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So where to next? A survey of the future for discrete-event simulation

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Discrete-event simulation (DES) has been with us for around 50 years. During this time, the field has seen significant progress as witnessed by the plethora of software packages and reported applications. But what of the future? Where does the field of DES need to go in the next 10 years? As part of this first issue of the *Journal of Simulation* (*JOS*), the Editors-in-Chief have surveyed the Editorial Board for their answers to this question. In particular, those surveyed were asked to comment on four areas: simulation technology, simulation experimentation and analysis, simulation applications and simulation practice. The findings from the 13 responses obtained are summarized under these same headings in the *JOS* 2006 Survey.

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Introduction

Discrete-event simulation (DES) is a field that arguably began in 1957 with the creation of the General Simulation Program (GSP) by Tocher and Owen (1960). Almost 50 fruitful years have passed since then, all well accounted for by (for instance) Nance and Sargent (2002), Robinson (2005) and Hollocks (2006). Certainly, over the history of DES, a plethora of software packages have emerged and many successful applications of simulation have been reported.

Reflection on the past is helpful and it is useful to understand where our field currently stands. It is, however, also beneficial to pause for thought about the future. What are the priorities for the next 10 years? To answer this question, and to celebrate the launch of the *Journal of Simulation* (*JOS*), we, the joint Editors-in-Chief of *JOS*, asked the *JOS* Editorial Board to provide us with their opinions on the future of DES. Editorial Board members were asked to consider *where they believed the field of DES needs to go in the next decade*. As experts in the field of DES, and representing a range of interests in theory and application, those surveyed seemed well placed to answer this question. Four categories were provided for their answers. These were:

- Simulation technology
- Simulation experimentation and analysis
- Simulation applications
- Simulation practice.

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The 19 board members were canvassed and 13 responded. The following sections present each of the above categories by setting out the major points that were identified and summarizing the major issues that the respondents commented on. The findings are also summarized in tabular format in alphabetical order to prevent any misinterpretation that another ordering might cause. We now present the collected observations of the *JOS* 2006 Survey on the future of simulation.

Simulation technology

The first area that our respondents were canvassed on was simulation technology, that is, where they saw the technology that we use to perform simulation changing over the next decade. General comments were made on the need for continual improvement in simulation technology to facilitate the capability to model (eg, the ability to model human performance and associated factors). Comments were also made on the expressive power of the conceptual frameworks that we use to create models. Better conceptual frameworks are needed for modelling at both the conceptual and programming levels. For example, at the programming level event scheduling, activity scanning, process interaction and the three-phase approach are all conceptual frameworks created in the 1960s. Surely, after almost 50 years, we can create integrated conceptual frameworks that help us to create conceptual models and facilitate the creation of the programmed model.

Following this, comments were received concerning the need for new simulation software that is domain specific. Domain-specific simulation software exists in areas such as manufacturing, transportation and network modelling.

However, other domains such as health care, services and business processes are either not represented or are represented in such a way that needs to significantly improve over the next decade. Within this context, it was also felt that such software should be usable by people with domain knowledge, but little knowledge of simulation methodology. A need was also expressed for higher level modelling techniques that abstract away from low-level model detail and promote rapid prototyping of (scoping) models that could be used to justify the development of full-scale models.

Repeating the need for domain-specific simulation software, a respondent made a case for the emergence of model building block libraries that are founded on a sound conceptualization of specific domains. A suggestion was made for 'library engineering' that is rooted in the analysis of modelling needs of a particular domain, rather than on a library that has developed from the needs of one domain and then generalized and reapplied to the needs of another. The motivations for this are cited as being model use and re-use, credibility and acceptance. Object-orientation is suggested as being an important cornerstone in this direction (that has re-emerged) and the reader is referred to Narayanan *et al* (1998) and Balci and Nance (2002) for interesting perspectives on this. Other approaches such as DEVS and Petri Nets are also suggested as being techniques on which new libraries can be engineered.

