Path dependence and transients in random and adaptive walks on strategy fitness landscapes

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ABSTRACT

Over the last decade complexity theory in general, and Kaufmann's NK fitness landscape model in particular, have been very popular means of promoting evolutionary and prosessualistic approaches to strategic management. However, either in pure conceptual, or in more formal forms, these models assume rather naïve, "memoryless" and unrestricted by past choice strategy processes (organisational structure and decision making), i.e. they ignore the internal dynamics of the strategy-formulation system. In this paper, we demonstrate how system dynamics modelling can enrich the NK fitness landscape model so that these drawbacks are overcome, especially with respect to the way the fitness landscape is searched/walked. The resulting modelling framework becomes particularly useful for understanding strategic behaviours and assessing strategic flexibility under the assumption of resource-based competition as it allows the explicit modelling of the dynamics of assets accumulation and the complementarity and substitution effects among strategic decisions and actions towards resource and capability development for achieving higher fitness. We demonstrate our approach in the modelling of operations strategy as an emergent process of distributed decision making for capabilities development.

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1. INTRODUCTION

There are different uses of models and simulations in strategic management. Sometimes simulation modelling is used to predict the value of an environmental variable, sometimes to evaluate future consequences of decisions, sometimes to demonstrate complex behaviours and support learning, and sometimes, in more academic endeavours, to support theory development and testing. As far as its practical use is concerned, the type of models and the mode of employment of simulation are contingent on the organisational culture, the competitive environment on which the organisation operates and the approach adopted with respect to the strategy development process. Simulation modelling for prediction (the so-called "hard" models (Pidd, 2003)) has mostly been associated with a rationalistic approach to strategic management in organisations with a machine-like culture (Morgan, 1997), competing in relatively stable environments. More exploratory and demonstrative forms of simulation use ('soft" models for structuring the debate and for learning (Pidd, 2003)) have been associated with the evolutionary and the prossesualistic approaches to strategic management (van der Heijden, 1996).

Complexity theory and complex systems modelling and simulation have been introduced to strategic management primarily to demonstrate and provide insights on the evolutionary nature of systems of firms, markets and other institutions. Not paradoxically, however, as very few people would insist on the pure evolutionary nature of these systems, complex systems modelling and simulation have been more frequently used in association with the processualistic approach, i.e. as learning instruments or "transitional objects" (Lyons, 2004). As complexity theory indirectly denies that managers can use the techniques of planning (which includes prediction) to achieve objectives, models of these nature have been used to gain insights, make sense and learn about increasing the ability of their organisations to survive, adapt and achieve high fitness with the environment.

As Jackson (2003) indicates "Complexity theory attracted the interest of management scholars and practitioners because it focuses on the things of organisational life that bother the majority of managers most of the time: disorder, irregularity and randomness. It takes as granted instability, change and unpredictability and offers appropriate advice on how to act". It is a network of interrelated concepts, one of which the fitness landscape model is, together with concepts such as the sensitive dependence on initial conditions, the notion of self-organisation, the concept of strange attractors, etc. As a whole complexity theory rejects reductionism and maintains that the parts of a system can only be understood in terms of their relations with each other and with the whole. The NK fitness landscape approach of Kaufmann (1993) has been increasingly popular because it is easily applicable, by means of simulation modelling, for understanding how the speed and effectiveness of adaptation with respect to objectives or the environment within a modular system (organisation, strategy, product, supply chain, etc.) are influenced by its structural characteristics, i.e. how its components are related and how they interact (Davis *et al*., 2007) and how they augment or inhibit the organisation's strategic flexibility (Volberda, 2003). Though it differs methodologically from system dynamics, as part of the complex systems paradigm, they both belong to the same "flux and transformation" metaphor of organisations (Morgan, 1997). In addition, as far as the appropriateness as intervention methodologies is concerned, both complexity and system dynamics are associated with the same class of problems: complex problems for which a single view prevails (Flood and Jackson, 1991; Jackson, 2003). Complexity, however, is more attached to the physical structure of the issue/problem, system dynamics being more conceptual. Nevertheless, as it was already mentioned, this does not mean that they can not be used as part of methodologies (SSM, SODA, etc. (Rosenhead and Mingers, 2001)) for use in situations where a diversity of opinions regarding the nature of the problem/issue and its solution exists.

