710	73 (10.3%)	4	4	0
Mathematical Programming	139	2 (1.4%)	0	0	0
Mathematics of Operations Research	287	13 (4.5%)	0	0	0
Naval Research Logistics	313	35 (11.2%)	0	0	0
Operational Research	473	81 (17.1%)	5	5	1
Operations Research Letters	428	11 (2.8%)	0	0	0
Totals					
OR journals	6731	837 (12.4%)	85 (10.2%)	85 (10.2%)	49 (5.9%)
Simulation journals	551	551 (100%)	92 (16.7%)	91 (16.7%)	29 (5.3%)

publishers are *IIE Transactions*, the *Journal of the Operational Research Society* (*JORS*) and *Operations Research*. However, the leading publishers of real-world papers are *Interfaces* and *JORS*. Overall, the percentage of OR/MS real-world simulation papers is lower than for simulation journals (16% *versus* 10%). The percentage of papers with real-world benefit is about the same (5%). One might also make a comment about journal quality (as defined by impact factor) and real-world papers. However, the low numbers of such papers make the comparison meaningless. We acknowledge that there are many more OR/MS journals. Even so, we again see overall quite low numbers of real-world papers (and real-world papers with benefit). Two journals in particular, however, do have a remarkable of real-world benefit papers. Virtually all real-world simulation papers in *Interfaces* have demonstrated benefit and around half of real-world papers in *JORS* (all such papers appear as *Case Study* papers). Are these journals good models of real-world involvement?

Are real-world papers being published in area-specific journals?

Another place to look for real-world papers are the area-specific journals that represent the wide range of areas included in our survey. A complete survey of these journals would produce some fascinating results but is a monumental task. However, to begin the discussion, what can our leading publishing areas of General, Manufacturing and Logistics and Networks and Communication tell us? General we will remove as an area as it is covered in the discussion of OR/MS papers. Networks and Communication papers have their own 'type' of real-world problem in that different communication protocols and network technologies are often investigated to their own end. Manufacturing and Logistics is clearly an area that could have substantial amounts of simulation papers with real-world problems. Table 6 presents the results of publishing in our period from a sample of Manufacturing and Logistics journals.

In this survey a further 1077 papers representing 21% of published volume were identified. This is a larger proportion than OR/MS but is only an additional 240 papers in volume. In this period, the 'leading' journals publishing simulation work are by volume the *International Journal of Production Research*, the *Journal of Manufacturing Science and Engineering* and *CIRP Annals of Manufacturing Technology* and by proportion *Robotics and Computer-Integrated Manufacturing*, *CIRP Annals of Manufacturing Technology, IEEE Transactions of Semiconductor Manufacturing*, *Journal of Manufacturing Science and Engineering, Production Planning and Control* and *International Journal of Production Research*. These all have around 25% simulation paper content. Proportionately simulation has a higher prominence than OR/MS (12%). In this literature papers tend to use simulation modelling for investigation rather than contribute to simulation modelling methodology. The lower levels of real-world involvement, solution and benefit reflect the type of investigative paper. These are somewhat similar to Networks and Communication papers in that the research subject is a common process, a machine type or a product, that is, an 'accepted' problem worthy of investigation. Even so, not all papers fall into this category. The proportion of real-world papers are very low (5%), lower than the OR/MS and simulation modelling journals. It appears, in this sample of one application area at least, that researchers are not publishing real-world papers in area-specific journals either.

Is the lack of real-world involvement a simulation modelling problem?

Is this solely a simulation modelling problem? There have been several commentaries in OR/MS on this topic. Reisman and Kirschnick (1994) report an analysis of the content

Table 6 Simulation publishing in representative manufacturing and logistics journals

Journal title	*Total papers*	*Simulation papers (% total)*	*RW?*	*So?*	*B?*
CIRP Annals Manufacturing Technology	733	170 (23.2%)	0	0	0
IEEE Transactions of Semiconductor Manufacturing	283	73 (25.8%)	6	6	6
International Journal of Production Economics	747	95 (12.7%)	12	12	3
International Journal of Production Research	1472	370 (25.1%)	20	18	2
Journal of Manufacturing Science and Engineering: Transactions of the ASME	613	173 (28.2%)	0	0	0
Journal of Scheduling	120	4 (3.3%)	0	0	0
Materials and Manufacturing Processes	325	27 (8.3%)	2	2	1
Production and Operations Management	192	21 (10.9%)	0	0	0
Production Planning and Control	420	94 (22.4%)	16	15	5
Robotics and Computer-Integrated Manufacturing	202	50 (24.8%)	2	2	2
Totals					
Manufacturing journals	5107	1077 (21.1%)	58 (5.4%)	55 (5.1%)	19 (1.8%)
OR journals	6731	837 (12.4%)	85 (10.2%)	85 (10.2%)	49 (5.9%)
Simulation journals	551	551 (100%)	92 (16.7%)	91 (16.7%)	29 (5.3%)

