Article

MANAGEMENT DECISION-MAKING: RISK REDUCTION THROUGH SIMULATION

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Abstract

This research presents findings from two studies conducted by the Universities of Cranfield and Sheffield, which investigated two complimentary, but unrelated, areas of research – manufacturing cladistics, an evolutionary classification scheme from the biological sciences, and evolutionary systems modelling, from the physical sciences. Using this new evolutionary framework, designed to model through simulation the evolution of manufacturing form, new structural organizations were explored. A second study is presented that explores the diversity of management decision-making and the potential consequences on the evolution of manufacturing form. This research compares and contrasts the different opinions of decision-makers. The results, in terms of the evolutionary trajectories that the firm may take, provide interesting insights into the consequences of decision-making of different managers that inevitably base their decisions on different information, values and beliefs. The aim of this and related research is to develop a user-friendly decision-support tool for management.

Keywords
manufacturing cladistics; evolutionary complex systems; simulation

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Summary

This paper presents the basis of a new evolutionary framework with results from two related studies that explore, through simulation, the evolutionary consequences of manager's opinions of how practices and policies interact in an organization. The aim of the approach is to reduce uncertainty and risk in the decision-making process. Uncertainty in decision-making can hinder the introduction of important innovations in technical, organizational and social domains. This new framework would enable the exploration of evolutionary processes involved in the interactions of technologies and practices, facilitating decision-making, as well as the exploration of new organizational structures.

Unpredictability, risk and uncertainty are all important factors in decision-making. For example, how certain are the estimated impacts of certain technologies or practices in terms of economics, society and the environment? How can uncertainty and risk be reduced? How much do foresight and precaution play in certain decisions? The extent and importance of the fundamental processes involved in the evolution of organizational form require clarification. Why do technologies and practices succeed in one organization but not in another? Another area of inquiry relates to the interaction of existing technologies and practices with new and innovative ones. What barriers, institutional, psychological and economic, exist in the adoption of new technologies and practices? Can all costs, benefits and risks be calculated beforehand? Problems may lie in the fact that different decision-makers have different values, attitudes, beliefs, approaches, etc. The research reported here attempts to tackle some of these problems and questions.

Evolutionary complex systems modelling

Originating from Prigogine's (1973) Nobel Prize winning research, evolutionary systems theory (Allen, 1976, 1997, 2001; Allen and McGlade, 1986) with its modelling methodology derives from the science of complex systems. From the first application in 1976 to the evolution of an ecosystem, evolutionary systems modelling has been successfully applied to several very different areas and disciplines including urban and economic systems, fishery management, crime rates, design, climate change, and new product development. All applications demonstrate the ability of the model to realistically represent the evolutionary nature of the system and the ability to explore different strategies, decisions and policies.

According to Allen (1992, 1998a, b) a hierarchy of models can be elicited based on modelling assumptions taking the purpose of the model from prediction and certainty to exploration and potentialities. All models can be thought of having at least two underlying assumptions. The first is that there is a boundary between the system and its environment and the second is that the components of the system can be classified leading to a taxonomy. Additional assumptions are then made pertaining to components and their interactions.

Predictive models, such as system dynamic models, appear to have perfect knowledge and understanding, and assume that both components and their interactions are normally distributed about the mean; in other words, average. With everything being average, there is just one future path – the most probable. When the modeller begins to introduce non-average interactions between system components, like with most agent-based models, more scenarios are explored and the predictive capability reduces. In other words, when diversity is introduced, all types of interactions are accounted for and explored through self-organizational processes, which leads to many potential future states. There are two limitations associated with these models. One relates to the generation of the diversity of interactions, which is typically represented by "noise" produced by a stochastic mechanism in the equations. The second relates to the components – although interactions are non-average, the system components are assumed to be all of an average type.

To better mimic true evolutionary processes, this assumption has to be removed so that the components are also treated as non-average. The introduction of this internal or micro-diversity takes the modelling from just blind adaptation to co-evolution; from random interactions to experiential learning, which is a more accurate representation of real evolutionary change. The "means" and the "end" are transitory and in continual paradoxical dialogue through feedback (Allen and Ebeling, 1983). Control is devolved from the global to local situation – a manifestation of how all the diverse behaviours perform relative to one another. Evolution involves both chance and determinism impacting the transfer of information which is imperfect and inevitably involves a degree of "error-making" (Allen and McGlade, 1986). This is a necessary requirement, however, and creates the forum for learning through the continual exploration of behaviour space. In summary then, assumptions are made of average interactions and components that increasingly reduce complex reality to simplicity. By removing these assumptions the potential of the model changes from being predictive to explorative – the more evolution is accurately modelled the less the model is capable of predicting. However, the underlying, evolutionary processes give modellers a deeper insight into the system under study. Instead of prediction, different possible future states may be explored, which provide modellers with the ability to reduce uncertainty and risk and to glimpse possible future system states. In reality we have one "run", with computer simulations evolutionary runs are limitless. What may not have evolved this time for one reason (possibly chance) or another (e.g. decisions), may evolve next time.