Despite its extensive use, the NK fitness landscape modelling approach suffers from a number of drawbacks, which are important as far as its applicability to strategic management is concerned. First, the two-way dynamic relation between what constitutes the environment and the organisation's, or the organisational unit's, decision-making system (organisational structure and behaviour) cannot be easily accommodated in models. In reality, strategic decisions influence the environment as the environment influences decision making, but in NK models the search strategy remains constant independent of the state of the environment (Davis *et al*., 2007). Similarly, the way fitness is assigned to strategies remains constant independent of past choices. Secondly, in effect, it assumes a costless (frictionless) decision-making, while on the other hand, it does not take into account the reinforcing rewards of timely (correct) decision-making, and more importantly, it does not consider dynamic relationships among the constituent parts of the system. In other words, searches on the strategy landscape are independent of path dependence, while at the same time transients are not mirrored in the overall performance of the strategizing organisation. Clearly, given the current emphasis on strategic flexibility, especially under the resource-based view of competition perspective, these drawbacks are rather serious and constraining with respect to both the content and the process of strategy. To unleash the potential of fitness landscape modelling and simulation in the field of strategic management, we turn to system dynamics for a helping hand. We present the resulting modelling formalism and demonstrate its use in the modelling of operations strategy formulation as an emergent process of distributed decision making for capabilities development.

2. THE NK FITNESS LANDSCAPE MODEL AND ITS DRAWBACKS

In situations where interdependencies among decisions and actions play a crucial role, complex systems modelling based on the NK model of fitness landscape has been used to evaluate the performance of a system with respect to the interdependencies. This approach which was developed by Kauffman (1993) to explore the emergence of order among biological organisms, in its basic form, has two principal parameters: N, the number of interdependent elements (decisions/choices) and K, the number of elements each of the N elements depends on. A fitness level (value) is assigned, usually by a random function, to each system/model configuration. Usually, choices are assumed binary but, in the general case, they may take A different values. Choice by choice contributions to fitness levels are drawn randomly from a uniform distribution over [0,1] for each of the 2K+1 distinct payoff combinations a choice can be part of. The total fitness of a particular choice set is the average of the N choice-by-choice fitness levels.

As far as K is concerned, when its value is 0, the fitness landscape is smooth having a single peak. In this case, changes in the setting of one choice variable do not affect the fitness contributions of the remaining variables. Setting choices to their highest fitness contribution values leads to the highest overall fitness value. At the other end of the spectrum, when the value of K is N-1, a change in a single choice variable affects the fitness contribution of all the other choices. This results in a fitness landscape with many local peaks which cannot be improved by changing a single policy choice. In addition, conflicting constraints among choices limit the value of the highest peak which can be attained on the landscape. The same holds with respect to the value of N. As N is increased, mutual choices become increasingly constrained and the highest possible value of overall fitness is reduced. In this modelling framework, strategy can be thought as a search on a strategy fitness landscape constructed by the fitness values which correspond to all possible strategic choice configurations. Each binary choice corresponds to a particular strategy attribute and can be set either to 1 or 0, and optimal search paths can be determined by using dynamic programming techniques. Alternatively, fast searches can be accomplished by parallel activity (Beinhocker, 1999).

The NK fitness landscape theory and modelling framework was introduced into economics and management by its developer and his colleagues (Kauffman, 1993; Kauffman, 1995; Kauffman *et al*., 2000). Nevertheless, the conceptual models of Beinhocker (1999) made these ideas more accessible to the strategic management community. The model has been used, in either conceptual or quantitative forms, for a variety of investigations, which include those concerning the efficiency and effectiveness of strategic management processes as a result of organisational design (Rivkin, 2000; Rivkin and Siggelkow, 2003; Siggelkow, 2003) and the role of tradeoffs in operations and manufacturing strategy (McCarthy, 2004; Rose-Anderssen *et al*., 2004). (These two areas are related to the example presented below.)

In the strategic management applications of the NK model, the process of strategy formulation is assumed to be a random or adaptive (structured) walk (search) on a fitness landscape constructed by the strategic decision set. Strategies are assumed to be modular consisting of a set of N interrelated decisions, or strategic attribute settings. Each attribute is influenced/constrained by K other attributes.

