Proceedings of the 2006 Winter Simulation Conference
L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds.

APPLICATIONS OF DISCRETE-EVENT SIMULATION TO SUPPORT MANUFACTURING LOGISTICS DECISION-MAKING: A SURVEY

Marco Semini

Department of Production & Quality Engineering
Norwegian University of Science and Technology
Trondheim, 7491, Norway

Hakon Fauske
Jan Ola Strandhagen

Department of Logistics
SINTEF Technology and Society,
Trondheim, 7465, Norway

ABSTRACT

This paper presents a literature survey on recent use of discrete-event simulation in real-world manufacturing logistics decision-making. The sample of the survey consists of 52 relevant application papers from recent Winter Simulation Conference proceedings. We investigated what decisions were supported by the applications, case company characteristics, some methodological issues, and the software tools used. We found that the majority of applications has been reported in production plant design and in the evaluation of production policies, lot sizes, WIP levels and production plans/schedules. Findings also suggest that general-purpose DES software tools are suitable in most of these cases. For different possible reasons, few applications for multi-echelon supply chain decision-making have been reported. Software requirements for supply chain simulations also seem to differ slightly from those for established application areas. The applications described were carried out in a variety of different industries, with a clear predominance in the semiconductor and automotive industries.

1 INTRODUCTION

In this paper we present a survey which investigates recent Winter Simulation Conference (WSC) Proceedings in order to address the following question: When and how is discrete-event simulation (DES) used to support manufacturing logistics decision-making? More precisely, we analyzed over 50 relevant application papers using the following criteria:

- Characteristics of the decision(s) supported (within the broad field of manufacturing logistics as defined in Section 2),
- Characteristics of the case companies (industry, size and country),
- Modeling methodology and
- Software tool(s) used.

The purpose of our survey is to provide the manufacturing industry with an insight of the applicability of DES; to inform researchers and practitioners about recent trends and future directions for theoretical development; and to compile a reference for papers reporting on DES applications in manufacturing logistics. The survey is part of a larger research initiative, which investigates when and how different quantitative modeling techniques are used to support manufacturing logistics decision-making.

We reviewed previous survey literature and found a considerable number of company surveys on the use of operations research techniques, frequently identifying DES as one of the most popular techniques in practice (Morgan, 1989; Fildes and Ranyard, 1997; Munro and Mingers, 2002). However, very few have investigated when and how DES is actually used to support decision-making in industry, not to mention in manufacturing logistics. Whenever possible, we compare the present study's findings to this previous work.

The paper is organized as follows: First, scope and decision areas of manufacturing logistics are presented, followed by a brief introduction to the use of simulation modeling for decision-support. The methodological approach is discussed next, before findings from the survey are presented and analyzed. Finally, some conclusions are presented together with suggestions for further work.

2 THEORY

2.1 Manufacturing Logistics

Manufacturing logistics deals with the design, planning and control of material flows and related information flows in manufacturing companies and their supply chains. It includes strategic, tactical and operational tasks, with scopes ranging from a single piece of equipment all the way to global supply chains encompassing several independent actors.

1-4244-0501-7/06/$20.00

Manufacturing logistics encompasses aspects of several overlapping fields, including operations and production management, logistics and supply chain management, and advanced planning. Wu et al (1997) suggest a taxonomy that characterizes research problems in manufacturing logistics, as well as research directions and opportunities.

As manufacturing logistics is rooted in several fields, there are different approaches to grouping decisions into functional areas. Chan, (2005) for example, places the manufacturing planning and control system at the heart of manufacturing logistics. In this paper, a slightly adapted version of the Supply Chain Planning Matrix as defined by Fleischmann et al (2005) is employed. 15 decision areas are distinguished and roughly arranged along "decision horizon" and "supply chain process" (Figure 1). The long-term decision areas are shown in a single box to illustrate the comprehensive character of such tasks. Note further that the importance and detailed role of each decision area in the matrix varies between enterprises. The matrix is simply one way of structuring the decisions constituting the field of manufacturing logistics.