In terms of its application to industry and management decision-making, our interpretation of the data that would be needed are the opinions of experts of how technologies, practices and policies, used to define organizational structure, interact with one another. If all the interactions between, what we term, "characteristics" or "character-states" are collected, through, for example, questionnaires and interviews with experts, then limitless evolutionary "runs" of manufacturing organizations may be simulated. In industry, characteristics may include "standardisation of parts", "assembly time standards" and "division of labour", etc. The potential advantages of this approach are several. For example, a world-class manufacturer contemplating a major organizational transformation could conduct a thorough exploration of the pros and cons of crucial, and perhaps not-so-crucial, decisions. Decisions may be explored time and again in, for example, different contexts or with the presence or absence of other important variables. Another advantage would be if an organization developed a new characteristic of its own, for example, a new plant layout, but were unsure of the consequences of adopting it, then the model could be applied to explore many possible outcomes of the adoption and in turn reduce uncertainty and to some extent the risk associated with change. For instance, problem practices/technologies could be identified and investigated or different scenarios could be run. Furthermore, potential barriers to introducing new technologies and practices could be identified beforehand and discussed and planned for in more detail.

Modelling organizational re-engineering

To model organizational re-engineering, the project attempted to synthesize evolutionary systems theory with an approach called manufacturing cladistics, an evolutionary classification scheme pioneered by McCarthy *et al.* (1997), McCarthy and Ridgway (2000) and McCarthy (2005). There are now several good working examples including cladistic classifications of the hand-tool industry (McCarthy *et al.*, 2000) and the automotive industry (McCarthy *et al.*, 1997). Figure 1 is a visual representation of the cladistic classification of the automotive industry (the numbers in Figure 1 refer to the characteristics in Table 1).

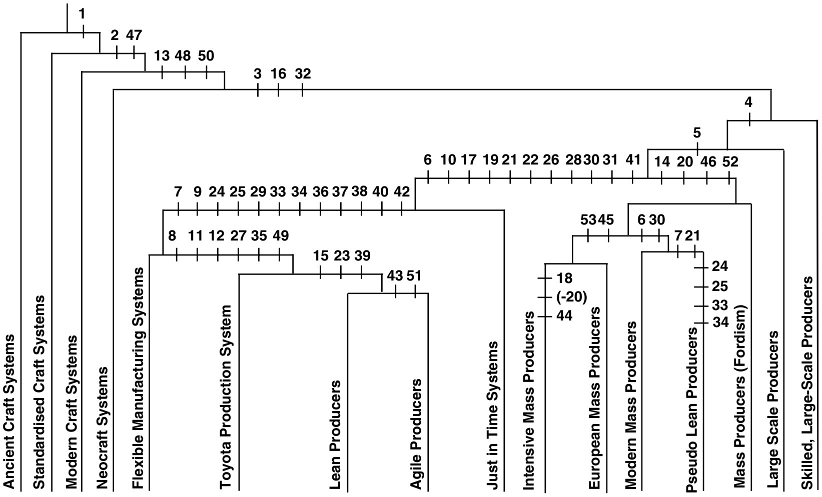

Figure 1 A cladogram of automotive assembly plants (from McCarthy *et al.* (1997))

Table 1 Characteristics of automotive assembly plants (from McCarthy *et al.* (1997))

1. Standardization of parts
2. Assembly time standards
3. Assembly line layout
4. Reduction of craft skills
5. Automation (machine paced shop)
6. Pull production system
7. Reduction of lot size
8. Pull procurement
9. Operator-based machine maintenance
10. Quality circles
11. Employee innovation prizes
12. Job rotation
13. Large volume production
14. Suppliers selected primarily on price
15. Exchange of workers with suppliers
16. Socialization training (master/apprentice learning)
17. Proactive training programmes
18. Product range reduction
19. Autonomation
20. Multiple sub-contracting
21. Quality systems (tools, procedures, ISO9000)
22. Quality philosophy (TQM, way of working, culture)
23. Open book policy with suppliers; sharing of cost
24. Flexible multi-functional workforce
25. Set-up time reduction
26. Kaizen change management
27. TQM sourcing; suppliers selected on basis of quality
28. 100% inspection/sampling
29. U-shape layout
30. Preventive maintenance
31. Individual error correction; products are not re-routed to a special fixing station
32. Sequential dependency of workers
33. Line balancing
34. Team policy (motivation, pay and autonomy for team)
35. Toyota verification of assembly line (TVAL)
36. Groups *vs* teams
37. Job enrichment
38. Manufacturing cells
39. Concurrent engineering
40. ABC costing
41. Excess capacity
42. Flexible automation for product versions
43. Agile automation for different products
44. Insourcing
45. Immigrant workforce
46. Dedicated automation
47. Division of labour
48. Employees are system tools and simply operate machines
49. Employees are system developers; if motivated and managed they can solve problems and create value
50. Product focus
51. Parallel processing
52. Dependence on written rules; unwillingness to challenge rules as the economic order quantity
53. Further intensification of labour; employees are considered part of the machine and will be replaced by a machine if possible