In its basic form, a landscape can be considered as a map

$$s = \{0,1\}^N \to R_+$$

i.e. $s \in S$ is a vector/string of decision representing binary digits of length *N*, whereas each *s* is associated with a fitness $\phi(s) \in R_+$. The mapping is constrained by K (the "intranalities" of the decisions). When K is large, a large change on a digit of *s* can result in significant changes in the fitness of a new (mutated) vector. The opposite (no change) happens when K=0.

To generate a landscape, a value of fitness $\phi(s_i)$ taken from a uniform distribution is assigned to each value of s_i (i.e. different values for $s_i = 0$ and $s_i = 1$). In the case that s_i is connected s_j, s_i has four possible – again randomly assigned – values of fitness, each for every combination of values of the couple (s_i, s_i), i.e. one value for (0,0), one for (0,1), one for (1,0) and one for (1,1). The fitness of the string of digits representing the overall organisation's strategy is usually an average value, i.e. given by

$$\phi(s) = \frac{1}{N}\sum_{i=1}^{N} \phi_t(s_i; s_j^1, \ldots, s_j^k), i \neq j$$

What this model indicates is that the fitness landscape is not externally given but it is constructed by the properties of the decision making system per se and usually, in simulation experiments, it is constructed at the same time that is searched. In addition, as in the majority of cases in the natural and organisational world where species do not evolve independently, choices are dependent on other choice sets. For instance, the strategy of a specific organisation may co-evolve with the strategies of other organisations, such as suppliers, competitors, etc. In the NK model, this co-evolution is modelled by an additional parameter C, which denotes the number of external interactions associated with each decision/choice.

In the case of strategic management, the fitness landscape constitutes a rated representation (in an relativistic manner) of the content of an organisation's strategy, while the search for high fitness points on the landscape is a representation of the strategy formulation process. Clearly, both the content and the process of strategy depend on the adopted model of competition. In the resource based view of competition perspective, decision sets consist of decisions concerning the development, maintenance and depletion of the organisation's assets (resources and capabilities). Fitness levels, however, cannot be associated to decisions but to their outcomes, which do not only concern the endowment, or acquisition of assets, but also the quantities and rates of their development (Dierickx and Cool, 1989; Warren, 2002). Consequently, the strategy process – the way the fitness landscape is searched – becomes more complex than a simple setting of decision variables, and its representation has to take into account the dynamics of asset accumulation and depletion which determine strategic flexibility. In addition, it has to take into account the organisational dynamics and the dynamics of the strategy process per se. Such a process has to consider the path dependence on previous decisions and the inertia of the developed assets. The objective of the process is to maintain strategic consistency, not only to obtain instantaneous decisions synchronisation. As system dynamics modelling has been used extensively in connection with the resource based view of strategy and its dynamics (e.g. Morecroft, 1999; Mollona, 2002; Warren, 2002), it becomes an appropriate candidate for modelling the construction of the landscape and its search processes. In the following section, we demonstrate how this can be done by developing and using a system dynamics-based model of the NK fitness landscape approach for understanding the role of managerial ability in the development of operations strategy. Though it concerns a functional strategy, in the resource-based perspective, the operations strategy formulation process shares many important characteristics with strategic processes at the firm level.

2. OPERATIONS STRATEGY AS A CONSTRAINED SEARCH ON FUNCTIONAL CAPABILITIES FITNESS LANDSCAPES

The modelling approach we have developed extends the basic NK model by introducing resource and capability accumulation dynamics, as well as feedback loops in the selection of choices, for modelling more realistic situations under the resource-based perspective, where there is interplay between activities and capabilities/resources (Cuervo-Cazurra, 2003). As a result, it allows the inclusion of path dependencies due to capability accumulation and, in addition to steady-state analyses, permits the investigation of transient behaviours. For the demonstrative case of operations strategy, the underlying assumption is that the overall operations strategy is the emergent outcome of the decisions of three managers responsible for the management of the production system, the product development process and the supply chain, respectively. Managers make decisions which result in capability accumulation and depletion (Figure 1). Although all three functions could be put under the same umbrella of operations, structurally they constitute autonomous organisational entities and their strategic management, in the framework of resource-based competition, implies the development and leverage of distinct resources and capabilities, frequently by executing restricting and/or conflicting organisational processes.

