Manufacturing strategy: understanding the fitness landscape

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Abstract This theoretical paper presents, extends and integrates a number of systems and evolutionary concepts, to demonstrate their relevance to manufacturing strategy formulation. Specifically it concentrates on fitness landscape theory as an approach for visually mapping the strategic options a manufacturing firm could pursue. It examines how this theory relates to manufacturing competitiveness and strategy and proposes a definition and model of manufacturing fitness. In accordance with fitness landscape theory, a complex systems perspective is adopted to view manufacturing firms. It is argued that manufacturing firms are a specific type of complex system – a complex adaptive system – and that by developing and applying fitness landscape theory it is possible to create models to better understand and visualise how to search and select various combinations of capabilities.

Introduction
In 1997, the UK Confederation of British Industry (CBI) produced a report titled Fit for the Future (Confederation of British Industry, 1997). This report was targeted at UK manufacturing and it claimed that an additional £60 billion a year could be added to the UK gross domestic product if manufacturing performance was raised to US manufacturing performance levels. The report stressed the need for UK improvement programmes based on cost-cutting, efficiency gains and better product lead-times and quality. As a consequence of the popularity of this report, the concept of being “fit” was synonymous with being world-class.

However, what do the terms “fit” and “fitness” mean in the context of manufacturing and operations management? This question is the motivation and starting point of this paper. It is addressed by viewing manufacturing firms as complex adaptive systems and by developing and relating fitness landscape theory to the process of manufacturing strategy formulation. These concepts provide an interpretation of fitness that is consistent with the CBI view of fit, but with a number of subtle and important differences that revolve around firm survival and imitation.

This paper also develops and extends existing work that has judged fitness landscape theory appropriate for understanding organisational development and firm dynamics (Kauffman and MacReady, 1995; Levinthal, 1996; Reuf, 1997; Beinhocker, 1999; Barnett and Sorenson, 2002). These articles explain the value and relevance of fitness landscape theory, but avoid defining fitness and
relating it to the performance and behaviour of firms. There is an implicit assumption that fitness simply relates to competitiveness and effectiveness.

With this introduction, the contribution that this paper makes is to:

- explore how a complex systems view can be used to understand manufacturing strategy and competitiveness;
- create a definition and conceptual model of manufacturing fitness that provides a basis for better understanding the exploration of strategic options; and
- to consider the relevance of this model and fitness landscape theory to the practice of manufacturing strategy.

Manufacturing and complex systems theory
Fitness landscape theory has its origins in complex systems research and, in particular, the study of evolutionary properties in biological systems. Thus, before introducing fitness landscape theory and its relevance to manufacturing strategy, it is necessary to understand the term “complex system”.

According to the *Shorter Oxford Dictionary* (Brown, 1993), the word “system” first appeared in 1619 and is now defined as “An organised or connected group of objects: a set or assemblage of things connected, associated, or interdependent so as to form a complex unity”. It is a ubiquitous term that is used to describe and consider many entities in our social, physical and biological world.

Kuhn (1962), Capra (1986) and McCarthy *et al.* (2000a) discuss and review several eras and movements of systems thinking, including:

- the Aristotelian view (organic, living and spiritual);
- the Cartesian view (mechanistic and reductionism);
- the Newtonian view (principles of mechanics);
- the romantic view (self-organizing wholes);
- the general systems science view (elements and their relationship to the whole, and open systems versus closed systems);
- the cybernetic view (feedback, self-balancing, self-regulating and self-organisation);
- the soft systems view (mental constructs); and
- the complex systems view (non-linearity, self-organisation and emergence).

Despite the different stance each view has, a common and binding theme is that they are trying to understand complicated entities by:

- determining the system boundary, components, inputs and outputs, relationships and attributes; and
supporting the integration of views and knowledge to study the total system and how it interacts with its environment.

The complex systems view, also known as complex systems theory (Stacey, 1995; Anderson, 1999; Choi et al., 2001; Dooley and Van de Ven, 1999; Morel and Ramanujam, 1999), seeks to understand the interactions between the system elements and between the system whole and its environment. These interactions generate non-linearity, self-organisation and emergence, which are difficult to represent and understand using a mechanistic and reductionism view. For example, the mechanistic and reductionism view would typically attempt to understand systems by reducing the whole system (e.g. the whole manufacturing firm) into manageable individual elements (e.g. manufacturing departments or other sub-units). By separating and studying these individual elements of the system, this view seeks to understand and formulate theories about the behaviour of the whole system, while the complex systems view asserts that the whole system cannot be truly understood by reducing it into smaller manageable units. This is because non-linearity, emergence and self-organisation are a product of the individual system element rules and behaviours, which are often independent of any rules that may have been imposed on the system as a whole. Thus, a key reason why manufacturing firms change is because they are complex and evolving systems influenced by alterations in their environmental (internal or external) conditions. It is this ability to evolve that makes manufacturing strategy formulation necessary and difficult (Rakotobe-Joel et al., 2002).