Manufacturing cladistics purports to help manufacturers in three main ways: (a) best practice can be benchmarked (McCarthy, 1995), (b) change and transformations may be guided (McCarthy *et al.*, 1997), and (c) strategies may be developed as problem areas can be identified through the cladogram (Leseure, 2000). However, there are limitations. The cladogram is essentially a description of the past and is of no use to world-class manufacturers who can only compare with inferior organizations. It also says nothing about the "losers" (those organizations that did not survive for one reason or another), which is perhaps an important omission. Learning from past mistakes could prevent future disaster. Furthermore, the cladogram gives no insight, with the exception of *post hoc* analyses, into many of the problems confronting management decision-makers. By combining manufacturing cladistics and evolutionary systems modelling, cladograms may be constructed that include not only past and present organizations but also organizations that could have evolved or that may evolve in the future.

Data were collected from a questionnaire survey designed to gauge how managers think characteristics of the automotive industry (Table 1) interact with one another, that is, whether two characteristics together have a negative, neutral or positive effect on productivity. Seventy-three managers were surveyed. The evolutionary systems model, developed in Turbo Basic®, runs in the Microsoft Dos® operating system. It is based on the equations given in Allen (1984, 1985). There are numerous variables that can be manipulated and calibrated. These three are directly related to the running of the model that need to be explained. The first is the running time of the evolutionary model. This may be adjusted to accommodate reaching the final solution. Solutions are typically found between 10,000- and 50,000-time units. The second variable is the number of characteristics launched in the model. This can be controlled so that specific organizational forms may be explored. The third variable is the starting value of the characteristic. Characteristics may have a value of between 0 and 28 units. The value may be thought of as the success/importance to the organization. All runs launch the characteristics with a starting value of 5.

The simulations are able to investigate the "performance" of characteristics both within and between organizations. To study the performance of characters-states within an organization, the procedure is to launch an organizational form at its most stable solution, in this case the Modern Mass Producer (MMP) (see Figure 1), and then introduce new characteristics. There are two main objectives. The first is to relate the results to issues such as those surrounding decision-making uncertainty and specific barriers to the introduction of new practices. The second is to demonstrate the exploratory capacity of the model, particularly when evolving new organizational structure. The following section is devoted to this end. Next section takes the investigation a step further by then looking at how individual characteristics perform in different organizations.

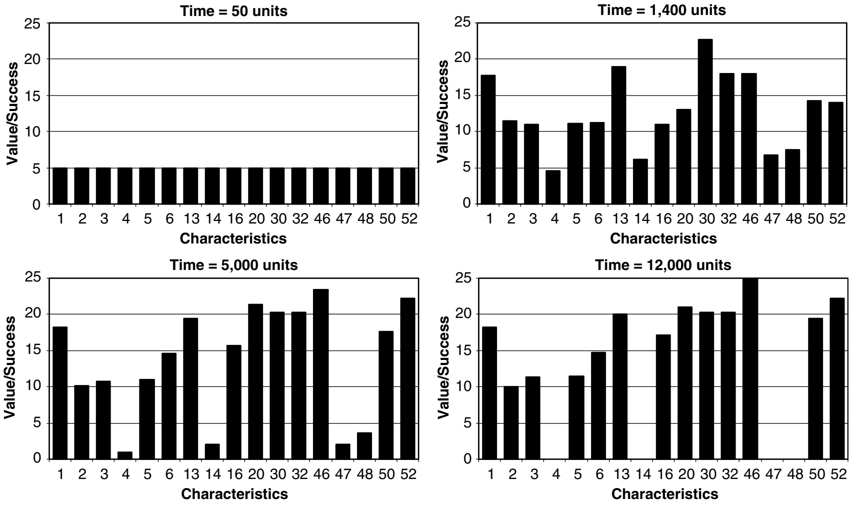

Figure 2 Simulation of the stabilization of character interactions of the MMP

Performance of characteristics within an organization

The first simulation was the evolution of the Modern Mass Producer seen in Figure 2. Each bar represents a characteristic (in the Figure the characteristic number is indicated below). At Time = 1,400 the more successful characteristics become prominent – CSs 1, standardization of parts, 13, large volume production, 30, preventive maintenance, 32, a sequential dependency of workers, and 46, dedicated automation. Conversely, character states 4, reduction of craft skills, 14, suppliers selected on price, 47, division of labour, and 48, employees are treated as system tools, performed poorly. At Times 5,000 and 12,000, with the demise of unstable characteristics, character states 16, socialization training, 20, multiple subcontracting, 50, product focus, and 52, a dependence on written rules, gain increasing influence and importance.