of three OR/MS journals in 1962 and 1992 (*Operations Research, Management Science* and *Interfaces* (1972)) in terms of applications where a clearly identifiable problem was defined ('a grounding in the real world, with real world data'). They concluded that overall, although *Interfaces* had helped to balance theory *versus* application and initiatives such as *Operations Research* launching a special section called *OR Practice*, their 1992 OR/MS publishing sample was clearly dominated by theory against application. Ormerod and Kiossis (1997) perform a similar comparison of three journals in 1994 (*Operations Research, European Journal of Operational Research* and the *Journal of the Operational Research Society*) and again identify that theoretical papers dominate publishing (the *Journal of the Operational Research Society* had the largest number of real-world-motivated application papers for that year (16%)). On the basis of a triangulated study of Information Systems and Production and Operations Management with OR, Pidd and Dunning-Lewis (2001) concluded that much published work in OR is unengaged (not clearly motivated by a real-world problem). It does seem that this is not a situation isolated to simulation modelling.

Is the lack of the real world actually a problem, and if it is what can opportunities exist?

Is this a problem or not? The discussion in this paper is based on our survey conducted between 2000 and 2005 for simulation modelling journals, OR/MS journals and Manufacturing and Logistics journals. Is this lack of real-world involvement a 'blip' that only occurs in our sample? The above discussion seems to indicate it is not. It may be argued that in the past there were many more real-world papers and a field that is 50 years old would naturally tend towards theory. A full investigation into the evolution of the field is a subject of future work. However, with regard to observations made in our relatively short survey, some insight might be taken from Reisman and Kirschnick (1994) and Corbett and van Wassenhove (1993) who advocate the sociologist Andrew Abbot's views on the evolution of classical professions (Abbot, 1988). He identified an 'internal stratification' or 'professional regression' that leads these professions to (effectively) two parallel worlds, both with their own, separate reward systems (academia and practitioners) as a natural and irreversible phenomenon. As Reisman and Kirschnick (1994) point out, this is further compounded by PhDs in OR/MS typically entering the academic community directly from graduate school without any 'real-world' exposure to problem solving. This is certainly also true for simulation modelling. Academics are rewarded for publishing in high-quality journals. The peer review process is self-perpetuating in that reviewers look for contributions that they consider complementing and reflecting the corpus of high quality published work. There is therefore no need for a real-world link as this is either implicitly understood or not required as the research clearly builds on previous work. From this viewpoint the lack of real-world involvement is not a problem. What is at odds to this view is there still is much real-world work to be done with clear real-world links. For example, simulation modelling is still not an embedded practice in many areas and the study of simulation modelling successes, barriers to wider use, related case studies, etc alone is a rich source for real-world research. Further, authors may be missing an important opportunity. Authors are strongly motivated to publish. If a research team performs an investigation into a system and writes this up for a leading area-specific journal, then that paper might present the case study, the methods used, the results and the consequences of that work with respect to that area. Given the readership may not be familiar with simulation, the methods section may be presented as introductory and many details that could be interesting to a simulation audience glossed

over. These could include conceptual model development, model implementation, data and models verification and validation issues, experimentation techniques, process issues, etc. There is plenty of material here to make a potentially interesting paper that focuses on simulation modelling issues in a real-world application that could be published in an OR/MS or simulation modelling journal. This may not be true for all cases of research but surely *some* such real-world papers should appear in OR/MS or simulation publishing?

Being more critical, should simulation modelling publication continue to be 'unengaged'? It could be argued that many researchers misunderstand real-world problems due to a lack of real-world exposure. Worse, papers could not stand up to a real-world test as they study fanciful and irrelevant problems that do not reflect 'realistic' scenarios and are rife with convenient assumptions. The 'unengaged' or academic world has little relevance to industrial practitioners who need to use research directly or at least understand how it might impact their 'real world.' Collaboration between the two worlds is difficult as neither really understand the needs and motivations of each other. The two worlds continue to exist and evolve almost without the intervention of each other, the academic world becoming more irrelevant and the real world becoming more uninformed.

