ENABLING THE USE OF SIMULATION

ANDREW GREASLEY

Submission for the award of
Doctor of Philosophy by Published Work

ASTON UNIVERSITY

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1. Andrew Greasley - Curriculum Vitae June 2007

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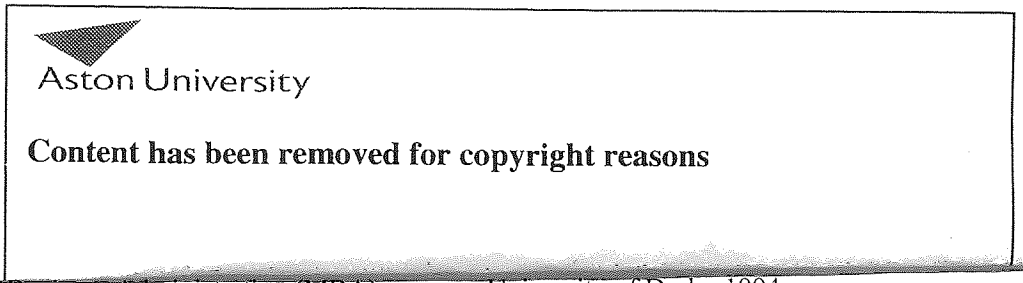

Master of Business Administration (MBA) University of Derby 1994

EMPLOYMENT

2001 -	Lecturer in Information Management, Operations Research and Statistics, Operations and Information Management Group, Aston Business School, Aston University, Birmingham, B4 7ET
1999-2001	Senior Lecturer in Operations Management, Derbyshire Business School, University of Derby.
1994-1999	Lecturer in Operations Management, Derbyshire Business School, University of Derby.
1988-1994	Research Assistant, Business Modelling Centre, Derbyshire Business School, University of Derby.

MEMBERSHIP OF PROFESSIONAL ORGANISATIONS

The Society for Modeling and Simulation International
European Operations Management Association (EUROMA)
Fellow of Higher Education Academy (HEA)

PUBLICATIONS

Books

1. Greasley, A. (forthcoming) *Enabling a Simulation Capability in the Organisation*, Springer Verlag.

2. Greasley, A. (2007) *Operations Management*, Sage Publications Ltd., London. 180 pages. ISBN 978-1-4129-1883-1 (pbk) ISBN 978-1-4129-1882-4

3. Greasley, A. (2006) *Operations Management*, John Wiley and Sons Ltd. Chichester. 500 pages. ISBN 0-470-01209-9

4. Bocij, P.; Chaffey, D.; Greasley, A; Hickie, S. (2006) *Business Information Systems: Technology, Development and Management for the e-business*, 3rd edition (edited by A. Greasley), Pearson Education Limited, Harlow. 827 pages. ISBN 0-273-68814-6

5. Greasley, A. (2004) *Simulation Modelling for Business*, Ashgate Limited: Aldershot. 226 pages. ISBN 0754632148

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8. Greasley, A. (1999), *Operations Management in Business*, Nelson Thornes Ltd., Cheltenham. 344 pages. ISBN 0-7487-2084-7

9. Bocij, P.; Chaffey, D.; Greasley,A.; Hickie, S. (1999), *Business Information Systems*, FT Prentice Hall, 640 pages. ISBN 0-273-63849-1

10. Bocij, P.; Chaffey, D.; Greasley,A.; Hickie, S. (1999), *Business Information Systems: Lecturer's Guide*, FT Prentice Hall. ISBN 0-273-64183-2

Contributions to Books

11. Greasley A, Bennett D and Greasley K (2005) "Virtual Learning Environment for Operations Management - Practical Application and Student Views", in Machuca JAD, Alfalla R and Sacristan M (eds), *Teaching OM Within THENEXOM: Innovative Practices and Links to Research*, @3d/THENEXOM, Sevilla, Spain, pp. 11-25. ISBN 84-689-1991-8

12. Greasley, A. (2005) Entries in *The Blackwell Encyclopedia of Management* (2nd Edition) Operations Management (edited by Slack, N. and Lewis, M.), Blackwell Publishing: Oxford. ISBN 1-4051-1096-1

13. Greasley, A.; Shaw, D. (2004) "Case Studies" in Greasley, A. *Simulation Modelling for Business*, Ashgate Limited: Aldershot, pp.195-219. ISBN 0754632148

