SIMULATION METHODS AND EDUCATIONAL GAMES: APPLICATION AREAS FOR LEARNING AND STRATEGIC DECISION-MAKING IN MANUFACTURING OPERATIONS

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ABSTRACT

A wide spectre of different types of quantitative models is available to address strategic operations management decision problems. This paper argues that business games are an alternative to "traditional" discrete-event and continuous simulation methods for analysing complex supply chain problems. Business games capture the organizational and human aspects in supply chain problems that are difficult to model with traditional simulation methods. The computerized version of the Beer Game is an example of the use of business games in supply chain decision making. The recommendation of business games is based on a simulation application survey carried out by the authors and the theoretical approach of Flood and Jackson (1991).

INTRODUCTION

In the field of production and operations management, quantitative modelling has long been a normal and well-accepted academic way of dealing with complex issues (Meredith et al, 1989). There is a wide spectre of different types of quantitative models available to address operations management decision problems, ranging from simple static spreadsheet models to advanced mathematical optimisation and simulation models. In this paper, the applicability of simulation to production and operations learning and decision-making is discussed. In particular, its limitations to the representation of behavioural factors are discussed and business games suggested as an alternative. Computerized versions of business games can be considered as an extension of simulation, where the managers themselves operate interactively within the simulated system.

The purpose of this paper is to

- present application areas of traditional simulation for learning and strategic decision-making in manufacturing operations by means of an applications survey,
- explain, by means of existing theory, the limited use of simulations for macroscopic supply chain issues, a major finding from the survey, and
- suggest business games as a more appropriate method for learning and strategic decision-making in the macroscopic supply chain setting.

The paper is structured in the following way. First, manufacturing operations decisions are categorized by their scope. Next, simulation and business games are presented as methods for learning and decision-support in manufacturing operations. Findings from a recent applications survey are then used to assess the appropriateness of simulation for learning and decision-support for different decision categories. A theoretical framework from Total Systems Intervention (Flood and Jackson, 1991) is used subsequently to explain the survey results. Finally, business games are suggested as an alternative when simulation does not appear to be an appropriate learning and decision-support method.

CLASSIFYING MANUFACTURING OPERATIONS DECISIONS ALONG THEIR SCOPE

Manufacturing operations decisions can be classified by their scope, ranging from a microscopic orientation (such as a machine or piece of equipment) to a macroscopic orientation concerning entire supply chains or manufacturing networks. McLean and Leong (2002) provide such a classification, with the categories presented in figure 1. As will be seen, classifying a decision problem along its scope is useful to identify when simulation is appropriate for learning and decision -making.

Table 1: Classifying the scope of decisions from microscopic to macroscopic.

Device	Equipment	Station	Line/cell	Department	Facility	Enterprise	Supply Chain

Decisions to the left of the continuous scale shown in figure 1 are microscopic, concerning a very limited part of a manufacturing system, such as machine tools, robots, automatically guided vehicles, cranes, conveyors etc. Examples of such decisions are capacities, sizes, functionalities and technologies of such devices and equipment. As one moves to the middle of the scale, the scope covers increasingly larger parts of the manufacturing system, such as lines, departments and facilities. Decisions include planning and scheduling, number, tasks and physical arrangement of resources (such as workstations, operators and WIP buffers). As one approaches the right of the scale, decisions concern several plants in an organization and supply networks consisting of independent actors. Such decisions include location and capacities of plants, aggregate material and information flows, collaboration and customer relationship management, joint planning and forecasting, profit sharing, inventory ownership, outsourcing etc.

SIMULATION AND BUSINESS GAMES TO SUPPORT LEARNING AND STRATEGIC DECISION -MAKING

Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical relationships necessary to describe the behaviour and structure of a complex world system over extended periods of time (Naylor et al, 1966). There are several reasons why a simulation study can support operations managers in decision making, including:

- A simulation model facilitates understanding of the real system and its behaviour.
- The actual exercise of building a simulation model reveals previously unapparent relationships and provides a systematic way to analyzing 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.

Simulations are often divided into two methods: discrete-event simulation and continuous simulation. In discrete-event simulation, changes in the state of a system are triggered by events, such as the arrival of a customer, the start or end of an activity, and so on. It focuses on the behaviour of the individual, discrete objects (entities) which make up the system. The entities are considered to move from state to state, and their behaviour is modelled explicitly by means of rules (Littlechild and Shutler, 1991). For further details, the reader is referred to a text book such as Robinson (2004) or Law and Kelton (2000). In continuous simulation, variables can take a continuous set of values rather than the discrete states occupied by discrete entities. The relationships between the continuous variables are described by means of differential equations. These equations cannot normally be solved mathematically, so numerical-analysis techniques are used to solve the equations numerically. For further details, the reader is again referred to textbooks, for example Sterman (2000).

