Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle

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*Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle*, tome 29, nº 3 (1995), p. 219-223.

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Recherche opérationnelle/Operations Research
(vol. 29, n° 3, 1995, p. 219 à 223)

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# INTRODUCTION

# COMPLEXITY AND INDUSTRIAL SYSTEMS (*)

by Charles S. TAPIERO (1)

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At the beginning of the industrial revolution, production was an art, unique and mostly irreproducible. When it became an organized and collective activity involving standardization, rationalization of work, division of labor, functionalization and management, it grew into an organizational and complex activity. Further, complex manufacturing organizations, coupled with de-responsabilization, information asymmetry and latent conflicts between members and agents in these organizations induced moral hazard, rendering the management of industrial organizations a hopeless task, or at best a very challenging one.

In some cases, the growth in complexity, seeded at the beginning of the century led to a breakdown in our potential to manage these, man-made systems. Thereby, fulfilling Ashby's law of requisite variety, where the controllers become less sophisticated then the systems they purport to control. Traditional managerial concepts including quality control, model buiding, operations research, cybernetics and the application of computer aided information and automatic control systems has of course been applied to deal with evolving needs, each generation inventing new options and new needs transformed into a new industrial "culture". This too has contributied to the growth of complexity. In this sense, complexity which was long been part of the solution, became a greater part of the problem.

For example, the trend towards increasingly smaller production lots has induced a growth in the complexity of production systems. Smaller lots are assumed on the one hand to reduce in process stocks while sensitizing the

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(*) Received March 1995.
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Recherche opérationnelle/Operations Research, 0399-0559/95/03/$ 4.00
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production process to customer wants. The management of these systems is of course extremely complex, far more complex than stock based production systems. The challenge of complexity thus induced has given rise to two cultures. On the one hand a "Japanese Culture" heralded by the Just in Time production technique, seeking to reduce the complexity of production systems through "straight jacket" managerial procedures. On the other, a large scale flexible automation culture which seeks to build in the manufacturing processes a greater number of managerial options, often coined flexible manufacturing systems (or FMS). Similarly, in the management of quality, a number of managerial cultures are increasingly co-existing. The traditional culture of SQC/SPC (Statistical Quality and Process Control) based on the monitoring of processes versus a management of quality approach which integrates preventive measures in the manufacturing process. The latter, often called TQM (Total Quality Management), results often in an added complexity. Of course, there are limits to the complexity we can deal with, given any specific technology. In this sense, concepts of re-engineering are already appearing seeking a reorganization far more in tune with the managerial tools recently invented (essentially including information technologies). Alternatively, attention is given to de-sensitizing the performance and operations of complex systems to uncontrollable events through robust design. In this latter approach, complexity is managed by increasing the tolerance of systems to unforessen events and thereby tolerate complexity as well. This leads in many cases to a search for new optimization objectives that can help identify robust solutions. There are of course many other problems, all of which arising from the Darwinian precepts for the survival of the fittest.

Additional factors, such as increased autonomy for workers, decentralized organizations, production to demand, incentive schemes, adaptive systems etc. which are part of the solution for many of the current industrial problems create their own problems as well, through the added complexity they impose.

The questions we are faced with are thus three fold. (a) Can we negate complexity and if so how. (b) Can we outsmart complexity and if so how and finally (c) Can we control complexity. These questions are of course part of the answers some of the papers in this special issue will consider. In other words, is simplification an answer to our problems or is greater sophistication required? When neither provides the technological and optimal economic solution we must then turn to constructing schemes which will help at least aleviate the effects that complexity has induced upon us. Operations

Research can provide some of the answers to these problems while pointing out some of the questions that modeling and computational technologies raise.