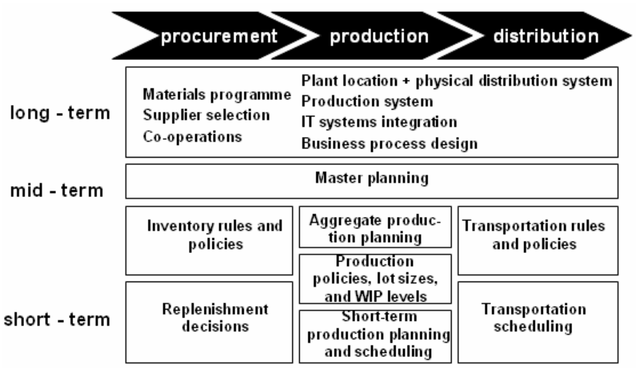

Figure 1: Manufacturing Logistics Decision areas

2.2 Simulation Modeling for Decision Support

There are several reasons why a simulation study can support manufacturing logistics decision-making:

- A simulation model facilitates understanding of the real system and its behavior.
- The actual exercise of building a simulation model reveals previously hidden relationships and provides a systematic way to analyze the situation
- A simulation model can facilitate communication and provide a basis for discussions.
- "What-if" analyses can be carried out, allowing the decision-maker to test the affects of different alternative scenarios without having to make changes in the real system.

Besides simulation, there are also a variety of other quantitative and qualitative techniques for decision support available to the decision maker, for example optimisation methods, cost models and "soft" techniques (see for example Daellenbach and McNickle (2005) for a recent overview). A critical requirement for the successful application of such techniques is to know what kind of problem situation can be addressed with which sort of technique (Flood and Jackson, 1991; Mayo and Wichmann, 2003). Advantages of DES include the ability to represent a system's uncertainty and dynamicity, and more generally to produce realistic (valid) representations of the real system; the possibility to add intuitive visualizations and animations; along with the fact that it lies within the grasp of non-mathematicians. On the other hand, DES studies can be expensive and time-consuming, requiring knowledge and experience often not available in-house. Further, a DES model cannot automatically generate optimal solutions to a decision problem; instead, an iterative trial-and-error process is required to identify "good" solutions. In conclusion, DES is one of several quantitative decision-support techniques, each having its own set of properties making it more or less suitable in a given problem situation.

3 METHODOLOGY

The proceedings of the WSC for the years 2002 – 2005 formed the sampling frame of our survey. This sampling frame was chosen because the WSC is an important platform for simulation modeling and contains many relevant papers that are accessible anytime over the internet, facilitating both the initial surveying and later reviewing.

We investigated every paper in this sampling frame and selected those reporting on DES applications that supported logistics decision-making in real-world manufacturing companies. In order to be included in the sample, papers also had to provide enough details to answer most of the questions in the survey. A number of papers use real-world data to test some methodology, framework or tool; these were not included, unless it is clearly stated that the case company received timely and required decision support. These parameters may unintentionally have led to the exclusion of some relevant papers. We do not think, however, that this has often been the case.

Finally, note that our study is restricted to discrete manufacturing enterprises and their associated supply chains. Discrete-parts manufacturing is characterized by individual parts that are clearly distinguishable such as circuit boards or engine blocks (Askin and Standridge, 1993). Thus, we excluded applications in continuous production, such as the petroleum industry. We did not consider models solely supporting logistics companies either, such as shipping companies, aviation and postal services. The reason for these exclusions is that our focus is on discrete manufacturing companies.

The results of our survey only hold for recent WSC proceedings. In fact, the limited sampling frame, restricted to four consecutive years of the same conference, does not allow any generalizations. For example, relevant papers can also be found at a number of European conferences, where industry and case company characteristics are likely to be different from those found at the WSC. Further, fluctuations in industry are not accounted for by the limited time period investigated. More generally, many simulation studies are never reported in literature, further biasing the sample. A questionnaire-based survey of simulation practitioners and manufacturing companies can be carried out in order to obtain a more representative sample.

