ELSEVIER

Journal of Materials Processing Technology 107 (2000) 347–352

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Manufacturing competitiveness and fitness landscape theory

I.P. McCarthy[a], Y.K. Tan[b,*]

[a]*Warwick Manufacturing Group, International Manufacturing Centre, University of Warwick, Coventry CV4 7AL, UK*
[b]*University of Sheffield, Department of Mechanical Engineering, Mappin Street, Sheffield S1, 3JD, UK*

Abstract

Manufacturing organisations recognise that the business environment has varying levels of unpredictability. To serve such unpredictability, they utilise forecasting and decision modelling techniques at all levels (strategic to operational), but with business and customer demands intensifying, the levels of unpredictability have been increasing and the confidence in such techniques is reducing. In order to satisfy customers and remain competitive, manufacturing organisations must be able to "sense and respond". This paper provides an introduction to the concept of developing and applying fitness landscape theory to help manufacturing managers make decisions in such a manner. This approach treats the organisational system and its decisional situation as a complex adaptive system, which is continually co-evolving with its environment, whilst searching for solutions and making decisions. Although this theory has biological origins, it has been applied to various areas including economic and organisational studies. In summarising, this paper argues that managers should learn from nature and develop decisions, which rely less on inaccurate forecasts and more on the ability to sense and respond (adapt). The paper concentrates on the process of making strategic decisions and the resulting organisational forms. © 2000 Published by Elsevier Science B.V.

Keywords: Complex adaptive system; Fitness landscape theory; Manufacturing strategy

1. Introduction

Many studies analyse manufacturing organisations and their problems by reducing or simply throwing away the interacting components, with the assumption that the latter are either negligible or behave linearly. These studies (referred to as reductionism) tend to overlook the importance of these interacting components. An alternative view is to adopt a "complex systems" approach, to understand the manufacturing organisation as a system which evolves over time by adopting characteristics to survive. This approach focuses on the interacting components in order to understand the *emergent* behaviour. The notion of emergence is that the characteristics of the whole organisation cannot be understood by simply studying individual sections of the organisation and then extrapolating to obtain holistic views. Manufacturing organisations are complex adaptive systems and thus can never be completely controlled, because researchers have discovered that complex adaptive systems are often impossible to predict, because they exhibit *punctuated equilibrium and path dependence*. Managers need to understand and live with emergence.

The biological world faces similar issues, in that species are constantly adapting to unpredictable environments. Nature does this without using sophisticated forecasting techniques. Adapting biological organisms are faced with conflicting constraints in their internal organisation as well as in their interactions with the environment. These conflicting constraints imply that it is impossible to search for the optimal solution and that there are many locally optimal compromise solutions that exist in the large space of possibility. For six decades, biologists have pictured a biological landscape where organisms adapt and search this space for genotypes which are fitness peaks on a rugged, multi-peaked, mountainous "fitness landscape". Although the fitness landscape concept has biological origins, it has stirred up interest in areas such as economics, computer science and organisational studies. Fitness landscape theory could help manufacturing organisations obtain new insights and understanding about the interrelation between internal characteristics (such as strategy, technology, management practices, etc.) and external environment (competition, demand, market legislation, etc.).

2. Manufacturing organisations as complex adaptive systems

Manufacturing organisations as with all organisations are systems. Casti [1] suggested that all systems could be

* Corresponding author. Tel.: +44-2476-573-136;
fax: +44-2476-524-307.
E-mail address: i.p.mccarthy@warwick.ac.uk (I.P. McCarthy).

0924-0136/00/$ – see front matter © 2000 Published by Elsevier Science B.V.
PII: S0924-0136(00)00687-7

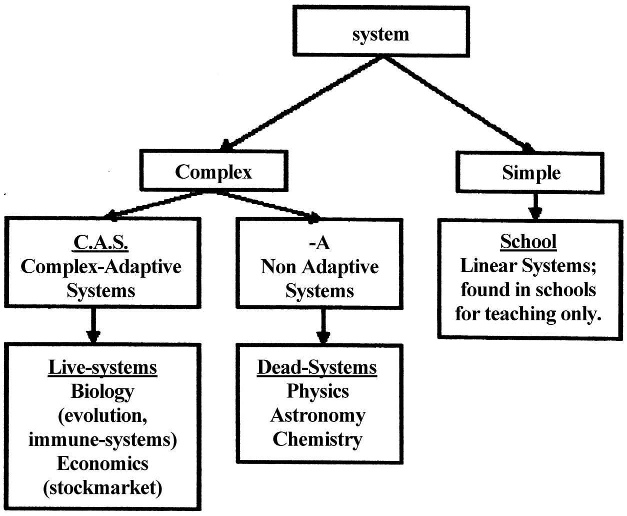

Fig. 1. Classification of system.