To further understand complex systems behaviour and its relevance to manufacturing firms, a discussion on these three related characteristics is provided.

Non-linearity
This is a system characteristic in which an input or change in the system is not proportional to the output or effect. Thus, effect is rarely relative to cause, and what happens locally in one part of a system often does not apply to other parts of a system (Sterman, 2002). For instance, if a manager decides to add additional resource, (e.g. workers and machines) to a production plant, the result is not always a corresponding and linear increase in the number of products manufactured. As most managers know, if one system parameter is changed there are interactions between the system elements (workers, equipment, departments, etc.) that can produce an aggregate behaviour which could not be derived by adding up the individual element behaviours or interactions.

Emergence
This attribute of a complex system results from the system’s evolution and non-linearity. Literally, emergence means “to dive out” or to come out of the
depths. Thus, emergence is the manifestation of new system performance due to the collective behaviour of the elements, as opposed to the individual behaviour of each element. Efforts to understand organisations in terms of formalization, differentiation and social adhesion cannot solely focus on individual members of the firm (Lazarsfeld and Menzel, 1961). Emergent behaviours are typically unanticipated and sometimes novel. For example, if a manager decides to discipline or dismiss an employee, then the unexpected and emergent result could be that the workforce goes on strike in protest and brings the business to a standstill. The phenomenon of system emergence is consistent with Mintzberg’s view of emergent strategies (Mintzberg, 1978), where an unplanned and unpredicted event can materialise regardless of the planned intention.

**Self-organisation**
Von Foerster (1960) defines a self-organising system as the rate of increase of order or regularity in a system. This definition is also dependent on the observer’s frame of reference. For example, as a manufacturing firm changes over time (e.g. more products, new technology, and new working practices) a manager should accordingly update and enlarge his understanding of the system and its possible states and behaviours. Self-organisation is also a product of the interactions, dependency and circularity of organisational systems and how they address and engage with the domains in which they operate. This leads to a range of dependent systems processes such as self-creation, self-production, self-maintenance and self-configuration, all of which are consistent with the complex systems and cybernetic view of firms and are known as autopoiesis – the process by whereby a firm produces and maintains itself (Maturana and Varela, 1980).

Before considering the concept of fitness and fitness landscape theory it is important to recognize that the complex systems view considers some systems to have elements (i.e. people) which have a decision-making capability (McCarthy, 2003). These elements are referred to as agents and their systems are referred to as complex adaptive systems. Agents are able to receive and process information according to a set of goal directed operating rules (schema) that the system may have. This decision-making capability creates the internal dynamic of the system and permits system adaptation (Wooldridge and Jennings, 1995). Thus, manufacturing firms are complex adaptive systems that consciously evolve and self-organise (adapt) in response to certain goals or objectives.

**Introduction to fitness landscape theory**
The origins of fitness landscape theory are attributed to Sewall Wright (1932), who created some of the first mathematical models of Darwinian evolution. He observed a link between a micro property of organisms (interactions between
genes) and a macro property of evolutionary dynamics (a population of organisms can evolve multiple new ways of existing). To describe this epistasis (the effect of one variable on another) Wright proposed a fitness landscape metaphor in which a population of organisms would evolve by moving towards a higher fitness peak, i.e. from population A to population B as shown in Figure 1.

More recently, fitness landscape theory has been used to investigate a number of life science problems including the structure of molecular sequences (Lewontin, 1974) and mathematical models of genome evolution (Macken and Perelson, 1989). One specific model, the NK model, was devised to examine the way that epistasis controls the “ruggedness” of an adaptive landscape (Kauffman and Weinberger, 1989; Weinberger, 1991; Kauffman, 1993). With this model, \( N \) represents the number of elements in a system and \( K \) represents the number of linkages each element has to other elements in the same system. This formal, but simple representation allows the model to be applied to other complex systems. For example, management and organisational science researchers have discussed and advocated the use of fitness landscape theory for investigating:

- organisational development and change (Beinhocker, 1999; McKelvey, 1999; Reuf, 1997);
- the evolution of organisational structures (Levinthal, 1996);
- innovation networks in the aircraft industry (Frenken, 2000); and
- technology selection (McCarthy and Tan, 2000; McCarthy, 2003).

![Figure 1. Evolution as a three-dimensional landscape](image)
Despite the contributions made by these works, the questions of what exactly is fitness and how does it relate to the studies in question are not fully addressed, and in some cases are avoided.