To demonstrate the approach's usefulness in supporting decision-making, new technologies and practices were introduced to existing organizational structure and potential obstacles identified. Using the MMP at its stable solution (see Figure 2), practices relating to quality were introduced both singularly and in "bundles". Quality systems (CS 21), was introduced singularly with a value of 5 and had an immediate effect on CS 20, multiple subcontracting, which became unstable and failed. This occurred during many simulations. Interestingly, when there was only slight commitment (e.g. a starting value of 2) it took much longer to embed itself and exert influence on the rest of the organization than with a strong commitment behind it (e.g. with a value of 5). Commitment of course is one of the potential problem areas in the introduction of new technology or practice. A bundle of three quality characteristics were then introduced (see Figure 3): quality circles (CS 10), quality

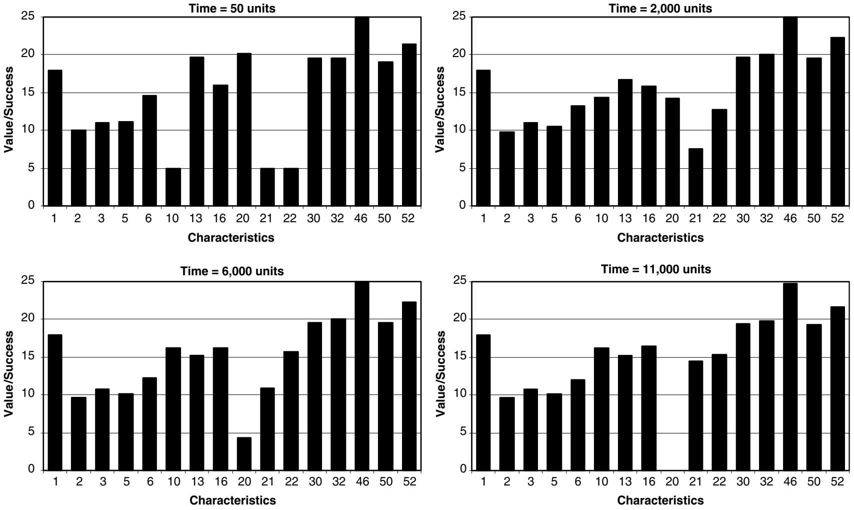

Figure 3 Simulation of the introduction of quality policies to the MMP configuration

systems (CS 21), and quality philosophy (CS 22). When launched, CS 13, large volume production, lost a quarter of its value and multiple subcontracting (CS 20) failed completely. The combined effect of all three quality characteristics, however, had an overall stronger value at the stable solution (Time = 11,000). Would the effect on large volume production have been anticipated beforehand with the introduction of quality policies? This gives some indication of the unpredictability, risk, and uncertainty in decision-making.

The simulation also demonstrates the models' capacity for identifying problem areas and exploring possible solutions. For example, having identified that multiple subcontracting reacted negatively with the new practices the procedure was then repeated for workforce policies. This included introducing characteristics 11, employee innovation prizes, 12, job rotation, 17, proactive training programmes, 24, flexible multifunctional workforce, 33, line balancing, 34, team policy, 36, team ethic, 37, job enrichment, 38, manufacturing cells, and 49, employees as system developers. These characteristics were introduced as a bundle with surprising consequences. First of all, all simulations showed an initial shock to the system, where most characteristics lost some value and became temporarily unstable (see Figure 4).

It took the system a relatively long time to recover (see Figure 5 at Time = 12,000), after which most characteristics stabilized including the new introductions. This perhaps reflects real situations when a package of new practices (in this case 10 new policies) challenges the rest of the organizational structure, having effects on both productivity and the internal workings and philosophy of the organization. Three characteristics, 20, multiple subcon-

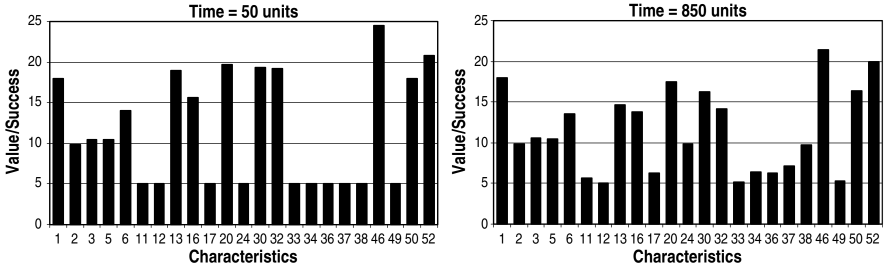

Figure 4 Simulation of introduction of workforce policies with initial system shock