The levels of five capabilities (N=5) are assumed to define, through their average value, the strategic position (fit) of each of the three organisational units with respect to the required (sought for) levels of fitness, i.e. the high fitness peak values on the fitness landscape. Indicative capabilities are: cost, flexibility, dependability, speed and quality for the production system; product performance, product cost, development cost, time-to-market and flexibility for the new product development unit; and, operational cost, volume handling, variety, innovation and speed/responsiveness for the supply chain management unit (Adamides and Pomonis, 2007). Accordingly, the overall operations strategy can be described by the levels of all fifteen capabilities (their average value in the general case). In the model, in accordance with the evolutionary economics (Nelson and Winter, 1982) perspective adopted, the three managers make choices in selecting the appropriate organisational routines that will result in achieving fit (reaching the peak points) (Figure 1) between the levels of their functional capabilities and a set of perceived levels (fitness values) which are defined randomly at specific time intervals (12 time units but can be varied accordingly) and remain constant in between, but are also influenced by the current level of the capabilities of the other two units (the functional coupling C is variable). The target values, in the general case, are calculated by a function, TCα, which for the ith capability of the kth organisational unit has the form

$$TCa_{ij} = 0{,}500R + 0{,}500\left(\frac{\sum Ca_{kl}}{10}\right)$$

where

R is an integer randomly selected form the range [0,5],

Ca_{kl} denotes the level of capability Cakl , and

k is an integer in the range [1,5],

l is an integer in the range [[1,3]-j] (all organisational units except the one that the value is calculated for).

Capabilities and target values of fitness take integer values from 0 to 5 (A=5). The objective of managers is to increase and decrease their unit's capabilities so that their levels are aligned, as much as possible, and as fast as possible, with the perceived target values (highest fitness values). In the base case, the model assumes that there is a delay of 6 time units between the setting of the target values and the time managers become aware of them. Decisions are constrained by the level of the other functional capabilities (K is variable).

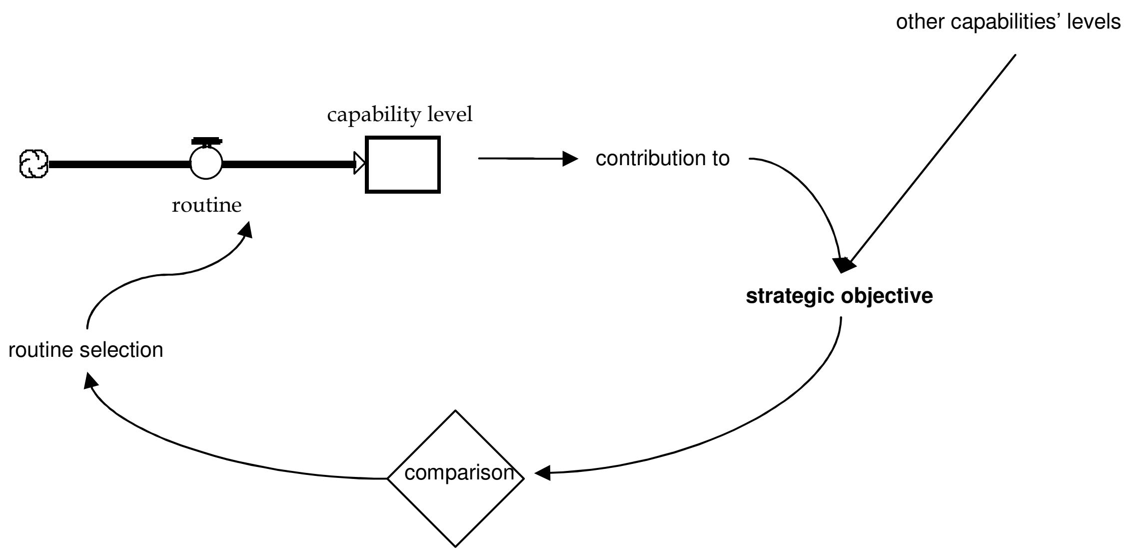

Figure 1. Capability development as dynamically adapting walk on a strategy landscape

Figure 2 below shows the basic structure of the system dynamics model used for modelling the above situation and for simulating different organisational structures. As in other RBV-oriented system dynamics modelling efforts (e.g. Morecroft, 1999; Grössler, 2005), array stocks (*production_system_capabilities*, *product_dvelopment_capabilities* and *supply_chain_mgmnt_capabilities*) represent the level of functional assets, whereas flows (such as, *psc_in*, *pscs_out*, *pdc_in*, etc.), their rate of increase/decrease. Converters are used for inducing and storing constant and calculated values (e.g. *target PSC*, *target PDC*, etc). At any simulation period, the current values of the flows result in an increase or decrease of stock levels by one. Nevertheless, if a capability level equals the target value, no action is taken. In other words, in the model, it is assumed that managers select routines from a diverse range of "decision areas" whose net effect on the capability levels belongs to the set {increase by one, decrease by one, do nothing} (Figure 1).