A review of fitness

Although the term fitness is used regularly in biological and evolutionary publications, its definition and use is unclear. This ambiguity has been transferred to those management and strategy papers that discuss the relevance and insights that fitness landscape theory could offer to management scholars. It seems that most authors assume there is a universally understood meaning of the term and therefore do not provide a working definition. This problem was identified by Stearns (1976), who observed that the term fitness has not been defined precisely, but that everyone seems to understand it. In an attempt to avoid repeating this problem, this paper presents a review and explanation of the term fitness, which will be the basis for the proposed definition and model of manufacturing fitness.

The term fitness was first used by Herbert Spencer in 1864 in the context of “survival of the fittest” and “natural selection” as proposed by Darwin in his *Origin of Species* four years beforehand (Gould, 1991). In a later edition of the same book, Darwin used the two phrases interchangeably, and later, it became widely known as “Darwinian fitness”, which generally meant the capacity to survive and reproduce. It was not until 1930 that Fisher (1930) related fitness to an organism’s reproduction rate, although he himself did not formally define fitness.

To better understand the biological meaning of fitness and its relevance to manufacturing strategy and survival, Table I presents a definition of fitness and four related terms (Endler, 1986). Each definition is translated into a manufacturing context.

The definitions in Table I show that fitness is traditionally defined as the relative reproductive success of a system as measured by fecundity or other life history parameters. Yet, it also indicates that fitness is a measure of a system’s ability to survive. Thus, we have two dimensions to fitness:

1. survival fitness, which is the capability to adapt and exist; and
2. reproductive fitness, which is an ability to endure and produce similar systems.

Manufacturing firms do not sexually reproduce, but those that compete by creating new strategic configurations often inspire others to imitate their strategy and mode of working. Thus, it is proposed that manufacturing fitness is the capability to survive by demonstrating adaptability and durability to the changing environment. This involves identifying and realising appropriate strategies, which in turn are perceived by competitors to be successful, who then adopt the same strategy. This process is similar to the biological view that considers fitness to be an observable effect (i.e. the reproduction rate) and is also
consistent with the notion of firm effectiveness. For example, Seashore and Yuchtman (1967, p. 898) describe the effectiveness of a firm as “its ability to exploit its environment in the acquisition of scarce and valued resource”. Therefore, firms with high fitness are able to adapt to survive. When faced with difficulties, they do not just dissipate, but find ways to overcome circumstances, even if this means sacrificing short-term objectives. This view is supported by Katz and Kahn (1978), who assert that the behaviour of a firm simply revolves around the primary goal of survival, i.e. “the continuation of existence without being liquidated, dissolved or discontinued” (Kay, 1997, p. 78).

The strategic management view of fitness is concerned with the balance between environmental expectations placed on the firm (costs, delivery, quality, innovation, customisation, etc.) with the resources and capabilities available in the firm. This is a process of matching environmental fit and internal fit (Hamel and Prahalad, 1994; Miller, 1992) and is consistent with the
theory of congruence, where each element of the firm fits with, reinforces, or is consistent with, other elements (Nadler and Tushman, 1980). Although these uses of the term “fit” were developed independently of fitness landscape theory, they are consistent with the biological view of fitness and the concept of epistasis (the effect of one variable on another).

At this stage, it is concluded that the fitness of any complex adaptive system is a measure of its ability to survive and produce offspring. Ultimately, the term fitness is used tautologically, because what exists must be fit by definition. The key issue for managers is to recognise that manufacturing strategy formulation and competition is a complex systems issue. Changes in one part of their firm can sometimes lead to non-linear and disproportional outcomes in other areas. As will be discussed, these changes also affect the shape and membership of the fitness landscape in which they reside.

The NK model
This section will explain how the NK model can be used to better understand strategy formulation as complex adapting system of capabilities and to recognise the epistasis between capabilities and competing strategies.

To begin with, the system of study is a manufacturing strategy as defined in detail in the next section. It is analysed and coded as a string of elements (N) where each element is a capability. For any element \( i \), there exist a number of possible states which can be coded using integers 0, 1, 2, 3, etc. The total number of states for a capability is described as \( A_i \). Each system (strategy) \( s \) is described by the chosen states \( s_1s_2\ldots s_N \) and is part of an N-dimensional landscape or design space (S). The K parameter in the NK model indicates the degree of connectivity between the system elements (capabilities). It suggests that the presence of one capability may have an influence on one or more of the other capabilities in a firm’s manufacturing strategy.