The general 'look and feel' of simulation tools was commented on by several respondents. One comment referred to the advances that computer games had made and suggested that in the next decade, simulation technology should be equal to that of these computer games. Two cited computer games such as SimCity™ and The Sims™ as good examples of what simulation software should look like. A respondent commented on the need for drag and drop photo realistic displays of simulation components that link seamlessly to the nearest element without the need for extra logic. This programmed logic should be drawn from existing code either from live machines or proposed by the equipment supplier. Further, a need was identified for models that run continuously as games to identify the effects of changes in a similar manner to scoring in computer games; a high score would reflect an excellent production strategy, for example. Similarly, reflecting advances in human performance modelling, operators should certainly be modelled as agents, each displaying their own characteristics and attitudes towards work (such as in The Sims™). There does indeed seem to be many interesting ideas that can be drawn from the computer games industry. We must remember that in the next decade there will be a new generation of simulation modellers who have been brought up with computer games. Will their expectations drive a major change? Greenblat and Duke (1981) present interesting perspectives on this issue.

Comments were also made on the trend for increasingly large simulation models that has emerged and is expected to continue in the next decade. This calls for greater support for larger models in terms of graphics, randomness handling, code efficiency and links to other applications. A suggested driver of this trend is operational modelling. Operational decision support with simulation can often involve integration with other applications and usually involves more modelling detail, reflected by a tendency to emulate more and simulate less. This issue presents interesting challenges over the next decade, not least of which is balancing the art of modelling against over-complication. Of course, large does not necessarily mean complex.

Several comments were made concerning the role of parallel and distributed simulation (PADS) in the next decade. PADS continues to be usable only by specialists trained to PhD level. This reflects a general problem in computing; parallel computers are difficult to use and distributed applications are difficult to develop without specialist skills. Better tools are needed to create simulations over multiple computers before this technology can be widely used. It appears that progress is slowly being made and there is an indication that software interfaces, from the very simple to the more complex (such as those concerning the IEEE 1516 High Level Architecture) are becoming more and more established. A trend that is also expected to continue is the appearance of examples of simulation projects using PADS (especially in supply chains) as well as increased networked and web functionality and services. As well as distributed models being linked together, suggested examples of practical applications of PADS allied technology that may well become commonplace over the next decade are browser viewing, web publishing of models and results, parallel distributed experimentation and optimization. JAVA and .NET technologies are expected to be driving technologies in this area. Grid computing is also expected to play a major role in simulation in the next decade. Interestingly, comments were made that certain simulation problems, such as supply chains, may well be only properly addressed with mature PADS technology.

Comments on the role of standards elicited strong opinions. Based on the experience in developing standards for US Government modelling and simulation, the observation was made that simulation standards can be developed but are possibly too demanding for the 'general public.' This led to a suggestion that over the next decade it would be better to expend effort creating 'best practices' rather than standards. However, another respondent called for simulation standards to support a common language for practitioners and researchers that would, at the very least, support a standard file representation and a standard graphic representation. It was felt that standards would do more to promote the use of simulation methodology than any research results or other additions to the field. Another respondent provided balance by offering the view that standards should be addressed but will never be solved, that is, the pursuit of standards can identify best practice. In

Table 1 *JOS* 2006 Survey simulation technology priorities

- Advanced conceptual frameworks that facilitate conceptual modelling and programming
- Agent-based discrete-event simulation
- Automation of modelling and model maintenance
- Computer gaming experiences and expectations driving simulation technology
- Continued improvement of modelling capability to enable modellers to address non-traditional topics (eg human performance modelling)
- Data interchange/interoperability standards
- Development of 'best practices' rather than 'standards'
- Domain-specific engineered libraries
- Domain-specific simulation software
- Easier and wider use of parallel and distributed simulation
- Easier building of models (more drag and drop functionality)
- Effective use of the high level architecture
- Grid computing for simulation
- High-level modelling techniques
- Improved computer-assisted 3D visualization tools and virtual reality 'type' visualization
- Integration of emulation and simulation within models
- Managing the complexity of models
- New applications of simulation made through maturing parallel and distributed simulation technology
- Pursuit of standards to create a common 'language' for simulation
- Realization of simulation software as a service rather than as a product accessible via the world wide web
- Simulation software usable by domain experts, not simulation experts
- Simulation technology accessible via the world wide web to replace the single PC/single simulation package
- Support of large models
- Technology-assisted integration with other tools and modelling approaches (optimization, system dynamics, etc)
- Technology facilitated modelling techniques
- Use of open source software in simulation