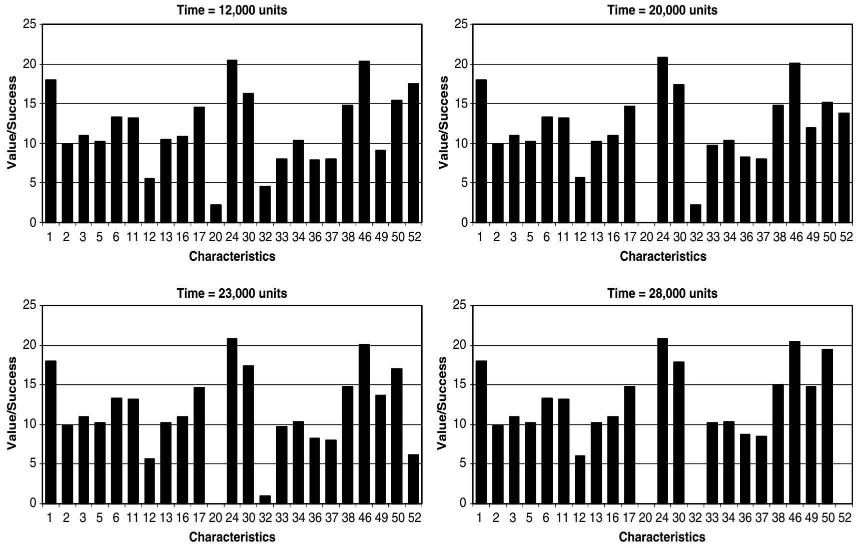

Figure 5 Simulation of the introduction of workforce policies to the MMP configuration (continued)

tracting, 32, sequential dependency of workers, 52, dependence on written rules, did not recover from the instability and disappeared from the system (see Figure 5 at Time = 12,000 to Time = 28,000).

The disappearance of all three of these characteristics is perhaps logical as they counteract many of the new practices introduced. Another interesting finding is that when the model approached a stable solution (see Time = 20,000), CS 52, dependence on written rules, suddenly and rapidly decreased in value and soon disappeared (see Time = 23,000 and Time = 28,000). This finding indicates that the interactions of technologies and practices can occur over long time periods and that some characteristics have certain thresholds that when crossed can have critical implications for the rest of the organization. In this instance, it appears that the new workforce policies needed time to embed themselves in the organization before they could influence other parts of the organization. This demonstrates the usefulness of the model when looking at problems with longer time horizons.

Performance of characteristics in different organizational forms

It is also interesting, in terms of both the effects of the different organizations on the CSs and in gaining another perspective of the evolutionary history (i.e. as depicted in Figure 1), to monitor the performance of individual characteristics throughout evolutionary runs. Three characteristics were selected for further analysis to get a deeper insight into the "fit", effectiveness and/or idiosyncrasies of different characteristics with respect to the overarching organizations.

Figure 6 graphs the values at the stable solution of CS 5, automation (machine paced shops), with respect to each organizational form associated with it. Following the automotive assembly plant cladogram (Figure 1), it is introduced at the beginning of the simulation of the Mass Producer (Fordism), and ended with a healthy 18 units of value. This value declined, however, during the next two simulations dropping 7 units of value for the MMP and a further 1 unit during the Pseudo Lean Producer. An increase in value occurred during the simulations of the European and Intensive Mass Producers as the characteristic gained 8 value units, an 80% increase, and regained the stabilization value of its first introduction. Nonetheless, the increase was only mirrored by the decrease in value during the remaining simulations throughout the leaner production side of the evolutionary history dropping an average of approximately 10 units with a final value of 7 units, around 40% of its highest value.

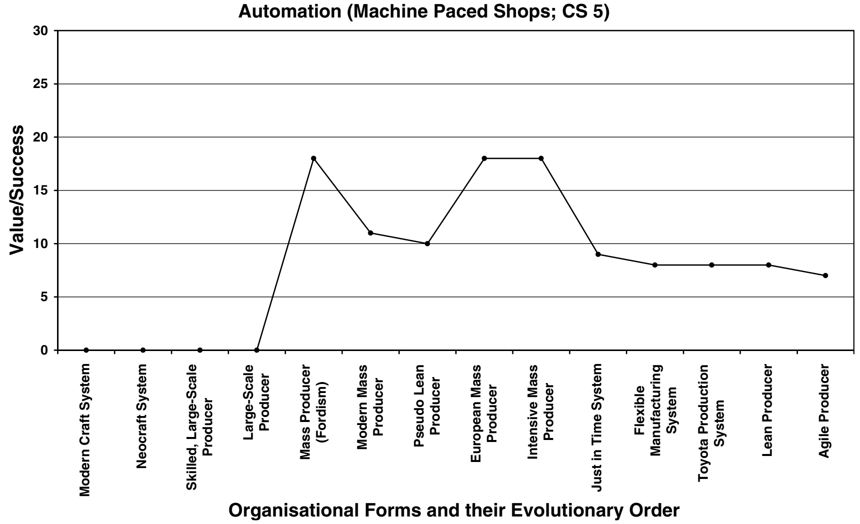

Figure 6 The value performance of CS 5 throughout the simulations.