To understand the significance of this design space to manufacturing strategy formulation, a seminal example is adopted and conceptually modified from Kauffman’s work (Kauffman, 1993, McCarthy, 2003). Table II shows the NK model notation and outlines its relevance to manufacturing strategy. Table III provides the data for the example, which has the following parameters:

\[
N = 3 \quad \text{(three capabilities such as quality, flexibility and cost)};
A = 2 \quad \text{(two possible states such as the presence (1) or absence (0) of a capability); and}
K = N - 1 = 2 \quad \text{(each capability will affect the other two capabilities in the strategy).}
\]

With these parameters the design space is \( A^N = 2^3 \), which provides eight possible manufacturing strategies, each of which is allocated a random fitness
value between 0 and 1 (see Table III). A value close to 0 indicates poor fitness, while a value close to 1 indicates good fitness. In principle, the fitness values can then be plotted as heights on a multidimensional landscape, where the peaks represent high fitness and the valleys represent low fitness. In Kauffman’s model, the fitness function \( f(x) \), is the average of the fitness contributions, \( f_i(x) \), from each element \( i \), and is written as:

\[
f(x) = \frac{1}{N} \sum_{i=1}^{N} f_i(x)
\]

As \( N = 3 \), a three-dimensional wire frame cube can be used to represent the possible combinations and their relationship to each other (see Figure 2). Each

<table>
<thead>
<tr>
<th>System (strategy)</th>
<th>Element 1 (capability X)</th>
<th>Element 2 (capability Y)</th>
<th>Element 3 (capability Z)</th>
<th>Assigned random fitness value</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>0.0</td>
</tr>
<tr>
<td>001</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
<td>0.1</td>
</tr>
<tr>
<td>010</td>
<td>Absent</td>
<td>Present</td>
<td>Absent</td>
<td>0.3</td>
</tr>
<tr>
<td>011</td>
<td>Absent</td>
<td>Present</td>
<td>Present</td>
<td>0.5</td>
</tr>
<tr>
<td>100</td>
<td>Present</td>
<td>Absent</td>
<td>Absent</td>
<td>0.4</td>
</tr>
<tr>
<td>101</td>
<td>Present</td>
<td>Absent</td>
<td>Present</td>
<td>0.7</td>
</tr>
<tr>
<td>110</td>
<td>Present</td>
<td>Present</td>
<td>Absent</td>
<td>0.8</td>
</tr>
<tr>
<td>111</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table III.
Manufacturing strategy as a three bit string

<table>
<thead>
<tr>
<th>Notations</th>
<th>Evolutionary biology</th>
<th>Manufacturing strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>The number of elements or genes of the evolving genotype. A gene can exist in different forms or states.</td>
<td>The number of capabilities that constitute the strategy and the resulting configuration. These could include: flexibility, facility location, technology management, degree of standardisation, process structure, approach to quality, etc.</td>
</tr>
<tr>
<td>K</td>
<td>The amount of epistatic interactions (interconnectedness) among the elements or genes.</td>
<td>The amount of interconnectedness among the capabilities. This creates trade-offs or accumulative dependencies</td>
</tr>
<tr>
<td>A</td>
<td>The number of alleles (the alternative forms or states) that a gene may have.</td>
<td>Number of possible states a capability might have. For instance, the quality capability could have four states: inspection, quality control, quality assurance, and total quality management</td>
</tr>
<tr>
<td>C</td>
<td>Coupledness of the genotype with other genotype</td>
<td>The co-evolution of one strategy with its competitors</td>
</tr>
</tbody>
</table>
corner point of the cube represents a manufacturing strategy and its hypothetical fitness value. Strategic change is assumed to be a process of moving from one strategy to another in search of an improved fitness. This is known as the “adaptive walk”. If we arbitrarily select a point on the cube (e.g. point 011), there are three “one-mutation neighbours”. These are points 010, 111 and 001. If point 011 has an immediate neighbour strategy with a higher fitness value then it is possible that a manufacturing firm would evolve to this fitter strategy (point 111). The arrows on the lines of Figure 2 represent either an uphill walk towards a greater fitness value, or a downhill walk to a smaller fitness value. A “local peak” is a strategy (e.g. point 101) from which there is no fitter point to move to in the immediate neighbourhood. A “global peak” is the fittest strategy (point 110) on the entire landscape.

As this is a simple example consisting of three capabilities, it is relatively easy to visualise the space of strategic options using a wire frame cube. If the example dealt with several capabilities, it then becomes harder to visualise the design space using a multi-dimensional cube. To overcome this problem a Boolean hypercube can be used to map the strategic design space. Figure 3 illustrates the landscape of strategic options generated by four capabilities (cost, quality, flexibility and delivery). The fitness values shown in Figure 3 are taken from the work of Tan (2001), who carried out an NK analysis of the Manufacturing Excellence 2000 competition data in the UK.