14. Greasley, A. (2003) "Denby Constabulary" in Johnston, R. Chambers, S. Harland, C. Harrison, A. Slack, N. *Case Studies in Operations Management,* Third Edition, FT Prentice Hall, pp. 219-224. ISBN 0273-655310

15. Oakshott, L.; Greasley, A.; Smith, D.J. (1996), "Applications of Simulation" in L. Oakshott, *Business Modelling and Simulation*, Pitman Publishing, pp. 147-158. ISBN 0-273-61251-4

16. Oakshott, L.; Greasley, A.; Smith, D.J. (1996), "Validation of Simulation Models" in L. Oakshott, *Business Modelling and Simulation*, Pitman Publishing, pp. 248-270. ISBN 0-273-61251-4

Refereed Journal Papers

17. Greasley, A. (2006) "Using process mapping and business process simulation to support a process-based approach to change in a public sector organisation", *Technovation: The International Journal of Technological Innovation, Entrepreneurship and Technology Management,* Vol. 26, pp. 95-103. ISSN 0166-4972

18. Greasley, A. (2005) "Using system dynamics in a discrete-event simulation study", *International Journal of Operations and Production Management,* Vol. 25 No. 6, pp 534-548. ISSN 0144-3577

19. Greasley, A. (2005) "Using DEA and simulation in guiding operating units to improved performance", *Journal of the Operational Research Society,* Vol. 56, pp. 727-731. ISSN 0160-5682

20. Greasley, A. (2004) "The case for the organisational use of simulation", *Journal of Manufacturing Technology Management*, Vol. 15 No. 7, pp. 560-566. ISSN 1741-038X

21. Greasley, A. (2004) "A redesign of a road traffic accident reporting system using business process simulation", *Business Process Management Journal,* Vol 10, No. 6, pp.636-644. ISSN 1463-7154

22. Greasley, A. (2004) "Using a simulation model for capacity management", *Control,* 30(3), pp.16-18. ISSN 0266-1713

23. Greasley, A. (2004) "Process Improvement within a HR Division at a UK Police Force", *International Journal of Operations and Production Management*, 24(2/3), pp.230-240. ISSN 0144-3577

24. Greasley, A.; Bennett, D.; Greasley, K. (2004) "A Virtual Learning Environment for Operations Management: Assessing the student's perspective", *International Journal of Operations and Production Management*, Vol 24 No 10, pp 974-993. ISSN 0144-3577

25. Greasley, A. (2003) "A simulation of a cladding and window production facility", *Manufacturing Engineering*, 82(1), pp.26-29. ISSN 0956-9944

26. Greasley, A. (2003) "Using Business Process Simulation within a Business Process Reengineering approach", *Business Process Management Journal*, Vol 9 No 4, pp. 408-420. ISSN 1463-7154

27. Greasley, A. (2003) "A simulation of a workflow management system", *Work Study*, Vol 52 No 5, pp. 256-261. ISSN 0043-8022

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35. Greasley, A. (1996), "Using Computer Simulation for Line Balancing: A Manufacturing Case Study", *Control*, 29(9), pp. 19-21. ISSN 0266-1713

Full Papers Published in Refereed Conference Proceedings

36. Greasley, A. (2007) "Gaining Acceptance of Simulation: A Social Challenge", Spring Simulation Conference, SCS, Norfolk, USA. ISBN

37. Greasley, A. (2006) "Managing Breakdown Events in an Automated Snacks Production Facility", *IAMOT 2006*. ISBN 0-9712964-8-0.

38. Greasley, A. (2005) "Increasing the Use of Simulation in Business", *Proceedings of the Summer Computer Simulation Conference*, SCS, pp. 400-405. ISBN 1-56555-299-7.

39. Borges, L.; Greasley, A. (2005) "A Survey of Continuous Improvement Practices in the United Kingdom and Mexico", *7th International Conference on Quality, Innovation and Knowledge Management*, Kuala Lumpar, Malaysia, 16-18 February.