Business or management games can be considered as an extension of simulation (Kleijnen and Smits, 2003), at least when they exist in computerized versions. In such games, a number of (crucial) tasks are carried out by humans, while other tasks are still executed automatically by the computer. Kleijnen (2005) defines business or management games as interactive simulations, where managers themselves operate within the "simulated" world. Such games have received much less attention in research and practice than simulation. Nevertheless, they can be usefully applied for educational purposes, learning, and decision-support. This topic has been treated by Riis, Smeds and Van Landeghem (2000) and Ten Wolde (2000).

APPROPRIATENESS OF SIMULATION FOR DECISION-MAKING IN OPERATIONS

Applications survey

Recently, the authors carried out an extensive survey on real-world applications of simulation to support operations management decisions in discrete manufacturing enterprises (Semini, Fauske and Strandhagen, 2006). The survey investigated application areas, industries and company characteristics, modeling methodology and software tools used. Relevant applications were identified by completely surveying the Proceedings of the Winter Simulation Conference of the years 2002 to 2005. The survey and its findings are described elsewhere (Semini, Fauske and Strandhagen, 2006). Here, only a partial finding related to application areas is used.

Out of over 1000 papers surveyed, 52 described a situation where a manufacturing company used simulation to support some decision related to operations management. When classifying these decisions by their scope as described, the authors made an interesting discovery: even in recent years, most real-world applications reported take a micro orientation, focusing on a limited part of a manufacturing system, such as a machine, line or a shop floor. Manufacturing enterprises have rarely used simulation to support decisions concerning larger parts of supply chains, encompassing several business units and/or echelons, not to mention (independent) actors. In fact, out of the total of 52 applications surveyed, only two papers describe a situation where a simulation model of several echelons has supported a company in decision-making (both were carried out by OEMs in the automotive industry).

Generalizing this finding is not justified by the nature of the survey due to different reasons, such as sample size and the fact that a large number of simulation applications never are reported on in research literature. Further, the results may simply be due to the fact that concepts such as supply chain management and global optimization are relatively new. Only recently, larger parts of supply chains have been analyzed in a holistic way (Beamon, 1998). Simulation modeling, which has a long tradition in the analysis of manufacturing plants, may need some time to adapt to this new and wider perspective. In particular, it seems that DES software needs some adjustment in order to be fully appropriate.

Nevertheless, the findings provide some indications and can be used to support statements about the applicability of simulation to support different operations decisions. In the survey, only two papers describe supply chain simulations, the remaining 50 describing simulations of machines, lines or shop floors. This result supports that simulation is appropriate for microscopic decisions, but may be less applicable for macroscopic supply chain problems. In the next section, this hypothesis will be further supported using previous research.

Note that the survey finding is in according with Neely (1993). In his examination of the papers published in the International Journal of Operations and Production Management, he found two groups of papers: one group had a narrow focus (such as a single machine) and attempted to develop mathematical approaches to system improvement; the other group attempted a broader purview and used more qualitative analysis methodologies considering organizational and human aspects.

Theoretical underpinning

The lack of supply chain simulation applications may have fundamental reasons that restrict the applicability of simulation for macroscopic supply chain decisions. Moving from a single machine manufacturing line 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, validity of analysis methodologies based on operational research and systems analysis decreases, since such aspects are too "soft" (i.e. ill-structured, behavioural) and do not lend themselves to quantification. They are no longer "hard" (structured, technical) issues adequately addressed by quantitative models and simulation (Min and Zhou, 2002).

This claim is supported by the work of Flood and Jackson (1991) and their Total Systems Intervention (TSI), where problem contexts are classified along two continuous dimensions in order to find suitable analysis methodologies:

1. From simple to complex systems: Simple systems follow well defined laws of behaviour, are unaffected by behavioural influences, are largely closed to the environment and are not evolutionary. Complex systems, on the other hand, are probabilistic in their behaviour, are subject to behavioural influences, and are open to the environment and evolutionary.
2. Form unitary, over pluralist, to coercive participants: Unitary participants share common interests, have compatible values and beliefs, and largely agree upon ends and means; pluralist participants have a basic compatibility of interest, their values and beliefs diverge to some extent, and they do not necessarily agree upon ends and means, but compromise is possible; and coercive participants, which do not share common interests, whose values and beliefs are likely to conflict, and where genuine compromise is not possible (some coerce others to accept decision).