As with the Figure 2 example, Figure 3 uses a binary notation to represent the presence (1) or absence (0) of a capability. For example, strategy 0011 indicates that the capabilities flexibility and delivery are present, while the capabilities cost and quality are absent. The base strategy 0000 is at the top of the diagram, while the maximum strategy 1111 is at the bottom of the diagram.
As a manufacturing firm’s strategy aggregates additional capabilities, it descends into the lower parts of the diagram. The assigned fitness value for the various combinations of capabilities is represented by the bracketed figure. Lines are used to connect two immediate neighbours and the direction of the arrowhead indicates an increase in fitness. The dotted lines represent the route from 0000 to 1111 that has the greatest gain in fitness with each move. The dashed lines with double arrows indicate two neighbouring strategies with the same fitness. When all the arrowheads are directed to a single strategy, this is considered an optimal strategy (either local or global). In Figure 3, there are two optimal points, 1101 and 1111, both with fitness values of 0.67.

The K and C parameters
As mentioned in the previous section, the K parameter is an indicator of a system’s (a strategy’s) connectivity. It represents the epistatic interactions between each system element (capability) and can range from \( K = 0 \) to \( K = N - 1 \). The former being the least complex system, where each element is independent from all other elements; and the latter being the most complex system; where each element is connected in some way to all other elements. For \( K = 0 \), the resultant landscape is relatively simple and smooth, except for one single global peak. This suggests that one single strategy dominates the
competitive landscape (see Figure 4). As $K$ increases from 0 towards its maximum of $N - 1$, the fitness landscape changes to an increasingly rugged, uncorrelated, and multi-peaked landscape (see Figure 5). This level of connectivity indicates frustration in the system, because it can lead to many local fitness maxima on the landscape. If the NK model is applied to the process of manufacturing strategy formulation it is assumed that the contribution of any capability to the overall fitness of a manufacturing strategy depends on the status of that capability and its influence on the status of the other capabilities in the strategy.
Kauffman’s NK model was originally a fixed structure model, in that the system under study was not be influenced by factors outside of its system boundary. In other words, it was a closed system in a static environment. In practice, this assumption is simplistic and invalid for complex systems. Therefore, Kauffman introduced a $C$ parameter, to indicate coupledness between the system and other systems in the environment. Coupledness means that any system will not just depend on internal factors, but also the behaviour and performance of the systems in the same environment. This notion is central to competition, because if the fitness of one firm’s manufacturing strategy is increased, it is almost certain to affect the fitness of other firms’ manufacturing strategies.

In summary, manufacturing firms are complex adaptive systems that aim to consciously evolve by seeking new strategic configurations. Fitness landscape theory and the NK model offer an approach by which to map, quantify and visualise manufacturing strategy formulation as a search process that takes place within a design space of strategic possibilities, whose elements are different combinations of manufacturing capabilities.

A definition and model of manufacturing fitness
At this point, the paper has discussed the concept of manufacturing firms as complex adaptive systems. It has introduced fitness landscape theory and the NK model, provided a review of the term fitness and briefly examined the relevance of the NK model to manufacturing strategy. The following sections of this paper develop these discussions by providing a definition and model of manufacturing fitness. Whilst not presenting a systematic review as such (Tranfield et al., 2003), a relatively comprehensive review of manufacturing strategy is offered. A theory of evolution is then presented to help understand how manufacturing strategies and their capabilities evolve according to “variation, selection, retention” and “struggle”. This theory provides the basis for the proposed definition and model of manufacturing fitness.

The anatomy of a manufacturing strategy
The previous sections view manufacturing strategy as a system of connected capabilities. Before providing a definition of manufacturing fitness, it is important to confirm and justify this view.

Skinner (1969) proposed manufacturing strategy as a process to help firms define the manufacturing capabilities needed to support their corporate strategy. He argued that an appropriate manufacturing strategy could provide a competitive advantage in terms of cost, delivery, quality, innovation, flexibility, etc. Since Skinner’s article, numerous other terms have been proposed by operations management researchers for describing capabilities. These include competitive priorities (Hayes and Wheelwright, 1984; Boyer,
1998), order winner and qualifiers (Hill, 1994), and competitive capabilities (Roth and Miller, 1992).

The field of strategic management has also made important contributions to the concept of firm capabilities, specifically through work dealing with the distinctive competences (Selznick, 1957) and resource-based perspectives (Penrose, 1959; Barney, 1991; Peteraf, 1993). To relate this and recent work to the anatomy of a manufacturing strategy and fitness landscape theory, this paper adopts and develops the dynamic capabilities view (Teece et al., 1997) by defining the following terms:

- **Resources** are the basic constituents of a manufacturing firm. They are the tangible assets such as labour and capital, and the intangible and tacit assets such as knowledge and experience.
- **Routines** are the norms, rules, procedures, conventions, and technologies around which manufacturing firms are constructed and through which they operate (Levitt and March, 1988, p. 320).
- **Core competencies** are created by developing and combining resources and routines. They influence performance and define and differentiate a firm from its competitors (Prahalad and Hamel, 1990).
- **Capabilities** are a collection of competencies (core or otherwise) that provide competitive advantage in terms of cost, delivery, quality, innovation, etc. (Skinner, 1969; Stalk et al., 1992).
- **Dynamic capabilities** provide a manufacturing firm with the ability to integrate, build, and reconfigure resources, routines and competencies that will create new capabilities and a competitive advantage (Teece and Pisano, 1994; Teece et al., 1997; Eisenhardt and Martin, 2000).
- **Configurations** are the resultant form or type of manufacturing firm. They are defined by the collection of resources, routines and resulting competencies and capabilities (Miller, 1996).