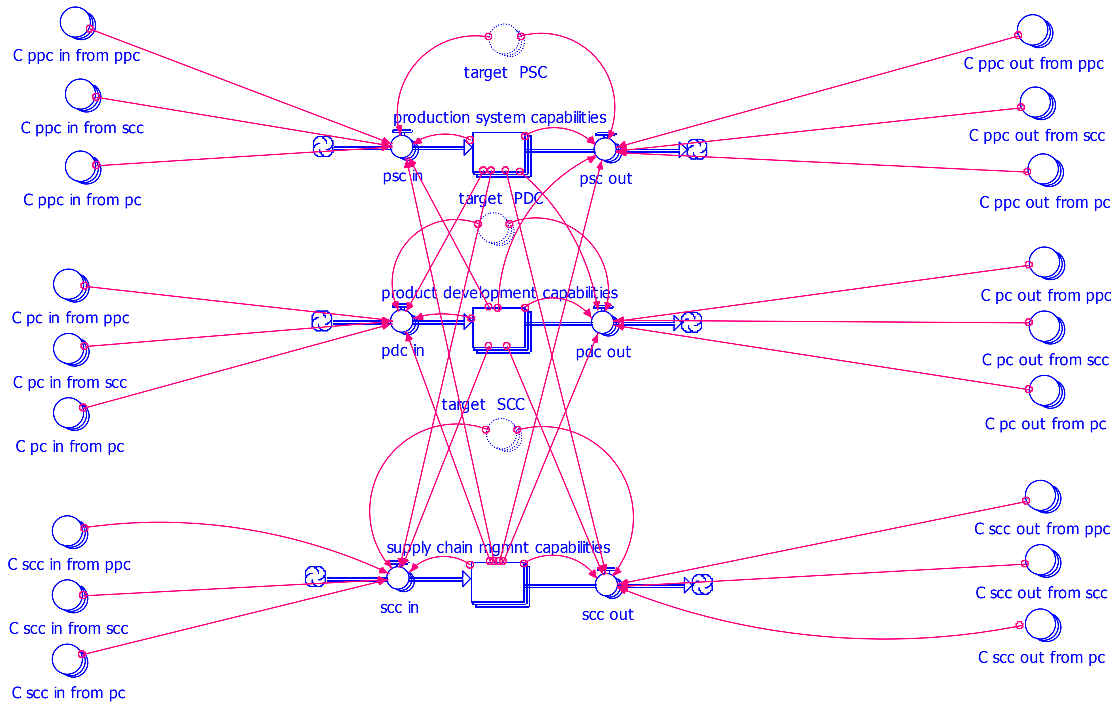

Figure 2. A high-level view of the system dynamics simulation model

4. UNDERSTANDING THE ROLE OF MANAGERIAL ABILITY WITH THE HELP OF AN ENHANCED *NK* FITNESS LANDSCAPE MODEL

Managerial ability is one of the contextual variables of organisation studies. It is a variable that is indirectly influenced by organisational design, but is highly influential on the efficiency and effectiveness of management processes, including the strategic ones. Organisational designs that promote managerial involvement with a wide range of tasks increase the complexity of managers mental models, whereas strong specialisation their centrality. Managers with complex mental models exhibit cognitive abilities for considering a wider range of alternatives when making decisions.