4 RESULTS AND ANALYSIS

In the present study, we surveyed WSC proceedings in order to investigate DES model applications for manufacturing logistics decision-making. The four conference proceedings we surveyed contain in total over 1000 papers, whereof we identified 52 as relevant for our study, i.e. describing DES models that provided timely and required decision-support to a real-world manufacturing company. We selected the papers according to the criteria outlined in the previous section. Author(s) and publication year of each paper selected are included in the appendix (ordered by decision area supported). This section is dedicated to the analysis of the applications described in the papers.

4.1 Characteristics of the Decisions Supported

First, we used the framework presented in Subsection 2.1 to study the decision areas supported by the applications, with Figure 2 illustrating the result. The majority of applications supported the design of production systems (30 applications). 21 applications evaluated production rules and policies including lot sizes and WIP levels, followed by 8 applications directly evaluating short-term production plans/schedules. Finally, 4 applications simulated inventory policies, one addressed physical plant location and distribution system design, and one evaluated an assemble-to-order strategy (materials programme). In the remaining decision areas, no applications have been reported recently. Note that some of the DES models we surveyed supported decisions belonging to several areas. This explains why the numbers of applications per decision area sum up to more than the number of papers surveyed. Figure 2 also shows the types of software tools used, which will be discussed in Subsection 4.4.

The above findings are not surprising and largely correspond to what is generally considered as typical application areas of DES in manufacturing. The findings are also similar to the findings in previous surveys. In the study carried out by the UK simulation study group (1991), the most frequent applications were in the areas named plant layout

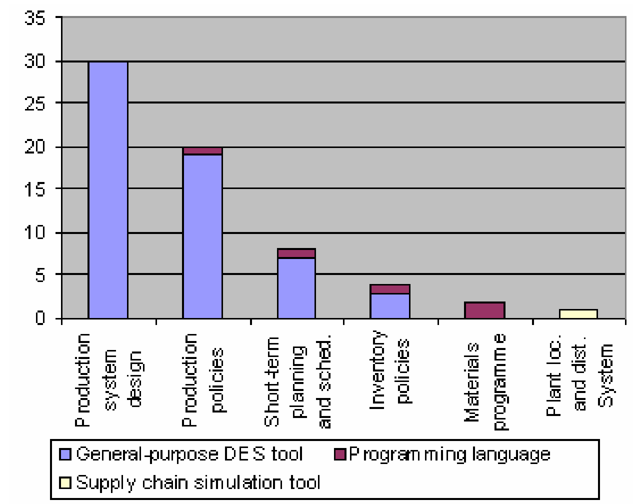

Figure 2: Decision Areas Supported and Software Types Used in the Applications

and utilization, analyzing required manning levels, capital equipment analysis, short-term scheduling and loading, and analyzing material control rules. The former three areas constitute central elements in the design of production systems, the latter two include short-term production planning and scheduling, production policies, transportation rules and policies, and inventory rules and policies. Thus, the UK study found essentially the same main decision areas as the present study.

Other surveys include Olhager and Rapp (1995) and Smith (2003). The former found that, among a variety of functions related to material planning and control, simulation was typically used in production planning and production activity control. The latter restricted the survey to “manufacturing system design” and “manufacturing system operations” and found, in accordance to the present paper’s survey, that the amount of papers falling into the manufacturing system design category is somewhat larger than the ones belonging to manufacturing operations. In conclusion, the findings from previous surveys and our study indicate that DES has been and continues to be regularly applied in a number of manufacturing logistics decision areas.