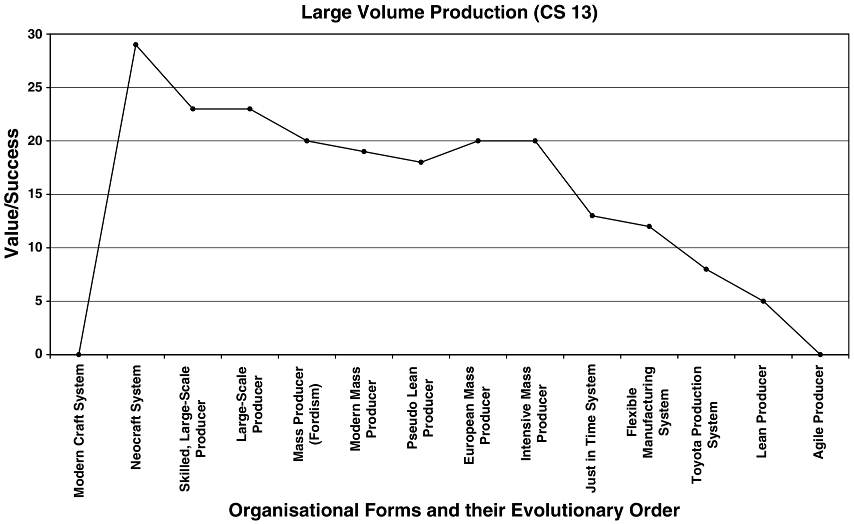

Figure 7 The value performance of CS 13 throughout the simulations

As can be seen from Figure 7, the introduction of CS 13, large volume production, is an instant success and stabilizes with the highest value score, when compared to the other characteristics, of approximately 29 units. This success is short lived, however, as the characteristic proceeds through a dramatic decline, halted only by a respite during the simulations of the European and Intensive Mass Producers. When comparing the mass production and "leaner" production sides of the evolutionary scheme, it can be seen that the characteristic is of significantly more value on the mass production side than for the leaner organizations. The characteristic, although in sharp decline, loses, on average, 9 units on the mass production side and 20 units on the leaner production side and fails altogether with the Agile Producer.

CS 32, sequential dependency of workers, had a very interesting evolutionary history during the simulations. The characteristic was introduced at the beginning of the simulation of the Skilled, Large-Scale Producer and instantly performed very successfully reaching a stabilized value score of 29 units (see Figure 8). The characteristic maintained this score during the next simulation of the Large-Scale Producer and only dropped 1 value unit throughout the simulation of the Mass Producer (Fordism). It was evident that in the simulation of the MMP that the characteristic lost 8 units of value, but overall was still at a very healthy value of 20 units. The interesting part was when the Pseudo Lean Producer was simulated and the characteristic dramatically lost all its value and disappeared from the organization. However, as the European Mass Producer does not evolve from the Pseudo Lean Producer, but from the Large-Scale Producer, the characteristic was present from the beginning of the simulation and again performed successfully for both

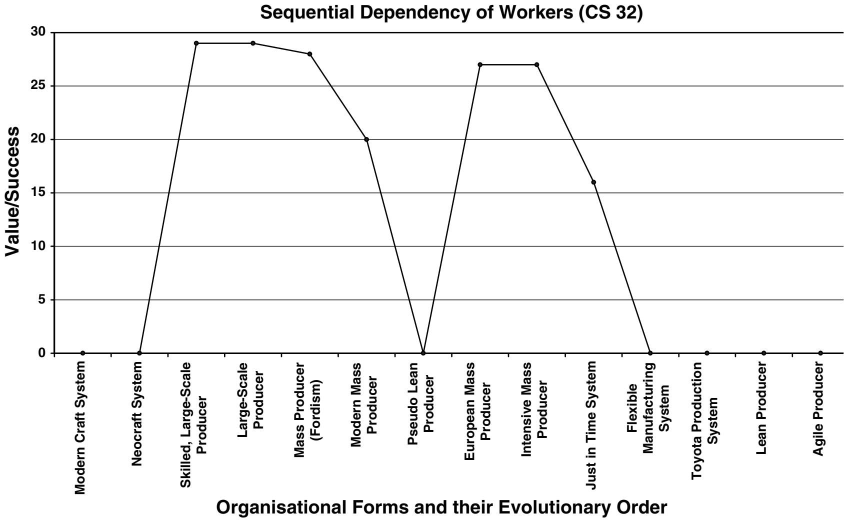

Figure 8 The value performance of CS 32 throughout the simulations

European and the Intensive Mass Producer ending both simulations with a value of 22 units. The cha-racteristic declined in value again during the simulation of the Just-in-Time System but still ended with a fairly healthy value of 16 units.