Simple, unitary problem contexts are suitable for analysis methodologies based on operational research and systems analysis. As problem contexts become more complex and/or more pluralist/coercive, validity of such approaches decreases and other "softer" methodologies are more appropriate. See table 2 and Flood and Jackson (1991) for further details. Applying to our context, moving from a single machine or production line to a supply chain including several echelons and plants, constitutes a shift in problem context from simple and unitary to complex and pluralist/coercive. The shift is mainly due to an increasing role of organizational and human aspects, as well as an increasing number of (independent) actors. This provides an explanation for the lack of simulation-based decision support in supply chain management in the survey; inversely, the lack of simulation-based decision support in supply chain management supports Flood and Jackson's framework. It is further supported by the fact that the survey has not identified a single simulation of business processes such as order processing: such systems are relatively complex in Flood and Jackson's understanding. Neely's (1993) survey also supports the framework.

Table 2: A grouping of system analysis methodologies, based on the assumptions Flood and Jackson make about problem contexts (Flood and Jackson, 1991).

	Unitary	**Pluralist**	**Coercive**
Simple	Operations research Systems analysis Systems engineering System dynamics	Social systems design Strategic assumption Surfacing and testing	Critical systems heuristics
Complex	Viable system diagnosis General systems theory Socio-technical systems Contingency theory	Interactive planning Soft systems methodology	?

BUSINESS GAMES FOR LEARNING AND STRATEGIC DECISION-MAKING IN MACROSCOPIC CONTEXTS

The authors suggest business games as a more appropriate alternative to simulation for managerial learning and strategic decision-making in macroscopic contexts. The difficulties of simulation to model human behavior can be overcome by letting managers themselves operate within the simulated world (Kleijnen, 2005). Thus, while some decisions and tasks are still performed by the computer simulation, human participants are assigned a number of task and decisions (which they perform interactively during the simulation run). This way, behavioural aspects can be included in the simulation, leading to more realistic results. Further, difficulties with quantifying human behaviour are avoided, making the development of the simulation model more straightforward. Such "extended simulations" still being carried out in an experimental setting, various "what-if" analyses can be carried out, just as with "traditional" simulation.

The most famous example of such a business game is the (computerized) Beer Game (Simchi-Levi et al, 2003). In this game, a simplified beer supply chain, consisting of a manufacturer, a distributor, wholesaler and a retailer, is simulated. The four actors' replenishment decisions are taken by four human participants; all other tasks, such as demand generation, material and information flows, and reporting activities, are taken care of by the computer. This game is used in university and executive education courses to illustrate the bullwhip effect (for details about the bullwhip effect, see for example Lee et al, 1997). It can also be used to experiment with different improvement strategies, such as information sharing, centralized management and lead-time reduction. This can be done within the tightly controlled environment of an experiment, holding all else constant, in the presence of behavioural and cognitive limitations. Croson and Donohue (2002) have carried out such experiments in an academic setting.

The authors suggest that such business games may be used more regularly by managers and practitioners to support strategic decision-making when the scope of the decision includes substantial human and organisational factors. Examples of such decisions are introduction of collaborative forecasting and planning systems, introduction of concepts such as VMI, adoption of just-in-time manufacturing principles such as KANBAN, use of alternative performance measures, etc. Such games may represent the supply chain in question with adequate precision, rather than being of a more generic kind like the beer game. The games can be designed in-house or by external consultants, and carried out in workshops including the decision-makers as well as the operational functions affected by the decisions (such as planners and operators). Benefits of such workshops are better understanding of the decision-problem and the effect of different alternative options. In addition, such workshops introduce operational functions concerned to the possible novel practices and working procedures. This educates and may reduce the resistance to change since employees affected by the decisions can experience its effects first-hand.

CONCLUSIONS

In this paper, an applications survey and some theoretical arguments are used to identify opportunities and limitations of traditional simulation methods as a means of supporting operations decisions in manufacturing enterprises. While adequate for decisions with a microscopic scope such as a machine or manufacturing line, such simulation methods may not be as suitable for macroscopic supply chain decision-making due to the increased relevance of human and organisational factors. Business games are suggested as an alternative. In business games, a number of (crucial) tasks are carried out by humans, while other tasks are still executed automatically by the computer. This way, behavioural aspects can be included in the simulation, leading to more realistic results. The authors suggest that business games may be used more regularly by managers and practitioners to support strategic decision-making when the scope of the decision includes substantial human and organisational factors.

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