Next, we investigate DES models of supply chains, i.e. manufacturing networks consisting of several, geographically separated echelons. Echelons represent for example suppliers, multiple production plants, or distributors. In recent years, there has been considerable focus on the management of relationships between such echelons in order to deliver superior customer value at less cost to the supply chain or network as a whole (Christopher, 1998). Not surprisingly, the last four WSC proceedings thus contain a considerable number of papers that describe frameworks, experiments, and software prototypes dealing with supply chain simulations (for example Liu et al, 2004). Rather surprisingly, however, only two papers describe decision contexts where DES actually supported a real-world multi-echelon supply chain. In the following two paragraphs, we attempt to explain the lack of such papers.

One possible explanation is that concepts such as supply chain management and global optimization are still relatively new. Only recently, larger parts of supply chains have been analyzed in a holistic way. DES modeling, which has a long tradition in the analysis of production systems within four walls, needs time to adapt to this new and wider perspective. Theoretical frameworks and conceptual models must be developed, practitioners trained, and methodologies reviewed. It also seems that existing DES software needs some adjustment in order to be fully appropriate to the new situation (this is also discussed in Subsection 4.4). In addition, the novelty character of supply chain simulations may increase the reluctance of industry to reveal the benefits obtained from such studies. If the limited number of papers on supply chain simulations is due to these reasons, a considerable increase is to be expected shortly.

There is, however, also a more fundamental explanation. Moving from a single manufacturing plant to a multi-echelon supply chain adds a number of new requirements, including the alignment of network strategies and interest, mutual trust and openness among actors, high intensity of information sharing, collaborative planning decisions and shared IT tools (Hieber, 2002). The role of organizational and human aspects increases, as well as the number of (independent) actors. In such a problem context, the applicability of quantitative modeling based on operations research and systems analysis is likely to decrease and other, "softer" methodologies become more appropriate. A literature survey by Neely (1993) also reports findings that support such a view. The limitations of quantitative modeling have been discussed by many authors (Ackoff, 1987; Rosenhead, 1991; Rosenhead and Mingers, 2001; Daellenbach and McNickle, 2005); several frameworks have also been proposed to characterize problem situations that lie within the grasp of quantitative approaches (Hopwood, 1980; Jackson and Keys, 1984). They typically emphasize that the problem situation must be of a technical nature and characterized by high consensus between stakeholders.

As a final comment, note the lack of business process simulations, such as order processing, in the applications surveyed. This lack may again be explained by the limitations of operations research, since business processes are of considerable human and organizational character. Nevertheless, this lack is rather surprising, since business process reengineering/management is frequently stated as a typical application area (Banks et al, 1996).

4.2 Case Company Characteristics

The second domain we investigated is the case companies. As far as industry affiliation is concerned, this has been identified as a significant factor when classifying manufacturing simulations (McLean and Leong, 2002). Thus, we grouped the applications based on the North American Industry Classification System (NAICS, 2002) and found the results shown in Table 1. By far the most applications have been reported in the semiconductor and in the automotive industry (13 and 10 applications respectively). In fact, all other industries have had at most three applications reported in recent WSC proceedings.

Table 1: Number of Applications Per Industry

Industry	Number
Semiconductor	13
Automotive	10
Other computer and electronics	4
Pharmaceutical	3
Primary metal	3
Fabricated metal product	3
Military	3
Wood	2
Aviation	2
Textile	1
Nonmetallic mineral product	1
Electrical equipment and appliances	1
Paper	1
Machinery	1
Printing and related support	1
Shipping	1
Miscellaneous	1

These findings are similar to the findings from the literature review by Meixell and Gargeya (2005), which identified the electronic and the automotive industries as leading in applying DES to real-world problems. One possible explanation for these findings is that both these industries are characterized by repetitive line production and stable, automated processes. Such situations often lend themselves to quantitative modeling, and even small improvements can result in important cost savings. Obviously, however, simulation has had numerous applications in other industries. In conclusion, while DES is applied in a large variety of industries, almost half of all applications described in recent WSC proceedings belong to the semiconductor or the automotive industry.