The characteristic failed for the second time with the simulation of the Flexible Manufacturing System. The complete failure of the characteristic from previously healthy values is interesting as, according to the original automotive assembly plant cladogram of Figure 1, the CS is ever present from the Large-Scale Producers onwards. What is consistent, however, is the introduction of potentially conflicting characteristics in both the simulations of the Pseudo Lean Producer and the Flexible Manufacturing System. The characteristics in question include CS 24, flexible, multifunctional workforce, and CS 33, line balancing, both of which arguably conflict with CS 32, sequential dependency of workers. The introduction of CS 38, manufacturing cells, during the Flexible Manufacturing System has also the potential to conflict. Perhaps all these characteristics in concert over-powered the influential role held by CS 32.

These results highlighted that the evolutionary model may also be used to gain a different perspective through studying the performance or fitness of individual characteristics throughout the simulations of the full evolutionary run. This procedure also permits the analysis of performance in the context of other characteristics providing additional insight into the evolution of both the characteristics and the enveloping organization. It explores in what types of organizations and with what other CSs, certain types of practices and technologies are more likely to succeed or fail.

Table 2 Company character states: Number and description

No.	*CS description*
1	International quality standards (e.g. ISO 9000)
2	Standards for material buying and reception
3	100% Inspection along whole production process
4	Preventive maintenance for equipment
5	Operator involvement in error detection/correction
6	Corrective maintenance subcontracted
7	5S's programme for shop floor, office and Warehouse
8	Annual training programme
9	Multi-skilled workforce
10	Line balancing between Group's companies
11	Operator rotation in the Business Units
12	Operator flexibility
13	Employee empowerment
14	ERP system to organize and monitor resources
15	Visibility of resources through stock to product
16	Automated set-ups in machines
17	Automated cells with robots
18	Set-up time reduction
19	Resources flexibility and priority control
20	24 hours of non-stop working
21	Traceability along the production process
22	MRP to replenish material
23	ERP integrated with clients' ERP
24	Cooperation with suppliers
25	Investment on R&D and equipment

Management diversity, evolutionary consequences, and risk mitigation

In the research reported so far, significant information was lost as the opinions of the managers were averaged out due to methodological difficulties. In overcoming this limitation, this second project aimed to focus on just an individual firm rather than an industry. It was then possible to compare and contrast the views of different people in one organization and examine the consequences of decision-making from people that inevitably have different opinions and base their decisions on different information, values, and beliefs. A Spanish group of four companies was selected for the case study. The CEO, and three directors, responsible for Sales, Quality, and Research and Development, were interviewed and 25 overarching company characteristics (listed in Table 2) were identified. A questionnaire was developed, similar to the previous questionnaire, to gauge how the 25 company characteristics or character states (CSs) interacted with one-another in terms of the overall performance of the company.

Like the results reported in the previous sections, the opinions of managers were averaged out and then simulated (see Figure 9). The first point is