With these definitions, capabilities are considered the basic elements of a manufacturing strategy, while a dynamic capability is the collective activity through which a manufacturing firm systematically generates and modifies its resources and routines to improve fitness (see Figure 6). Dynamic capabilities enable strategic choice and permit manufacturing firms to move from one position on the fitness landscape to another by re-deploying resources (Lefebvre and Lefebvre, 1998). This process of resource deployment is achieved by the firm’s routines, which connect, manage and co-ordinate the resources in a particular fashion. The importance of routines to manufacturing firms is such that Tranfield and Smith (1998) outline how strategic regeneration and performance improvement are underpinned by the routines found in a manufacturing firm. Thus, if competitive manufacturing firms inspire others to imitate their strategy and mode of working, then this is a process of
Figure 6.
The anatomy of a manufacturing strategy
organisational learning and evolution where routines become “transmitted through socialisation, education, imitation, professionalisation, staff movement, mergers, and acquisitions” (March, 1999, p. 76).

The notion of interconnectedness (the $K$ parameter) can be found in manufacturing strategy. For instance, Skinner (1974) argued that it would be difficult for a manufacturing firm to perform well if it adopted all capabilities, and that the firms should focus on a selection of capabilities only. This view implied that some form of trade-off or negative connectivity between capabilities was unavoidable (Corbett and Vanwassenhove, 1993; Mapes et al., 1997), while others argue that capabilities are positively connected and that certain capabilities must be in place before another can be adopted. Hence, capabilities can often reinforce each other, creating a strategy that is a sequential, cumulative and dependent system (Ferdows and De Meyer, 1990). Understanding and managing this connectivity is difficult, because strategy formulation attempts to serve an unpredictable environment and the process often leads to emergent strategies (Mintzberg, 1978). Also, a major constraint for strategy formulation is the inherent and incorrect assumption that the strategic options available on the known landscape are fixed. This assumption is false, because the size and shape of the landscape, along with the defining environment, is continuously changing. This creates new and unexplored niches for firms to discover or create. It is these territories that the firm should explore to ensure that maximum benefits are gained (Hamel and Prahalad, 1989).

Variation, selection, retention and struggle
These four processes underpin the evolution of a population of organisations (Campbell, 1969; Pfeffer, 1982; Aldrich, 1999). Though they will be presented and discussed individually, it is important to note that they act simultaneously and are coupled to each other.

Using these evolutionary concepts, this paper proposes Figure 7 as a model of manufacturing fitness. The model assumes that manufacturing strategy formulation involves populations of manufacturing configurations responding to and creating manufacturing systems around specific socio-technical configurations. It is important to note that the population concept asserts that for the configurations under study to follow an evolutionary pattern, they must exist in populations. That is, they must be a group of similar entities, which co-exist on a particular area of the landscape (Allaby, 1999). A population could be an industry or market sector, but is ultimately a collection of configurations grouped because they compete in and serve a common environment. Thus, the boundaries of a population can often exceed that of a single sector, and the criterion for membership is simply that a firm faces similar evolutionary and competitive forces to other firms in the population (McCarthy et al., 2000b).
Figure 7. Model of manufacturing fitness

Dynamic Capability

Survival Fitness = Adaptation and Survival
Reproductive Fitness = Durability and Reproduction

Variation
New combinations of capabilities create strategic innovations that result in new manufacturing configurations

Selection
Dominant manufacturing configurations and the corresponding strategy are selected

Retention
Forces retain or duplicate dominate configurations. Competing firms adapt their resources and routines accordingly

Struggle
Competing for resource, such as knowledge, raw material, energy, labour capacity, etc.

Evolution of a Population of Manufacturing Strategies and Configurations
The following sections describe Figure 7 by explaining variation, selection, retention and struggle.

**Variation**
This process is consistent with the concept of dynamic capabilities, as it involves changing resources, routines, competencies and capabilities to create a new strategy and a resulting configuration. Variations can be either intentional (planned) or blind (unplanned). They are intentional when decision makers in the firm deliberately seek new strategies and ways of competing. For instance, firms may have formal programs of experimentation and imitation such as benchmarking, internal change agents, research and development, the hiring of external consultants and innovation incentives for employees. Such programs are intentionally created to promote innovative activities that could change the current configuration of a firm. Blind variation occurs when environmental or selection pressures govern the process of change. This includes trial and error learning, serendipity, mistakes, misunderstanding, surprises, idle curiosity and so forth. It can also take the form of new knowledge or experience introduced into the firm by newly recruited employees.