40. Greasley, A. (2004) "Designing a Proposed Overseas Textile Plant using Simulation", *Proceedings of the Summer Computer Simulation Conference*, SCS, pp. 37-41. ISBN 1-5655-283-0

41. Greasley, A. (2003) "A Visual Interactive Modelling system as a Learning Tool", *Proceedings of E-Learn 2003: World Conference on E-Learning in Corporate, Government, Healthcare, & Higher Education*, Phoenix, Arizona, pp. 2167-2170. ISBN 1-880094-50-9

42. Greasley, A. (2003) "A simulation of a large-scale snacks production facility", *Proceedings of the EUROMA/POMS conference*, Vol II, pp. 591-600. ISBN 88-86281-78-1

43. Greasley, A. (2003) "A simulation of a production planning system in a gas cylinder manufacturing plant", *Proceedings of the International Conference on Industrial Engineering and Production Management*, Porto, Portugal May 26-28. ISBN 2-930294-13-2

44. Greasley, A. (2003) "The Use of Data Envelopment Analysis and Simulation in Process Redesign", *Proceedings of the Summer Computer Simulation Conference*, SCS, pp. 531-535. ISBN 1-56555-268-7

45. Greasley, A. (2002), "Assessing the computerisation of a road traffic accident reporting system using simulation", *Proceedings of the 30th International Conference on Computers and Industrial Engineering Vol 1*, Tinos Island, Greece, pp. 299-303. ISBN 960-431-791-1

46. Greasley, A. (2000), "Effective Uses of Business Process Simulation", *Proceedings of the Winter Simulation Conference*, Society for Computer Simulation, San Diego, USA. ISBN

47. Greasley, A. (2000), "A Simulation of a Valve Manufacturing Plant" *Proceedings of the 2000 Summer Computer Simulation Conference,* Society for Computer Simulation, San Diego, USA. ISBN 11-56555-208-3

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51. Greasley,A.; O'Neill, A. (1998) "Analysis of Police Arrest Costs using Simulation and Activity Based Costing", *Proceedings of the Simulators International XV*, ed. M. Ades, R.Griebenow, pp.127-129, Society for Computer Simulation International, San Diego, USA. ISBN 1-56555-143-3

52. Greasley, A.; Kerrin, M. (1996), "The Use of Simulation Modelling in an Organisational Context", *Proceedings of the IASTED/ISMM International Conference: Modelling and Simulation,* ed. M.H. Hamza, pp.224-226, IASTED, Anaheim, USA. ISBN 0-88986-201-X

53. Greasley, A. (1996), "Using Simulation for Capacity Planning in a Transportation System", *Proceedings of the 1996 European Simulation Multiconference,* ed. A. Javor, A. Lehmann, I. Molnar, pp. 135-137, Society for Computer Simulation, San Diego, USA. ISBN 1-56555-097-8

54. Greasley, A. (1996), "Increasing the Effectiveness of Simulation in the Organisation", *Proceedings of the 1996 European Simulation Multiconference,* ed.

A. Javor, A.Lehmann, I. Molnar, pp. 973-976, Society for Computer Simulation, San Diego, USA. ISBN 1-56555-097-8

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56. Greasley, A.; Kerrin, M. (1995), "Extending the use of Simulation: A Manufacturing Case Study" *ARGESIM Report No. 3 of the 1995 EUROSIM Conference,* ed. F. Breitnecker, I. Husinsky, pp. 115, ARGESIM, Vienna, Austria. ISBN 3-901608-03-6

TEACHING

Modules Currently Taught at Aston Business School

BN1160(UG) Information Technology for Business (module leader)
BN2225(UG) Business Game
BN2216(UG) Operations Management (module leader)
BNM702(PG) Simulation and Forecasting (module leader)

International Teaching Experience

Business Modelling at CERAM, Sophia Antipolis, France; 14-17 March 2002
Decision Analysis on MSc Strategic Management at Zimbabwe Institute of Management, Harare, Zimbabwe; 21 Feb – 25 Feb 2001 and 25 April – 29 April 2001
Decision Analysis on MSc Strategic Management at Malawi Institute of Management, Lilongwe, Malawi; 29 April – 7 May 2000 and 30 April – 6 May 2001
Simulation Modelling, Keckesmet Institute, Keckesmet, Hungary; 12-16 May 1999

RESEARCH DEGREES SUPERVISION

Anand Assi Simulation Modelling (DBA) (Research in Progress)

INDUSTRIAL EXPERIENCE (1988 – present)

Marketing, demonstrating, analysis, design and implementation of computer-based business process simulation models to industrial clients including Golden Wonder Ltd., Textured Jersey Ltd., Derbyshire Constabulary, ABB Transportation Ltd., Rolls Royce Ltd., Stanton Valves Ltd., GMT Hunslet Ltd., Hearth Woodcraft Ltd and Luxfer Gas Cylinders Ltd.