This special issue of RAIRO *Operations Research* on Complexity and Industrial Systems arose from the current concern both in industry and academia to deal with the growth of complexity in all facets of management processes in industrial, engineering and business systems. Current advances in robotics and automation, integrated software systems, networks of various sorts (whether for communication and computing systems or innovation and industrial networks) are raising great challenges to the Operations Research profession. There are of course multiple and intertwined problems spanning modelling issues, computational power and strategic managerial issues. To a large extent, the OR profession has, ever since the second world war been involved in providing solutions to the problems raised by increasingly complex systems. This has been achieved through better modelling techniques and tools such as queueing theory, linear programming, reliability, network design, statistical quality control and detection theory and so on. Increasingly, however, a creeping complexity has began to raise ever greater problems, becoming the essential part of the problem OR has to reckon with. It is in this spirit that this special issue was conceived, on the one hand raising some outstanding issues in complex systems modeling and problem solving and on the other, by indicating some of the tools one may apply in the solution of real problems. Of course, this issue is not exhaustive but seeks to provide only some indications for the many problems OR researchers and practitioners have met in the course of their solving practical and theoretical problems.

The issues is organized as follows. We begin by a paper by Lemoigne who, starting from Weaver's typology proposed fourty years ago, suggesting that we differentiate models as disorganized and organized complexity, proposes a broader typology including "organizing complexity". The latter, emphasizes qualitative reasoning, symbolic and process integration rather than just quantitative reasoning, numerical and decomposition processes as it is the case in the traditional OR profession. The paper provides as well a broad appreciation of the various notions of complexity and particularly the approaches conceived to deal with and manage complexity.

Cohendet, Llrena and Mutel hypothesize that the control of complexity in a firm is intrinsically dependent on the search for flexibility. The need and growth for complexity has thus fed the growth of complexity of our industrial design. To manage these complexity there are a number of methods.

Nevertheless, the paper proposes a structural approach based on group technology.

Makridakis evaluates in his paper, "Forecasting Accuracy and System Complexity", the relative performance and accuracy of alternative forecasting schemes. A review of basic results on forecasting models performance is first outlined and critically appraised. Subsequently, an important case is made for simple forecasting tools which can in many cases outperform complex models. There are many reasons for this observation, among them, the "butterfly effect", indicating an extreme sensitivity to initial conditions, leading to potentially chaotic behaviors.

The paper by Garavelli and Pontrandolfo: A Heuristic Approach to Evaluate Some Effects of Uncertainty and Complexity in Project Scheduling uses a notion of network complexity in project management based on the size, the denseness of the network as well as the stochastic durations of the project. Project durtion is studied in three ways. First, using the classical analytical framework of PERT networks, second using simulation and finally, using a heuristic algorithm, a project duration is computed efficiently.

Giard and Triomphe, in their paper "Analysis of Investment Flexibility: Methodology and Application to a Sorting Center" report on a real study performed by the french Post Office for planning and assessing a complex mail sorting center. Multiple issues are adressed. First, a large scale mixed (0-1) linear programming problem is shown to be intractable except through some decomposition of the problem at hand and second, validate the procedure followed through simulation. This results in a decision support system of particular usefulness, providing on the one hand a working learning tool and an analytical tool on he other, preempting numerous problems which result from the introduction of new technologies.

The Proth and Minis paper: Production Management in a Petri Net Environment, demonstrate the utility of Petri nets in designing complex manufacturing systems. First they consider cyclic manufacturing systems for which it is always possible to construct an event graph model which represent both the facilities of the system and the decision making processes associated to these facilities. Given such a representation, a near-optimal scheduling algorithm is proposed that maximizes productivity while minimizing WIP (Work in Process) in the deterministic case. Subsequently, they study non-cyclic manufacturing systems for which only the physical facilities are represented by a Petri net. Through such analysis, Proth and Minis demontrate how complex manufacturing systems can be simplified and rendered tractable.

Finally, Jacobson and Yucesan paper's on Intractability Results in Discrete Event Simulation, provide a study of complexity in discrete event simulation. In particular, they consider three new search problems associated with structural issues in simulation modeling are defined and proven to be NP-hard. The implications of this computational complexity is discussed not only for simulation model building but for assessing the performance of DEDS systems as well.

## ACKNOWLEDGMENTS

Support of the CERESSEC and EEC Contract ERB 4050PL930200 on Decision Support for Maintenance Management and Quality control (Human Mobility Program, 1993-1995) is gratefully acknowledged.