**Selection**
This process eliminates certain variations. It is a filtering function that removes ineffective strategies and their routines, competencies and capabilities. The selection forces can be internal or external. For example, external selection occurs when customers request a certain management practice or an approach to quality, or when industry norms and regulations demand certain performance standards. Internal selection refers to intra-organisational forces such as policy, group behaviours and culture. Such forces not only select variations, but also create a positive reinforcement of old innovations and practices. The result is that manufacturing firms can sometimes carry on doing what they know best, and maintain their existing strategy rather than exploring the landscape for alternatives.

**Retention**
Once variations have been selected, the process of retention preserves and duplicates the strategy. The strategy and its elements are replicated and repeated, in a fashion that is consistent with the concept of fitness and the ability to reproduce. For example, the JIT practices that existed in the US supermarket industry in the 1950s were positively selected by Japanese automotive firms, who then demonstrated the competitive value of this approach to other manufacturers, and this led to further selection and retention of JIT configurations across a wide range of industries. The retention process allows firms to capture value from existing routines that have proved or are perceived to be successful (Miner, 1994).
Retention can occur at two levels, the organisational and the population level. Organisational retention occurs through the industrialisation and documentation of successful routines, and by existing personnel transferring knowledge about the routines to new personnel. Population level retention takes place by spreading new routines from one manufacturing firm to another. This can happen through personal contacts, or through observers, such as academics or consultants publishing successful new technologies or management practices. Retention is the process that promotes capabilities and routines that are perceived to be beneficial, because firms unlike biological systems, have the capacity to observe and imitate successful firms.

Struggle
Struggle occurs because the resources on offer to manufacturing firms are not unlimited. This process governs the other three evolutionary processes by fuelling or limiting their potential. For example, during the industrial revolution, raw material and energy were key resources, while the present need is for knowledge-based resources such as skilled workers, research partners and value adding suppliers. In new industries, the leading firms have ample gain and enjoy fast growth. As competition and volume in the industry grows, the resources become more limited, and failure rates increase.

In summary, Figure 7 helps represent how manufacturing firms evolve strategies and configurations to serve different environments or niches. It shows that variation, selection and struggle govern survival fitness and that selection, retention, and struggle govern reproductive fitness. To a degree, this is consistent with aspects of the institutional view of strategic evolution (Meyer, 1977; Scott and Meyer, 1994; Tranfield and Smith, 2002) which states that variations are introduced primarily by mimetic influences; selection is due to business conformity (regulative and normative) and retention occurs through the diffusion of common understanding. Figure 7 is the basis for the following definition of manufacturing fitness:

The capability to survive in one or more populations, and imitate and/or innovate combinations of capabilities, which will satisfy corporate objectives and market needs, and be desirable to competing firms.

Conclusions
So what is the significance of fitness landscape theory and the NK model to the process of manufacturing strategy formulation? To address this question, this concluding section reviews the implications and relevance of these concepts under three headings. Central to each is the view that manufacturing strategy formulation is a combinatorial system design problem. It involves identifying the elements of the strategy and recognising that the connectivity between the
elements and the coupledness between competing strategies will influence the topology of the fitness landscape.

The Red Queen effect
The complex adaptive systems view asserts that manufacturing strategy is a consciously evolving system of resources, routines, competencies and capabilities, which co-evolves with similar competing strategies. Thus, any improvement in one manufacturing firm’s fitness will provide a selective advantage over that firm’s competitors. Thus, a fitness increase by one manufacturing firm will lead to a relative fitness decrease in other competing firms. The result is that competing firms take steps to improve their strategy and maintain their relative fitness. This process is central to the population concept and was termed the “Red Queen effect” by the evolutionary biologist Van Valen (1973). The Red Queen refers to a character from Lewis Carroll’s Through the Looking Glass, in which Alice comments, that although she is running, she does not appear to be moving. The Red Queen in the novel responds that in a fast-moving world “it takes all the running you can do, to keep in the same place.” Thus, the Red Queen metaphor represents the co-evolutionary process where fit manufacturing firms will increase selection pressures, and those competing firms that survive by adapting and enduring will be fitter, which in turn creates a self-reinforcing loop of competition.

For leaders of manufacturing firms, traditional strategic management theory and practice advocate avoiding the Red Queen effect by finding niche or monopolistic positions on the fitness landscape. However, isolation from competition tends to be temporary, and as reported by Barnett and Sorenson (2002), it has a less-obvious downside, in that it deprives a firm of the engine of development. This results in a trade-off in which those firms occupying safe places on the fitness landscape eventually suffer over time as they fall behind those who remain in the race.