2. Outline of Submission of PhD by published work 'Enabling the Use of Simulation'

Introduction

Discrete-Event Simulation (DES) modelling (referred to as simulation in this submission) can be described as the development and use of a model of a system to better understand processes enabling evaluation and redesign in order to improve performance. Thus simulation has the potential to have a significant effect on the design of organisational systems and their efficiency and effectiveness.

In terms of undertaking simulation most current research concerns technical issues such as the ability of the simulation software package used or the appropriateness of any quantitative analysis undertaken during the simulation project. The papers submitted for the award of PhD by Published Work have sought to assess the use of DES within a wider perspective of its use in organisational systems in order to address the challenges stated above. A case study research methodology has been used which builds on descriptive information and practical experience.

The contribution to knowledge of the submitted papers is to establish how the use of simulation can be enabled in the organisation. Three themes or enablers of use have been identified in the submitted papers presented here in the form of research questions:

(1) How can a process-centred change methodology be used as a framework for undertaking a simulation study?
(2) How can the qualitative outcomes of simulation be utilised?
(3) How can simulation be combined with other operational research techniques?

It should be noted that in line with the research paradigm these questions are not designed to find a relationship between variables, so words such as 'effect' and 'influence' have purposely been avoided. In a phenomenological paradigm the research questions are simply designed to delineate the focus of the study. Also note that the study has been delimited in terms of its being about simulation (discrete-event simulation specifically) and organisations (i.e. simulation is not considered in its role in modelling natural phenomena such as climate change for example). It should also be noted that no cross case study analysis has been undertaken in this submission as the original contribution to knowledge in a PhD by published work is contained within the published work. What is presented is a summary of the contribution to knowledge contained within the papers, structured as a coherent body of knowledge within the research themes presented above.

Simulation Terminology

Simulation in general covers a large area of interest and in order to clarify the particular area of interest in this report a short explanation is given of common terms in this area. Simulation can refer to a range of model types from spreadsheet models, system dynamic simulations and discrete-event simulation. *Discrete-Event Simulation* or *Simulation Modelling* is the subject of the submitted papers. Early simulation systems generated reports of system performance, but advances in software and

hardware allowed the development of animation capabilities. When combined with the ability to interact with the model this technique became known as *Visual Interactive Simulation (VIS)*. Most simulation modelling software is now implemented using graphical user interfaces employing objects or icons that are placed on the screen to produce a model. These are often referred to as *Visual Interactive Modelling (VIM)* systems. Finally because of the use of simulation in the context of business process re-engineering (BPR) and of other process-based change methods the technique is also referred to as *Business Process Simulation (BPS)*. The term *Business Process Modelling (BPM)* is also sometimes used, but this term is traditionally related to information system development tools. More recently the termed *Business Activity Monitoring (BAM)* has been used to refer to the use of simulation to monitor ongoing organisational performance.

Methodology

This section outlines the multimethodology research paradigm and case study methodology used within the individual case studies presented in the submitted papers.

The research paradigm

A phenomenological research paradigm (Moustakas, 1994) is one that is concerned with the question of how individuals make sense of the world around them and how, in order to gain access to people's thinking it is important to interpret their actions and their social world from their point of view. In Operational Research a phenomenological research paradigm is associated with what is termed 'soft' OR and is seen as an appropriate approach to understand the organisational context in which the simulation method has taken place. However DES has been associated with the other end of the continuum, hard OR, which is associated with a positivistic paradigm. The terms hard OR and soft OR are briefly described and then the place of DES within this framework is considered in order to validate the research paradigm used.

Checkland and Howell (2004) outline what they see as the difference between the hard and soft approaches to OR. Beyond the usual description of hard as being for well-defined problem situations and soft being for messy problem situations, they see hard and soft approaches as indicating fundamentally different taken-as-given assumptions about the nature of social reality. Soft OR is associated with the phenomenological paradigm in which social reality is seen not as a "thing" but as a process which is continuously created and recreated in human discourse and action. Hard OR is associated with a positivist philosophy in which the world can be objectively investigated empirically, by disinterested observers, to create true knowledge based on empirical data gathered from repeatable experiments.