classified into two categories, *simple* and *complex* (Fig. 1). Simple systems are only found in schools for teaching purposes, i.e. to simplify and elucidate basic principles and theories. As for the complex ones, they can be divided into two further classes, *non-adaptive systems* (∼A), and *complex adaptive systems* (CAS). A complex adaptive system defined by Mitchell [2] is when the "*behaviour of the system as a whole emerges from the interaction of large numbers of simple components, and in which the system is able to adapt, to automatically improve its performance (according to some measure) over time, in response to what has been encountered previously*". From this definition, there are several important characteristics. Firstly, each system is a network of *agents* (people, machines, products, etc.) that interact in various ways, using their own internal rules, states, and experience. These internal rules are called *schemas* and strongly influence an organisation's responsiveness. Secondly, a CAS has the ability to learn and hence adapt to a new environment. The system is constantly revising and re-organising its agents as experience is gained from past interactions. From this learning, the system will develop its strategies for the future by changing its schema. Without this adaptability, the system is likely to face extinction. A complex adaptive system will sense changes and disruptions based on the internal and external assumptions of the agents relative to the environment. From the above, it is clear that manufacturing organisations are complex adaptive systems, as they learn, adapt and evolve over time [3]. This final point is what differentiates adaptive systems from non-adaptive systems, that is the rules within non-adaptive systems do not change at all. Examples include 'dead' systems found within physics, astronomy, chemistry, etc.

Finally, complex adaptive systems usually have many niches. A newly adapted agent can satisfy these niches, but the act of satisfying the niche will open up more niches for other agents. Holland [4] noted that since the system is always changing, it is pointless for the agents to optimise their function or fitness. The space of possibility is too large and there is no practical way of finding the optimum. The best the agents can do is to change and improve themselves against what the other agents are doing.

3. Fitness landscapes

The creation and application of fitness landscape models to help search and select solutions to manufacturing problems is the principal area of novelty within this paper. The concept of fitness landscapes has been used by biologists since the 1930s to characterise the adaptive evolution of genotypes as a search across a landscape of fitness points [5]. Kauffman [6,10] used this notion to investigate the process of self-organisation and natural selection. He noted that adaptation is usually thought to be a process similar to "hill climbing" where minor variations of the species (from one generation to the next generation) result in a move towards a peak of high fitness on a fitness landscape. The concept of natural selection and survival of the fittest will push a population of species towards such peaks. A failure to do so may make the species face extinction. This fitness landscape can be imaged as a series of hills and valleys of different heights and depths. To represent such landscapes Kauffman's research created NK models, which are derived from the spin-glass model created by physics research. Fitness is the ability to successfully navigate such landscapes to survive and compete.

The NK model is valuable for determining how many local optima there are and the route of adaptive walks to achieve improved fitnesses. Within business and management there is no widely accepted definition of what constitutes "organisational fitness", but it is associated with terms such as competitiveness, effectiveness, profitability, return on investment and customer satisfaction.

Using a complex systems perspective and a simple manufacturing example, this paper will develop a working definition of manufacturing fitness. The example is concerned with the decision "how many pieces of equipment should be purchased for a customised job, this paper will explain the concept of NK models". If there are three types of machine that could be purchased to satisfy a machining requirement, then this set of alternatives is known as $N = 3$ (machine A, machine B and machine C). The solution to the problem is to buy one or all three pieces of equipment or any of the intermediate combinations. For each machine there are two values: to purchase the machine (1) or to not purchase the machine (0). This simple example provides a straightforward binary code of the problem, with the total combination of 2^3 (i.e. eight possible combinations).

With each combination, a value (from 0 to 1) called *fitness* can be allocated according to criteria which could be based on cost, flexibility, speed, etc. The definition and function of *fitness* is not simply to optimise. The term fitness was first used by Herbert Spencer as "survival of the fittest" in 1864,