recent years, the debate on simulation standards has created strong discussion and, in the light of the growth of the Simulation Interoperability Standards Organization (SISO: www.sisostds.org) and SimSummit, it will be very interesting to see what 'shape' this discussion will take in the next 10 years.

Table 1 summarizes the priorities in simulation technology over the next decade identified by the survey.

Simulation experimentation and analysis

Our next surveyed theme was simulation experimentation and analysis. Concerns were voiced on the state of output analysis, simulation optimization and the design and analysis of experiments. There was a strong indication that, despite a long history of research on these topics, much more research needs to be done in all these areas in the next decade. A series of questions arise from the respondents' comments. How can knowledge gained from previous runs be easily exploited? How can the sensitivity of the output of a model be easily related to the input? How can the 'black box' of the model be 'opened up' during experimentation, that is, how does the output relate to the model structure? How can optimization become more directed by human expertise? Can results be easily post-processed into more easily read formats (rather than long lists)?

A call to better handle non-steady-state scenarios was also made. In manufacturing and logistics systems (and surely in other application areas of simulation), the output cannot always be characterized as steady state. There are often underlying patterns and cycles in the input data that, if not represented or analysed properly, make any results inappropriate. In a similar vein, a suggestion was also made for techniques that can identify systems that are unstable, for example, overloaded queues or systems with infinite variance. A possible, and very interesting, idea was suggested through the integration of simulation with real-time systems. The suggested goal is to use the latest state of the real system as the starting point, rather than populating the model through a warm-up period.

The future use of simulation models for gaming also appeared in this section. A need was identified for the inclusion of facilities for detailed decision analysis, for example, a replay option that allows for studying the trace of decisions made by the user relative to their consequences for system performance. The creation of a 'film' of the model was presented as one possible solution as was a partial trace. The latter was argued as possibly being the better alternative if alternative actions needed to be investigate (see Van der Zee and Slomp, 2005).

Another theme that emerged as a priority for the next 10 years was education. For example, one respondent was concerned that what was being taught in this area in the late 1970s is still the same today as described in DES textbooks. Further, improvements in this area rely on the field of statistics. The question is how can progress be stimulated in

Table 2 *JOS* 2006 Survey simulation experimentation and analysis priorities

- Advances in statistics
- Better scenario management
- Better scenario management for experimentation
- Design and analysis of experiments
- Detailed decision analysis that relates consequences to model detail
- Experimentation tied into learning experiences for education
- Gaming-based approaches to experimentation
- Human-in-the-loop optimization
- Identification of non-stable systems
- Integration of experiment results with key business performance indicators
- Integration with real-time systems as an alternative to warm-up methods
- Interfacing optimization tools into model code
- Making models less black box and easier to understand
- More robust input modelling techniques
- More robust output analysis techniques
- More sophisticated simulation optimization
- Multiple objective optimization
- Output formatting
- Predictive analysis from current live data
- Reflection on the state of experimentation and analysis as described in simulation textbooks
- Relationship between output analysis and input analysis
- Support for non-steady-state scenarios

Table 3 *JOS* 2006 Survey simulation applications priorities

- Agent-based simulation
- Bioengineering
- Credible simulation work to promote the use of simulation
- Domain-specific modelling
- Ease of simulation tool use
- Economics of simulation application
- Evaluation of deterministic scheduling
- Gaming
- Health care
- Human performance modelling
- Macro economic modelling (future scenarios)
- Macro simulation modelling of competitiveness showing the dynamics of economic situations
- Manufacturing
- Modelling of complex behaviour (eg scheduling systems in manufacturing)
- Modelling of human decision making
- More sophisticated representation of operators
- Process mapping and process analysis
- Promotion of credible published simulation studies
- Requirements
- Services
- Social computing

the field of statistics that is relevant to DES? Are contemporary textbooks holding back progress in the practice of simulation? Further, how would a simulation project developed for education and/or training effect experimental design (choice of factors, range, number of runs, run length, etc). How could experimentation be tied in with learning experiences?