However, although the hard and soft approaches are fundamentally different Checkland and Howell (2004) find that they are complementary to each other in that the hard approach can be viewed as a subset of the soft. The soft position allows the differences of people's views to be explored and within that exploration any or all of the hard framework and techniques can be adopted as a conscious strategy. However the complementarity is asymmetric, as it is not possible to move from the hard to soft paradigm as this means abandoning the ontological stance of hard OR and this by definition puts the user into the soft paradigm.

Pidd (2004:10) considers the practical aspects of hard and soft OR from a number of viewpoints and Robinson (2001) addresses whether DES should be considered as a hard or soft approach. He concludes that:

- DES is traditionally viewed as a 'hard' OR technique
- Techniques are simply the methods used within the context of a wider methodology and paradigm (Mingers and Brocklesby, 1997)
- Because DES is a technique and not a methodology, it can in fact be used within a soft or hard paradigm.
- DES modellers should consider using a methodology which incorporates soft issues.

The paradigmatic approach to the research regarding the use of simulation can now be explained. As stated earlier DES has been traditionally undertaken using a 'hard' paradigm, usually following the steps in a simulation study outlined by authors such as Law and Kelton (2000) and having a main objective as the estimation of quantitative performance measures. However the author has supplemented the hard approach with a soft approach to generate additional outcomes from the simulation study – for example a stakeholder discussion of the system represented by the simulation and facilitated by the visual animated display. This can be termed a multimethodological approach which is defined as the linking of or combining methods or techniques together in a particular intervention (Munro and Mingers, 2002). Examples of this approach can be found in Clarke and Lehaney (2000), Mingers (2003), den Hengst et al (2007) and Sachdeva et al (2007). Mingers (2006) outlines the advantages of multimethodology:

- Adopting only one method often gains only a limited view of a particular research situation, for example, attending to only that which may be measured or quantified; or only to individuals' subjective meanings and thus ignoring the wider social and political context.

- Research and intervention is not a discrete event but a process that has phases (or, rather, different types of activities) that will predominate at different times. Particular methodologies and techniques are more useful for some functions than others, and so a combination of approaches may be necessary to provide a more comprehensive outcome.

The research methodology

Although in practice action research and case study research are similar in many of their procedures (Collis and Hussey, 2003) and both are associated with the same research paradigm of phenomenology, the author maintains that in the individual submissions the research methodology is case study. This is because the purposes of the intervention from the client perspective was to provide data from the simulation for an organisational decision and was not concerned with the author's research interest in enablers of simulation use. Thus there is a separation between the outcome of the consultancy and the outcome of the research analysis. Action research is associated with the mutual control by the researcher and client of the research and analysis of results. In addition the final action plan to be implemented is usually the client's responsibility, supported by the researcher and the research report is often

published jointly by the researcher and client (Collis and Hussey, 2003). Bryman and Bell (2003) state that although there is no single type of action research it can be broadly defined as an approach in which the action researcher and a client collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis.

In choosing a case study methodology the author of this report is aware that other researchers may feel this approach is not 'proper' research or that nothing of value can be derived from a single case study. Yin (2003) states the following:

'The case study has been (and continues to be) stereotyped as a weak sibling among social science methods. Investigators who do case studies are regarded as having downgraded their academic disciplines. Case studies have similarly been denigrated as having insufficient precision (i.e., quantification), objectivity, or rigor. This stereotype of case studies that began in the 20th century continues into the 21st century...'

Yin (2003) offers the following advice for researchers:

'Do case studies, but do them with the understanding that your methods will be challenged from rational (and irrational) perspectives and that the insights resulting from your case studies may be underappreciated.'

Gummeson (2000) states that case study research has the advantage of providing an holistic view of a process. According to a holistic view the whole is not identical to the sum of its parts and so the whole can only be understood by treating it as the central object of study. Also case studies are of particular value in applied social sciences where research often aims to provide practitioners with tools.

In the submitted papers the author believes the case study research methodology fits with the stated research paradigm, relates to the form of the research questions presented, does not require control of behavioural events and does focus on contemporary events. The data are collected primarily by participant observation (Yin, 2003) and are of a qualitative nature, but a questionnaire survey eliciting quantitative and qualitative data is conducted within one paper (paper 10) in order to elicit the view of stakeholders regarding the business problem under investigation. The author also maintains that a case study approach is an ideal mechanism for enabling the views of the people actually involved in the process to be gathered and used in the analysis.