In addition to industry affiliation, we classified the case companies according to country and size. The overwhelming majority of papers report on applications that were carried out in the U.S.; this is, of course, natural since the WSC has its roots in this country. Turning to company size, we found that most case companies were large. Remember that these findings primarily hold for the WSC proceedings we surveyed; in fact, typically only larger companies have the resources for research-based simulation studies, which more easily find their way into the academic literature. Nevertheless, it seems likely that larger companies achieve the highest return-on-investments from

DES studies. After all, flagship examples of simulation studies in literature, such as Ingalls and Kasales (1999), Lin et al (2000), and Lee et al (1993), were all carried out in such companies. More generally, a positive correlation between company size and use of operations research has been found in several company surveys (Morgan, 1989). We encourage further research to investigate how DES (and other operations research techniques) can be profitably applied in small and medium-sized companies.

4.3 Modeling Methodology

Next, we noticed some methodological issues. Note that the analysis of our survey is limited to DES. However, when we read the four proceedings, we also looked for continuous simulations and static spreadsheet simulations applied to manufacturing logistics. While we found some papers on system dynamics, for example Mayo and Wichmann (2003), none of these supported logistics decision-making in real-world companies. This may be due to the scope of the conference, but it may also indicate that system dynamics is not a frequently applied decision support approach in manufacturing enterprises, possibly because it does not have the granularity required in most cases (Mayo and Wichmann, 2003). As far as static spreadsheet simulations are concerned, two Monte Carlo simulations have been reported, assessing risks in manufacturing networks from a material flow perspective (Deleris and Erhun, 2005; Deleris et al, 2004). Finally, there was a deterministic spreadsheet application for capacity-related decisions (Ozturk et al, 2003). Obviously, static spreadsheet applications are very common in industry, but such applications are not normally described in research literature. In conclusion, most papers describe DES applications, which is also the focus in our study.

We were also interested in the combination of DES with optimisation techniques (simulation-optimisation). We found five such applications; interestingly, they used four different ways of combining DES with optimisation. Baesler et al (2002) and Finke et al (2002) use DES to calculate objective function values in heuristic algorithms; Joines et al (2003) estimate queuing times and slack repeatedly in an iterative scheduling algorithm; Chong et al (2003) identify bottlenecks in a bottleneck-based scheduling algorithm; and Greenwood et al (2005), finally, use DES to assess the performance of a flow shop schedule created by a scheduling heuristic. This finding reflects the variety of purposes a DES module can have within an optimisation procedure. If we consider the decisions supported by these applications, it turns out that four applications concern short-term production planning and scheduling. This may indicate that optimization has a greater potential to support DES in operational planning processes rather than strategic decision-making such as production system design.

Finally, no real world applications of parallel/distributed simulation have been reported. This corresponds to the findings in Terzi and Cavalieri's survey (2004), which pointed out that parallel/distributed simulation has not become a frequently applied approach. Possible reasons for this are similar to the ones in Subsection 4.1 which explain the lack of supply chain simulations.

4.4 Software Tools

Finally, we examined which types of software tools were used in the applications. Of the 52 DES applications, 46 employed general-purpose DES software tools (high-level simulators), 5 used in-house applications developed using general programming languages (C++ or Java). The application described by Dalal (2005) used a commercially available tool specifically developed for supply chain simulation.

As shown in Figure 1, all applications in production system design and most applications in production policies, plans and schedules, and inventory policies, used general-purpose DES software tools, confirming their popularity in these areas. Quite the contrary is the case for the applications in other areas, none of which used this type of tools directly, including both supply chain simulations. In our experience, and pointed out also by Terzi and Cavalieri (2004), this is because general-purpose DES tools are not fully appropriate for supply chain simulations. It explains the recent appearance of several commercially available DES tools specifically developed for supply chain simulations. The near future will show if these tools provide the functionalities needed. In the meantime, we encourage further research to identify the specific requirements to simulations of supply chains as opposed to single plants.