Table 2 summarizes the simulation experimentation and analysis priorities over the next 10 years identified from the survey.

Simulation applications

In response to this topic, calls for more research in contemporary applications and new research in novel applications were made. As well as the applications noted in Table 3, health care was identified as a priority application area. This was noted as being a rich field, in need of tools to improve efficiency. The key requirement appears to be the realization that health-care models are very complex and need to be prototyped rapidly. It was suggested that a solution may be the development of pre-built high-level modelling constructs so the model building is more a process of selecting and configuring components than coding programs. A similar need was identified for the service industry with the additional call for improved capabilities to represent human decision making.

Supply chains were also strongly identified as a major application area for simulation. The complexity of supply chains makes DES a ‘natural approach’ rather than analytic evaluation. But how can simulation be used for problems including, as one respondent put it, mutually accepted candidate supply chain designs for which a high performance is indicated? If decision making in simulation is essentially a heuristic search for good-quality solutions led by people, then the success of a simulation study largely depends on the joint availability and use of the skills of the analyst and the chain members, as well as the facilities offered by the simulation tool. Interestingly, the respondent identifies that the autonomy of supply chain partners and problem complexity stress the role of a simulation model as a *communicative means* between the analyst and the problem owners, that is, a facility for exchanging thoughts on model correctness and ideas about alternative supply chain scenarios. The promotion of effective communication should not only contribute to better solutions, but also to model acceptance; a better understanding of models and the building up of trust among partners (see Van der Zee and Van der Vorst (2005) for an interesting discussion on this topic). Similar comments can be made for health care and patient-centred care chains.

In manufacturing, as identified by another respondent, model operators in manufacturing systems are often represented as robots. It is argued that this practice does not result in a complete picture of relevant human attributes and that a framework that identifies principal human factors and relationships is needed. This leads to the observation that agent modelling may well be a promising vehicle for representing human behaviour to a fuller extent as it foresees in autonomous behaviour, and social abilities, that is, interaction with other agents that exceeds basic manufacturing logic. A good introduction to this viewpoint is found in Baines *et al* (2005) and Gilbert and Troitzsch (2005).

An interesting observation made in support of the success of simulation applications was that sufficiently credible simulations must be built so that decision makers can be convinced that simulation is a useful solution methodology. Following this, a comment was made that there is little published on this topic and how to tackle it, for instance, the issue of unrealistic input and its consequences on the output. A possible solution to this was a demand for each simulation application paper to substantiate the credibility of their simulation. Authors (and reviewers) should be made aware of this issue.

Finally, a short but vital question was raised. It was argued that the economics of simulation application is an area still needing more research. In short, 'Can we show that the benefits of simulation justify the expense?'

Table 3 shows the priorities for simulation applications over the next decade identified by the respondents.

Simulation practice

The study of simulation practice is a fascinating area. How do we actually set and pursue the goals of a simulation project within limitations of time and cost? A need to improve project management for simulation practitioners was a strong theme that appeared in this part of the survey. A concern was identified relating to poor project management and poor results implementation leading to project failure. Failed simulation projects tarnish the use of simulation within an organization and, by word of mouth, across an industry. Interestingly, it was further noted that successful project managers tend to be promoted to higher levels of management. The implication of this is that they may become ambassadors to simulation, promoting its use wherever possible. Improving project management skills is, however, a problem. What constitutes best practice? How do successful simulation practitioners manage the risk in their work? Can experience from software engineering/information systems practitioners benefit the management of simulation projects? The answers to these questions seem to be an urgent priority and work in this area is encouraged.