Generalisability

In terms of generalising case study research Gummeson (2000) draws a distinction between quantitative studies based on a large number of observations that are required to determine how much, how often, and how many and in-depth studies based on exhaustive investigations and analyses to identify certain phenomena that may also exist in other cases. Ritchie and Lewis (2003) state that the generalisation of qualitative data is very different from quantitative data. Qualitative data cannot be generalised on a statistical basis, but it is the content or 'map' of the range of views, experiences, outcomes or other phenomena under study, and the factors and circumstances that shape and influence them, that can be inferred to the researched

population. 'Although individual variants of circumstances, viewed or experiences would undoubtedly be found within the parent population, it is at the level of categories, concepts and explanation that generalisation can take place' (Ritchie and Lewis, 2003).

In this submission the use of a phenomenological research paradigm means that generalisability should not be considered in the same way as for a statistical survey results. In other words, research outcomes can be derived from a single case study, although not the context-free generalisations associated with a positivistic paradigm.

Epistemological Assumptions

In order to elucidate the epistemology assumptions behind the phenomenological approach adopted in the papers and to provide a reflective perspective some background is provided about the author and the role of the author within the studies.

The author has been involved in the use of simulation for 19 years, first becoming involved in the application of SIMAN/CINEMA simulation systems at the Business Modelling research centre at the University of Derby in 1988. As head of the centre the author was involved in implementing discrete-event simulation for a number of industrial clients and became passionate about the use of simulation in organisations. He was involved in many research activities, including the sole programming of a complete graphical discrete-event simulation software package in the programming language Pascal containing over 25,000 lines of code! Over the years the author has become more interested in enabling greater simulation use which in his view presents an important and difficult aspect of simulation research, not discounting the contribution of technical developments in simulation software.

The author's interest in the lack of use of simulation and thus how use could be enabled was triggered in part by the first major survey of simulation use in the UK by the Simulation Study Group in 1991 (Simulation Study Group, 1991), the results of which can also be found in Hollocks (1992). This found that awareness of the technique in manufacturing industry was very low and some £300 million of benefits were being missed. The survey revealed only 11% of UK manufacturers using simulation as a decision support tool. Other than awareness, the principal obstacles to wider use were found to be lack of skills or training, difficulties in data acquisition, the time taken to build the model and a lack of management commitment. The ESPRIT working group on Simulation in Europe (SiE) stated that this general picture of proliferation was reflected across Europe (Kerckhoffs et al, 1995). Hollocks (2001) maintained that there has been no evidence to indicate any material shift in the level of simulation use in UK manufacturing since the original survey and repeated this assertion in 2006 (Hollocks, 2006). Melao and Pidd (2003) conducted a survey among potential business process simulation (BPS) users. This survey also revealed a low usage of business process simulation in the design, modification and improvement of business processes.

The development of a methodological stance to simulation studies can be seen as an outcome of the experience of the author over time as his deep involvement in the research process and interaction with other participants. This led to a feeling that the 'traditional' methodological approach to simulation as a fixed number of steps (method) leading to quantitative outcomes was not generating the full benefits of the

technique. There was also a feeling that the objective approach of 'hard' OR was not incorporating the different perspectives of the stakeholders involved in the simulation project. This developed into a change in stance from a hard to a multimethodological paradigmatic approach where hard issues where seen as a subset of soft issues concerning the organisational social context. This probably also reflected increased confidence of the author, developed from experience, in initiating 'soft' analysis, such as discussion events, in addition to the traditional simulation activities such as model building. Munro and Mingers (2002) discuss how the hard and soft methodologies do require different skills and orientations from their practitioners, with in particular people skills being required for soft methods. These people skills were developed through the interaction at a simulation project level in terms of meeting clients and personnel. Pidd (2004) identifies the technical skills required to undertake the simulation project, while softer and organisational skills are required to perform the simulation problem. This report looks at the author's attempt to apply soft skills to the simulation problem as well as the simulation project.

The Submission

In a PhD by Published work the contribution to knowledge must by definition be contained within the published work as no new work is presented in the accompanying documentation. Thus the importance of the rigour of the research contained within the papers submitted. The papers submitted are the results of 8 years (1998 to 2006) of exhaustive work by the author and hopefully demonstrate a capability to conduct research by the fact that they have been published in academic journals of high standing.