Most papers specify the name of the DES software tool used. We counted the number of papers per tool, which resulted in Table 2. Arena and Automod/Autosched were used most frequently, followed by Quest, ProModel, Sigma, and Extend. Each of SLAM II, DSOL and Supply Chain Builder was used once. Investigating the link between tool and industry reveals that Arena's 13 applications cover a variety of industries. On the other hand, 7 of the 11 applications of Automod/Autosched were carried out in the semiconductor industry. Inversely, almost all cases from the semiconductor industry were carried out using Automod/Autosched, confirming that this is a very frequently used software suite for studying wafer fabs (McGinnis, 2004).

5 CONCLUSIONS

In this paper we have presented a survey of discrete-event simulation (DES) applications that have been reported in recent Winter Simulation Conference proceedings. Its purpose is to learn more about when and how DES is used to support manufacturing logistics decision-making. The sur-

Table 2: DES Tools Used in the Application Surveyed

Name	Number
Arena	13
Automod/Autosched	11
Quest	6
ProModel	5
Sigma	4
Extend	3
DSOL	1
SLAM II	1
Supply Chain Builder	1

vey's sample consists of 52 DES applications and was obtained by selecting all the papers reporting on DES models that supported logistics decision-making in real-world manufacturing companies.

Even though such a limited sample does not allow any generalizations, a number of relevant findings has been made:

- In accordance to earlier surveys, the majority of applications has been reported in production plant design and in the evaluation of production policies, lot sizes, WIP levels and production plans/schedules. This confirms the popularity of DES in these fields. Also, general-purpose DES software tools appear suitable in most of these cases.
- There have not been reported any applications in business process design. We conjecture that this and related decision areas involve too many "soft", for example human and organizational, aspects to allow useful quantifications.
- Likewise, there have been reported very few real-world applications for multi-echelon supply chain decision-making. This may have similar reasons, but is may also be because supply chain simulations are a relatively new concept. In either case, it seems that software requirements for supply chain simulations are slightly different from those for traditional application areas. Considerable research is currently being reported in this field at a conceptual/prototype level. As stated, however, papers reporting real-world applications are scarce and thus encouraged by the authors.
- Recently, many applications have been reported in the semiconductor and the automotive industry. DES appears particularly appropriate in these industries, which are characterized by production lines and continuous production with stable, automated processes.
- Finally, several papers have reported on the combination of DES with optimization. This confirms the feasibility of such endeavors, which typically combine the strengths of each approach.

There are several opportunities for further research. An industry survey and case studies could be carried out in order to support or falsify the present study's findings. Also, the use of DES for multi-echelon supply chain modeling needs further attention. Finally, applications of other quantitative modeling techniques, such as optimization and queuing theory, should be investigated and their different characteristics compared in order to support selection of appropriate techniques in practice.

ACKNOWLEDGMENTS

We would like to thank Kari Fauske for increasing the correctness and readability of the paper. We would also like to thank the participants at the internal doctorate seminars carried out regularly at the first author's department. These seminars are a valuable source of comments and improvement suggestions.

APPENDIX: PAPERS INCLUDED IN THE SURVEY

In this appendix, references to each paper included in the study are given, sorted by decision area. For each paper, the authors' names are specified, followed by the year of publication in the WSC proceedings.

Production system: Ali et al (05); Chu et al (05); Faget et al (05); Jain and Leong (05); Grimard et al (05); Hasgül et al (05); Ingemansson and Oscarsson (05); Maas et al (05); Mosca et al (05); Altinkilinc (04); Baesler et al (04, 02); Gujarathi et al (04); Lu et al (03, 02); Murray et al (03); Saraph (03); Shikalgar et al (03); Aybar et al (02); Choi et al (02); Farahmand et al (02); Jimenez et al (02); Gonzales-Lujan (02); Muller et al (02); Patel et al (02); Potti (02); Saraph (02); Shikalgar (02); Thomas (02); Williams et al (02);