Data collection and analysis was also identified as a priority. One respondent observed that often 30–70% of simulation project time is spent on collecting model input data. Again, what is the best practice in this area? How can it be streamlined? How can data be guaranteed to be accurate, appropriate and timely. What should be done if data are incomplete, uncollectible or unavailable? For models that are repeatedly used, how can data collection and analysis be automated? Given the importance of this, how can data quality be maximized while reducing the impact on simulation project time/cost? To what extent can this be automated?

Simulation project management and the collection and analysis of data reflect two ongoing concerns in our field. An interesting and strongly felt issue in simulation practice made by one respondent reflects the loss of simulation skills as practitioners come and go. How can we capture knowledge and experience in model building? A suggestion is made that 'learning' simulation models are developed where expert systems learn model behaviours in areas where information is hard to establish. Further, the expert system is then embedded in the model to effect logic while different scenarios are tried. The respondent cites this as 'just one example of a trend towards increasing intelligence being implemented in simulation systems.' Whether or not this is possible and to what extent this can be exploited in the next decade is a fascinating aspect of simulation practice.

Following these practice issues came very strong concerns relating to simulation education. A lack of simulation practice-related textbooks covering hard and soft practice issues and full life-cycle coverage was one concern. Following from this, and balanced by other views, was the question of the degree to which simulation practitioners should be educated in software engineering. Should simulation practitioners be software engineers? Can there ever be a 'breed' of simulation practitioner that are trained as software engineers *and* OR/MS practitioners? Further, can the problems faced by simulation modellers improve education? Concerns were voiced on simulation project educational issues in relation to experience with real clients against classroom problems. Another concern was an unintentional split between undergraduate and postgraduate (Masters) programmes where simulation is sometimes taught at different intensities. Can all these issues be addressed? This seems costly and infeasible but also a fascinating challenge!

Coincident with practice concerns was a strong indication of the role of *gaming*. One fascinating response likened simulation education and training to a racing simulation. One could not pass onto the next 'stage' without successfully passing the 'practice lap.' How many current practitioners are aware of how computer games train their players? How many upcoming potential simulation practitioners play computer games? The computer (simulation!) game market is enormous. Are there lessons that these players can teach us?

In terms of the use of DES with other modelling approaches, the problems and a need to 'solve' the link between DES and system dynamics was highlighted as was a similar need to make the link between DES and general OR/MS techniques. Further, issues concerning how to make DES conveniently link to manufacturing programs such as Six Sigma and Lean manufacturing were highlighted as well as to other areas such CAD and process modelling systems.

Table 4 *JOS* 2006 Survey simulation practice priorities

- Data collection and analysis
- DES integration with system dynamics and other modelling approaches
- Education
- Effective model building
- Expert system support for modelling
- Gaming
- Interoperability with other modelling systems such as CAD
- Links to programs such as Six Sigma, etc
- Model testing
- Problem structuring
- Project management
- Verification and validation

A driver to this appears to be the general trend of enterprise integration and interoperability.

As a final point, the following concern was raised for the next 10 years. Paraphrasing, the comment was made that in reality our field will not be much further forward than today. This is because there is not the volume of sales to generate revenue that will fuel vendor's business plans to make radical changes as suggested in this paper. However, the pressures to deliver answers rapidly will still be a vital issue, otherwise management will loose interest in simulation as a decision support technique.

Table 4 lists simulation practice priorities identified by the *JOS* 2006 survey.

Conclusions

This paper has presented the *JOS* 2006 Survey, the collected observations of the Editorial Board of the *JOS* on the future of four areas of DES over the next decade. Views have been presented on simulation technology, simulation experimentation and analysis, simulation applications and simulation practice. We hope that both practitioners and researchers alike find these stimulating and thought-provoking. Our field has made substantial progress in almost 50 years and we hope that the next 10 years will continue this trend. Let us keep the momentum going!

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