This section represents the contribution to knowledge of the papers as a coherent body of work and is structured around the research questions stated in section 1 of this report. Although the papers are discussed within the research question that best fits their outcomes, a particular paper may cover more than one research question within its analysis.

Research Question 1 - How can a process-centred change methodology be used as a framework for undertaking a simulation study?

Paper 1 addresses research question 1 by relating the use of simulation to the main stages of the Business Process Reengineering (BPR) methodology (see table 1 in paper 1). It also outlines the outcomes of a simulation study that are relevant to a process-centred change methodology, namely ability to measure performance, ability to try alternatives and ability to communicate processes. The paper provides an original contribution to knowledge in showing the relevance of simulation in a service-based process change environment and this helps enable its use in this context.

Paper 2 relates Business Process Simulation (BPS), using the Aguilar et al (1999) framework, to a process-centred management approach to change in order to help enable the tool in these initiatives. Providing case study evidence of the usefulness of simulation in this context helps establish the contribution to knowledge. In order to develop the analysis of the links between BPS and BPR the benefits and limitations of BPS for BPR are discussed. The main benefits of BPS are its ability to provide a dynamic picture of process execution over time which is not provided by the

traditional static flowchart methods used in this context. In addition the qualitative outcomes of simulation, in particular the ability of the simulation animation display to provide a forum for communication is discussed. It is also important to identify any limitations of using simulation in this context to ensure users do not abandon the technique due to unrealistic expectations. Limitations discussed in the paper include the difficult of introducing a simulation capability in the organisation, a possibility of over-analysis using simulation, the need to generate new process designs (the simulation will not do this) and the difficulty of model validation of unstable systems sometimes found in organisations. Finally the contribution of BPR to BPS are discussed. BPR can potentially provide assistance to the use of simulation in the organisation by providing a framework for implementation and providing a methodology that incorporates the assessment of human factors and the organisational context within which the simulation study takes place.

Paper 3 shows how a particular aspect of the Police case was the use of a methodology for process improvement developed by the author and Police personnel. The methodology is presented based on a study of process change with the Human Resources division of a police force. Simulation was not used in this case, but indicated as a potentially useful tool in the redesign stage to explore ESIA (Eliminate, Simplify, Integrate, Automate) areas for redesign.

Paper 4 provides further case-based evidence regarding the relationship between simulation and a process-based approach to change. The paper uses a case study regarding the implementation of an information system for road traffic accident reporting in a UK police force. The ability of simulation to proof new designs was seen as particularly important in a government agency where past failures of information technology investments had contributed to a risk averse approach to their implementation. Thus the traditional use of simulation to reduce risk in major investment projects can now also be related to the reduction of risk due to uncertainty in implementation, which considerably widens it potential usage. Thus, through the dissemination of a practical implementation of an original process change methodology and the stated potential of simulation to assist in its implementation, an original and significant contribution to knowledge has been made.

Research Question 2 - How can the qualitative outcomes of simulation be recognised?

Paper 5 reports that an assessment of the use of simulation should incorporate factors such as the potential of using the model building process to gain understanding of a system and the use of animation to communicate ideas.

Paper 6 shows how simulation animation facilities are particularly useful in communicating the operation of dynamic and interacting systems such as transportation facilities. In this case study a novel use of simulation was to show capability to a third-party client in meeting service level targets for the operation of a train maintenance depot.

Research Question 3 - How can simulation be combined with other operational research techniques?

Paper 7 demonstrates by case study methodology the use of simulation in combination with the technique of Activity Based Costing (ABC). The case study is of a police custody operation which has been operated on an overall budget with annual adjustments for inflation. ABC analysis was to be used to identify the sources of cost and thus provide information in order to improve the management of the operation. When using ABC cost is calculated by multiplying how many times an activity occurs (activity driver) by how much resource the activity uses (cost driver) by the cost of the resource used (resource driver). What simulation can do is generate occurrences of an activity over time (in response to customer arrivals for example), but also defines when these activities occur. This is important because it is not just the number of times an activity occurs that affects cost, but when it occurs. The timing of events can effect how much resource and the cost of the resources needed to execute them. Thus a contribution to knowledge is made by showing how ABC provides a framework for identifying the parameters of cost and simulation provides a technique for the dynamic calculation of cost over time.