Lot sizes and WIP rules: Ali et al (05); Chu et al (05); Jacobs et al (05); Grimard et al (05); Jadhav (05); LeBaron and Domasche (05); Marvel et al (05); Mosca et al (05); Arisha et al (04); Govind et al (03); Saraph (03); Sunkara et al (03); Türkseven et al (03); Choi et al (02); DeJong and Wu (02); Mane et al (02); Patterson et al (02); Shikalgar (02); Smith et al (02); Thomas (02);

Short term production planning and scheduling: Greenwood et al (05); Marvel et al (05); Arisha et al (04); Chong et al (03); Joines et al (03); Lehtonen et al (03); Finke et al (02); Williams et al (02);

Inventory policies: Jain and Leong (05); Maas et al (05); Morrice et al (05); Cao et al (03);

Materials programme; Gosh (05); Yee (02);

Plant location and physical distribution system: Dalal (03).

REFERENCES

Note that references to the application papers included in our study are not included in this list. They are all published in the WSC proceedings of the year indicated in parentheses wherever mentioned.

Ackoff, R.L. 1987. OR, a post mortem, *Operations Research*. **35**, 471-4

Askin, R. G., and C. R. Standridge. 1993. *Modeling and analysis of manufacturing systems*. Wiley.

Banks, J., J. S. Carson, and B.L. Nelson. 1996. *Discrete-Event System Simulation.* 2nd edition. Upper Saddle River, NJ. Prentice-Hall.

Chan, J.W.K. 2005. Competitive strategies and manufacturing logistics – an empirical study of Hong Kong manufacturers, *Int. J. of Physical Distribution & Logistics management* **35**(1), 20-43

Christopher, M. 1998. *Logistics and Supply Chain Management - Strategies for Reducing Cost and Improving Service.* 2nd edition. London: Prentice-Hall

Daellenbach, H. G., and D.C. McNickle. 2005. *Management Science. Decision making through systems thinking.* Palgrave McMillan.

Deleris, L.A. and F. Erhun. 2005. Risk Management in Supply Networks Using Monte-Carlo Simulation *In Proceedings of the 1999 Winter Simulation Conference*. ed. M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, 1643-1649

Deleris, L.A., D. Elkins., and M.E. Paté-Cornell Analyzing. 2004. Losses From Hazard Exposure: A Conservative Probabilistic Estimate Using Supply Chain Risk Simulation *Proceedings of the 2004 Winter Simulation Conference* ed. R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters,1384-1391

Fildes, R., and J.C. Ranyard. 1997. Success and survival of operational research groups – a review. *Journal of the Operational Research Society* 48(4).

Fleischmann, B., H. Meyr and M. Wagner. 2005. in: H. Stadtler and C. Kilger, *Supply chain management and advanced planning* (3rd edition, Springer, Berlin

Flood, R. L., and M. C. Jackson. 1991. *Creative problem solving. Total Systems Intervention*. Wiley.

Hieber, R. 2002. *Supply chain management: a collaborative performance measurement approach*, VDF Zurich.

Hopwood, A.G. 1980. in: *Topics in Management Accounting*, edited by J. Arnold, B. Carsberg and R. Scapens Deddington: Philip Allen.

Ingalls, R., and C. Kasales. 1999. CSCAT: The COMPAQ supply chain analysis tool. *In Proceedings of the 1999 Winter Simulation Conference*. ed. P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1201-1206

Jackson, M.C. and P. Keys. 1984. Towards a system of systems methodologies, *Journal of the Operational Research Society*. 35: 473-486.

Lee, H. L., C. Billington, B. Carter, and H.E. Edmondson. 1993. Hewlett-Packard Gains Control of Inventory and Service through Design for Localisation. *Interfaces* 23(4).

Lin, G., M. Ettl, S. Buckley, S. Bagchi, D.D. Yao, B.L. Naccarto, R. Allan, K. Kim, and L. Koenig, 2000. Extended- Enterprise supply-chain management at IBM personal systems group and other divisions. *Interfaces 30(1)*.