To investigate this contextual variable using the model of previous section, we varied the number of decision variables that each manager has under his control. "Less able" managers cannot control effectively many decision variables. Assuming that there is no interaction between the decision variables, and that the uncontrolled decision variables take random binary values (0,1) uniformly distributed, table 1 presents the results obtained after executing 500 simulations and recording the average discrepancies (mean gaps) between the obtained and the sought for capability levels. In every setting of parameters, the effectiveness of the operations strategy process was measured by the mean value (of the 500 simulations) of the average fit discrepancy between the mean target values of every set of functional capabilities (assumed highest fitness configuration) and the mean of the actual values of the corresponding capability stocks, over a period of 60 time units. The efficiency of the process was observed in the capability-level traces produced by the simulation environment as the time taken for achieving the minimum gap (in many cases to achieve the same value) between the actual and required levels. The evolution of the mean discrepancy between the target and the achieved values also provides an indication of efficiency. Moreover, the same discrepancy measurements were recorded for the average of each of the 15 target values and the corresponding 15 capability levels. The initial values of the capability stocks were assigned randomly.

Table 1. The effect of managerial ability (mean discrepancies)

Decision variables	***Production***	***NPD***	***Supply chain***	***Operations strategy***
5	0,047	0,044	0,045	0,010
3	0,354	0,342	0,360	0,175
2	0,429	0,401	0,403	0,222

As it was expected, the above results and the simulation traces obtained indicate that managers which can control a greater number of decision variables contribute to more effective and efficient operations strategy processes. Figure 3 shows the evolution of the mean gap/discrepancy in opertional capabilities for the three cases of Table 1.

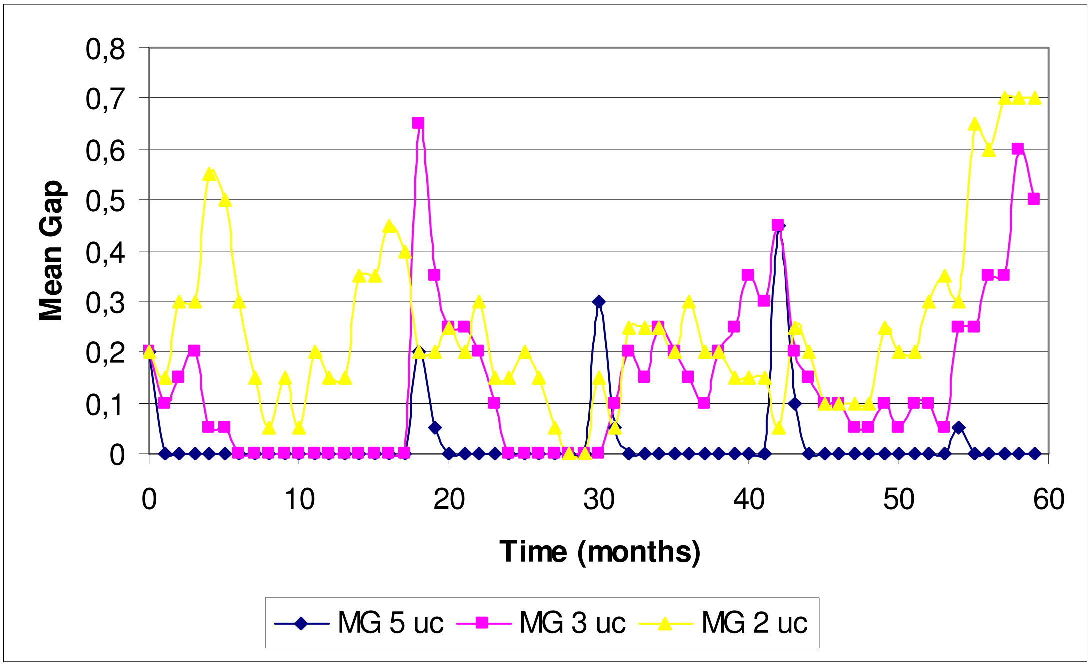

Figure 3. The evolution of the overall operations strategy Mean Gap between target and achieved capability levels for three different levels of managerial ability (control of 5, 3 and 2 decision variables under control).

5. CONCLUSIONS

In this paper we have supported the argument that system dynamics is a necessary addition, as a modelling base, for the employment of the NK fitness landscape framework into the strategic management research and practice. The resulting modelling framework becomes particularly useful for understanding strategic behaviours and assessing strategic flexibility under the assumption of resource-based competition as it allows the explicit modelling of the dynamics of assets accumulation and the complementarity and substitution effects among strategic decisions and actions towards resource and capability development for achieving higher fitness. We have demonstrated the use of system dynamics modelling within the logic of a NK fitness landscape in the modelling of operations strategy as an emergent process of distributed decision making to assess the effects of managerial ability on the effectiveness and efficiency of the strategy process.

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