The ABC model is developed in paper 8 in order to undertake scenario analysis. By using the simulation to identify the cost of activities, in this case arrests, the effect of changes in the 'product mix' could be estimated. The case study provides an example of a scenario of 'late drinking' in which a new arrest pattern scenario is simulated and subsequent costs are calculated. Simulation is thus shown as a powerful tool in which the consequences of policy decisions (which may be instigated from outside agencies such as the government) can be estimated in terms of cost and thus assists in requests for additional funds to execute these policies. Thus a contribution to knowledge is made in demonstrating a novel use of simulation in combination with another OR technique in order to enable further use.

Paper 9 shows mutually supporting ways in which simulation and the technique of Data Envelopment Analysis (DEA) can be undertaken. A significant contribution to knowledge is made in this paper by the presentation of a 3 stage model outlining the way in which DEA and simulation can be used in combination to analyse data sets. This includes generating data sets for the DEA analysis from the simulation of scenarios, providing a sensitivity analysis of the benchmark unit performance, comparing the performance of the current unit with the current design and the benchmark design. This model thus helps operationalise the DEA analysis and provide a role for simulation in the use of the increasingly popular DEA technique and thus enables simulation use.

Paper 10 provides an original contribution in the form of a case study of the use of simulation in conjunction with the technique of system dynamics. It is shown that the system dynamics approach is particularly appropriate in analysing factors impacting on the organisational context of a simulation study and thus could be used to maximise the benefits of simulation. The paper recognises that the DES technique may not always be appropriate to analyse the organisational context and shows how the technique of system dynamics can be a useful addition to the toolkit of DES practitioners. This helps enable the use of DES by showing how its 'hard' outcomes can be supplemented by a more 'soft' technique providing a more complete analysis of the problem.

Summary

The papers above provide a consistent approach to the significant challenge of enabling the use of simulation across and within organisations. A novel approach is taken in that organisational, rather than technical, issues are examined and the papers provide a significant contribution to knowledge in showing how attention to these issues can improve the relevance and usefulness of simulation and thus enable its use.

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3. Publications submitted in support of PhD by Published Work

Paper 1
Greasley, A.; Barlow, S. (1998) "Using simulation modelling for BPR: resource allocation in a police custody process", *International Journal of Operations and Production Management*, 18(9/10), pp. 978-988. ISSN 0144-3577

Paper 2
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Paper 3
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Paper 4
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Paper 5
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Paper 6
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Paper 7
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Paper 8
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Paper 9
Greasley, A. (2005) "Using DEA and simulation in guiding operating units to improved performance", *Journal of the Operational Research Society,* Vol. 56, pp. 727-731. ISSN 0160-5682

Paper 10
Greasley, A. (2005) "Using system dynamics in a discrete-event simulation study of a manufacturing plant", *International Journal of Operations and Production Management,* Vol. 25 No. 6, pp. 534-548. ISSN 0144-3577

4. Statement of the candidate's contribution to publication under joint authorship

All papers are written by Greasley as the sole author apart from paper 1 (Greasley and Barlow, 1998) which was approximately 95% written by A. Greasley.

5. Statement of prior submission of work for degree

No part of this work has been submitted, successfully or unsuccessfully, for a degree of this or any other university or educational institution.

6. Papers submitted for the degree of PhD by published work

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Using simulation modelling for BPR: resource allocation in a police custody process

Andrew Greasley
University of Derby, Derby, UK, and
Stuart Barlow
Derbyshire Constabulary, UK

Using business-process simulation within a business-process reengineering approach

Andrew Greasley
Aston Business School, Aston University, Birmingham, UK

Process improvement within a HR division at a UK police force

Andrew Greasley
Aston Business School, Birmingham, UK

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Using process mapping and business process simulation to support a process-based approach to change in a public sector organisation

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The case for the organisational use of simulation

Andrew Greasley

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USING SIMULATION TO ASSESS THE SERVICE RELIABILITY OF A TRAIN MAINTENANCE DEPOT

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SUMMARY

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Costing police custody operations

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A simulation analysis of arrest costs

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Using DEA and simulation in guiding operating units to improved performance

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Using system dynamics in a discrete-event simulation study of a manufacturing plant

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