Liu, J., W. Wang, Y. Chai, and Y. Liu. 2004. Easy-SC: A supply Chain Simulation Tool. *Proceedings of the 2004 Winter Simulation Conference.* ed. R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, 1373-1378.

Mayo, D. D. and K.E. Wichmann. 2003. Tutorial on business and market modeling to aid strategic decision making: system dynamics in perspective and selecting appropriate analysis approaches. *Proceedings of the 2003 Winter Simulation Conference.* ed. S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, 1569-1577

McGinnis, L. F. 2004. Distributing a large, complex fab simulation using HLA and Java: issues and lessons. *Proceedings of the 2004 Winter Simulation Conference.* ed. R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, 1373-1378.

McLean, C. and S. Leong. 2002. A framework for standard modular simulation. *Proceedings of the 2002 Winter Simulation Conference. E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, 1613-1620.*

Meixell, M.J, and V.B. Gargeya 2005. Global Supply chain design; A literature review and critique. *Transportation Research Part E* 41: 531-550.

Morgan, C. L. (1989). A Survey of MS/OR Surveys. *Interfaces* 19(6).

Munro, I. and J. Mingers. 2002. The use of multimethodology in practice – results of a survey of practitioners. *Journal of the operational research society* **53**, 369 – 378.

NAICS. 2002. *North American Industry Classification System (NAICS): United States, 2002*. Lanham: Bernan Publishers.

Neely, A. 1993. Production/operations management: Research process and content during the 1980s. *International Journal of Operations and Production Management* 13(1).

Olhager, J., and B. Rapp. 1995. Operations Research Techniques in Manufacturing Planning and Control Systems. *International Transactions Operational Research* 2(1).

Ozturk, O., M.B. Coburn and S Kitterman. 2003. Conceptualization, Design and Implementation of a Static Capacity Model. *Proceedings of the 2003 Win-*

ter Simulation Conference. ed. S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, 1371-1376

Rosenhead, J. 1991. in: *Operational Research '90*, edited by H.E. Bradley (Pergamon, Oxford, 1991)

Rosenhead, J. and J. Mingers, 2001. in: *Rational Analysis for a Problematic World revisited – Problem Structuring Methods for Complexity, Uncertainty and Conflict*, ed. J. Rosenhead and J. Mingers. Chichester: Wiley.

Simulation Study Group. 1991. *Simulation in UK Manufacturing Industry*. Birmingham.

Smith, J. S. 2003. Survey on the use of Simulation for Manufacturing System Design and Operation. *Journal of Manufacturing Systems* 22(2).

Terzi, S., and S. Cavalieri. 2004. Simulation in the supply chain context: a survey. *Computers in industry* 53.

Wu, S.D, R.O. Roundy, R.H. Storer and L.A. Martin-Vega. 1997. *Manufacturing logistics research: taxonomy and directions*. <http://www.lehigh.edu/~sdw1/nsfws.pdf>

AUTHOR BIOGRAPHIES

MARCO SEMINI is a Ph.D. student at the Norwegian University of Science and Technology. His research currently concentrates on the applicability and use of quantitative modeling techniques to support decision-making in manufacturing logistics, Supply Chain Management, and related fields. His email address is <marco.semini@ntnu.no>.

HAKON FAUSKE is a researcher at the department of Logistics at SINTEF Technology and Society. His research interests are Supply Chain Management, performance measurement, and production planning and control. His email address is <hakon.fauske@sintef.no>.

JAN OLA STRANDHAGEN is a professor at the Department of Production & Quality Engineering at the Norwegian University of Science and Technology and Research Director of the Logistics department at SINTEF Technology and Society. He received his Ph.D. from the Norwegian University of Science in 1994. His research and teaching interests are production planning and control and Supply Chain Management. His email address is <ola.strandhagen@sintef.no>.