The above is not ideal as, we argue, both worlds stand to gain much from each other. Clearly, however, an edict that requires real-world involvement in all papers is ridiculous as some methodology and investigation papers quite justifiably study 'accepted' problems that need no real-world basis as it is implied by the community of practice that 'own' the research. Equally, there are some real-world investigations that are of great benefit to the practitioner (in terms of revenue!) but have no research contribution.

In summary, is the lack of real-world involvement in published simulation modelling research a problem? Strictly speaking it is not as academic publishing will continue successfully irrespective of real-world engagement. It is however a great, missed opportunity. The appearance of more research papers motivated directly from real problems can only strengthen academic research and practitioner practices by bringing both communities closer together for mutual benefit (and quite possibly at the same time generating more research!) However, how can we as a community encourage such papers?

The root of this problem may well be engagement. Not all 'academics' have good links to real-world problem owners. Not all problem owners and practitioners know about simulation modelling and/or have the time (or incentive) to write research papers. Links between the two worlds are difficult and time consuming to forge and it is unrealistic to assume that every researcher needs to (or indeed can) create a successful relationship (and vice versa). Even when a successful link occurs, factors such as timescales and commitment (on both sides) may make it impossible to publish a paper based on results from an actual study. Further, it is sometimes difficult to find the research novelty in a simulation study sometimes required by peer-review, despite attempts to report on the successful use of the technique. It has been suggested that a good case study article should have a balanced clarity of message with enriching, but often intricate detail, be diplomatic to avoid unnecessary controversy, be subject to confidentiality issues, but most crucially, however well-written, usually have only a relatively narrow appeal restricting its academic impact compared with a theoretical paper. These are all challenges that can be met as papers that have appeared in the *Journal of the Operational Research Society* and *Interfaces* attest. Perhaps more senior academics with established links and substantial research experience have a mentoring role to play in this.

Conferences also have a role to play in bringing academics and practitioners together. For example, conferences attended by both researchers and practitioners such as the Winter Simulation Conference, the ORS Simulation Workshop and the ASIM Conference on Production and Logistics specifically aim to increase the involvement of both groups (eg the case study stream at the Winter Simulation Conference). Other conferences, such as the Simulation Interoperability Workshops sponsored by the Simulation Interoperability Standards Organization (SISO), have many more papers written by problem owners and practitioners than academic researchers (defence). However, few of these then get extended and published in simulation modelling journals. These are a rich, untapped potential source of real-world research. Perhaps conference chairs and journals editors should make formal links to create a planned throughput of appropriate papers?

Can we go further to encourage publication? Area-specific journals attempt to 'push' the combined agenda in a specific domain. For example, *The Journal of Defense Modeling and Simulation* (*JDMS*) publishes papers in defence. In this journal there is evidence of papers with slightly more real-world problems and solutions and reflects the US engagement with military modelling and simulation. However, it is difficult to see other areas having journals dedicated exclusively to them on grounds of generating a sustained stream of acceptable papers. Alternatively, in the UK at least, schemes exist to support industrial secondments for academics to work and study in industry. Should simulation societies and special interest groups sponsor meetings and events for members of both groups to meet (speed dating for simulation!)? As many practitioners have much experience and interesting ideas, but little time or experience (or possibly motivation) in writing these up, should academics specifically partner with industry to make this happen? The reward for academics is clear. Participation by practitioners could open up ways of better performing their role but also showcase excellent work. Certainly, editorial teams should encourage and target the publication of more real-world contributions, possibly honest reflections on engaged work and not just success stories. Careful 'nurturing' of both author and referees may well be needed to develop these papers. This is not a call for journals

to transform themselves into vehicles for case studies but a deliberate, planned attempt to strengthen the link between theory and practice supported by solid academic/practitioner relationships.

7. Conclusion

In conclusion, at 50 does simulation modelling need a reality check? We hope that on the evidence and discussion provided in this paper, future authors and current editorial boards may wish to reflect on this question and decide for themselves if the presence of more published research with real-world involvement will benefit the simulation modelling community at large.

As has been mentioned, there is still much more research needed to fully understand the themes and trends of 50 years of published simulation work. We hope (and encourage others) to draw on techniques such as those used by Ramos-Rodriguez and Ruiz-Navarro (2004) to study changes in the intellectual structure of strategic management research by identifying works that have had the greatest impact in strategic management, Nerur *et al* (2008) who complemented this by using co-citation analysis to identify authors who played a pivotal role between two or more domains, and Chen (2006) who has developed CITESPACE II a visualization tool that can be used to detect and visualise emerging trends and transient patterns in scientific literature.

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