Appropriate system variety
The ability to create new manufacturing strategies and resulting configurations is related to a manufacturing firm’s ability to understand and manage its system of routines and resources. Fitness landscape theory and dynamic capability theory state that systems must reconfigure themselves to respond to the challenges and opportunities posed by the environment. This capability to create strategic variations is dependent on the system having a variety that matches the array of changes an environment may create (Ashby’s law of requisite variety, Ashby (1970, p. 105)).

In terms of innovation strategies, this notion is well known and has developed into principles such as the law of excess diversity (Allen, 2001) and the rule of organisation slack (Nohria and Gulati, 1996). Both these principles assert that the long-term survival of any system designed to innovate requires more internal variety than appears requisite at any time. Appropriate system
variety facilitates exploratory behaviour (Bourgeois, 1981; Sharfman et al., 1988) and is a necessary attribute for fitness and a dynamic capability.

The implication of system variety for leaders of manufacturing firms is that they should recognise the connection and trade-off between system efficiency and system adaptability. Any effort to reduce system diversity and increase system standardisation could restrict the potential for innovation. This is because the evolutionary process of variation (especially blind variation) requires excess system diversity to fuel evolutionary adaptation (David and Rothwell, 1996). This ability to create blind variations is linked to the talent of producing innovative strategies. This claim is supported by a study of successful firms by Collins and Porras (1997, p. 141), who concluded:

In examining the history of visionary companies, we were struck by how often they made some of their best moves not by detailed strategic planning, but rather by experimentation, trial and error, opportunism and quite literally accident. What looks in hindsight like a brilliant strategy was often the residual result of opportunistic experimentation and purposeful accidents.

Understanding and exploring the landscape
Understanding the topology of a fitness landscape can help the manufacturing firms address the three questions that underpin the strategy process:

1. What is our current position on the landscape? (Strategic analysis).
2. Where should we be on the landscape? (Strategic choice).
3. How will we get there? (Implementation).

Figure 8 shows a highly rugged landscape with two manufacturing strategies, strategy A and strategy B. The route from strategy A to strategy B is represented by a dashed line. This route initially requires a downhill journey that is often accompanied by a reduction in firm performance, which related to the learning curve challenge and organisational disruption associated with the change. With this reduction in performance, a firm often stops the strategic change and returns to its original position on the landscape. Thus, for a manufacturing firm to successfully explore and achieve new strategies, it must recognise that:

- this often involves the removal of one or more of the capabilities and defining routines and resources that dictate its current strategy and position on the landscape;
- even though the landscape is posited as being static, when any firm moves or makes a change, the topology of the landscape and associated performance will also change.

Exploration of the landscape is a search activity and there are two basic search strategies. The first is a local search that enables manufacturing firms to build
upon their current capabilities. It involves investigating those manufacturing strategies in the immediate vicinity (the one-mutation neighbour strategies). The second search strategy is a long distance search, i.e. looking for strategies beyond the local area. This involves a relatively significant reconfiguration of the strategy and is likely to arise due to previous failure-induced searches (Tushman and Romanelli, 1985) or because of the innovative nature of the firm (Nelson and Winter, 1982). However, long distance searches rarely occur in reality (Cyert and March, 1963; Nelson and Winter, 1982), because the longer distance, the less time efficient and less cost efficient the search becomes. Also, firms that already have a relatively fit strategy are unlikely to risk a significant reconfiguration. Studies, practice and history show that a firm’s current strategic configuration frequently constrains a firm’s dynamic capability to remain focused on those resources and routines which are current and familiar to the firm.

Manufacturing strategy formulation can also involve multiple and constant searches, as suggested by Beinhocker (1999). This approach has direct relevance to strategy formulation as a process of organisational resource-investment choices or options (Bowman and Hurry, 1993). However, the capability to have options requires appropriate system variety.

Summary
This paper has reviewed, developed and synthesized a range of literature to present a definition and a conceptual model of manufacturing fitness. It is based on survival fitness; the capability to adapt and exist, and reproductive fitness; the ability to endure and produce similar systems. These two
dimensions of fitness are governed by the evolutionary forces – variation, selection, retention and struggle.

The definition and model offer a starting point for further research on how factors such as landscape topology, population and firm dynamics, the type and number of searches, and the associated costs and time to search would affect manufacturing strategy formulation and the propositions and ideas presented. To progress this work it is necessary to conduct empirical studies that measure manufacturing fitness as part of a longitudinal assessment of the changes within and between the manufacturing firms in a defined population. This type of work would provide a quantitative analysis of the claim that firms occupying a global peak on a $K = 0$ landscape gain benefits from this monopolistic position, but at the expense of maintaining and developing a dynamic capability.

References