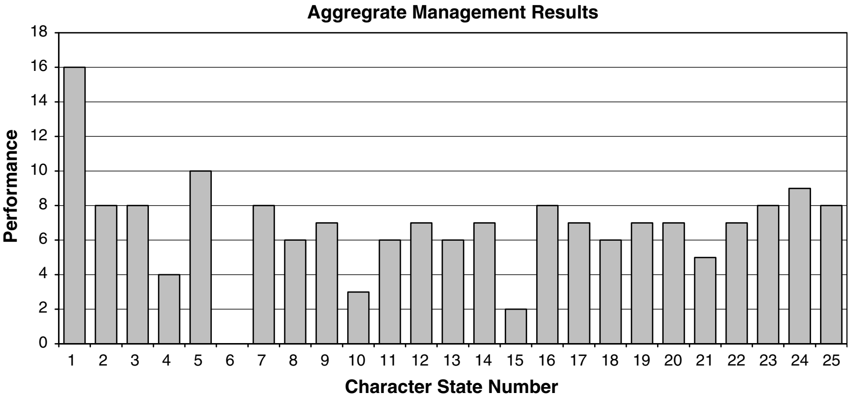

Figure 9 Simulation of company evolution based on averaged opinion scores

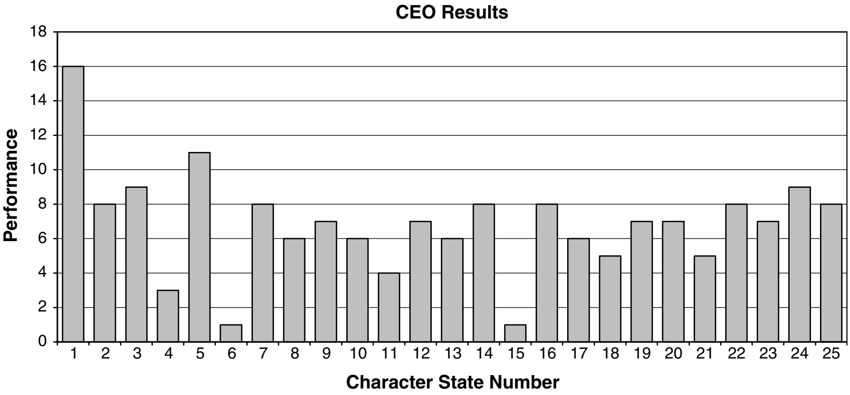

Figure 10 Simulation of company evolution based on CEO's opinion scores

that corrective maintenance subcontracted (CS 6) fails, pointing to some common belief that there is a potential problem with this practice, for example, that the practice has had unsatisfactory outcomes in the past or incurs significant costs. There also appears to be similar concerns over preventive maintenance (CS 4), line balancing (CS 10) and visibility of resources through stock to product (CS 15) as these performed poorly with respect to the other CSs. With these findings in mind, the simulation of the organization was, however, fairly successful suggesting that as a group the decision-makers work cohesively.

The next step in the procedure was to compare and contrast results by analysing the consequences of decision-makers in isolation. Figure 10 shows the stable solution of the CEO's opinions, which strikingly mirrors the previous simulation. How can this be interpreted? Does the CEO have a balanced view of the organization or is it the case of an overarching influence? What is also

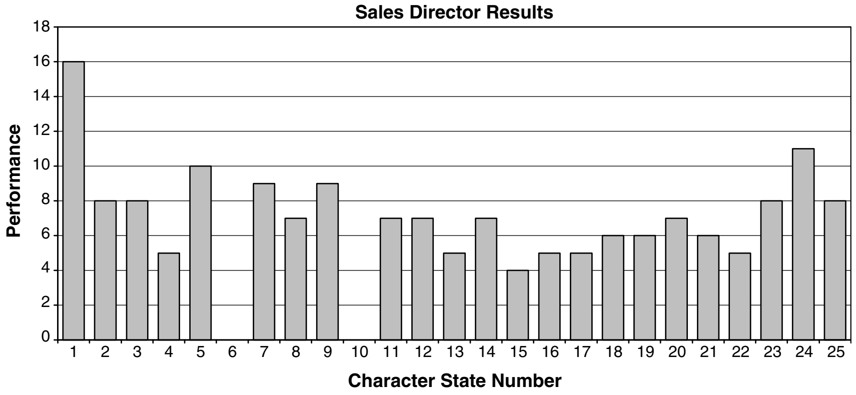

Figure 11 Simulation of company evolution based on Sales Director's opinion scores

interesting is this simulation was the only one without any failures. This supports the position that the CEO has a balanced view and understands how all the company policies, practices, and technologies fit and work together. However, concerns emerged over preventive maintenance (CS 4), corrective maintenance subcontracted (CS 6), operator rotation (CS 11), and visibility of resources through stock to product (CS 15).

Figure 11 is the stable solution for the simulation of the Sales Director's opinion scores. The main talking point with this simulation, particularly in terms of the CEO's results, was that two CSs, corrective maintenance subcontracted (CS 6) and line balancing (CS 10), failed altogether. Although the former CS agrees with the averaged out results and to a degree with the CEO, the latter opposes the opinion of the CEO. Why the Sales Director thinks negatively of the line balancing policy is not fully understood.

The Research and Development Director's results had both similarities and differences with the previous two simulation results (see Figure 12). The similarities were that both corrective maintenance subcontracted (CS 6) and visibility of resources through stock to product (CS 15) failed for the R&D Director – although in case of the latter the previous two decision-makers' simulations led to weak performances with 1 and 4 units of value, respectively. The main difference is the failure of the ERP system (CS 14) and the comparatively poor performance of the MRP system (CS 22). Interestingly, no other decision-maker agreed with this.

The Quality Director's simulation proved to be the most interesting as it represents the most extreme potential evolutionary trajectory of the firm (see Figure 13). First of all, there were a number of high scoring CSs, but the most noticeable difference was that six of the 25 CSs disappeared from the organization with a further two finishing with nominal value (under 2 units). Of these eight CSs, six related to workforce policies (i.e. multi-skilled workforce, line

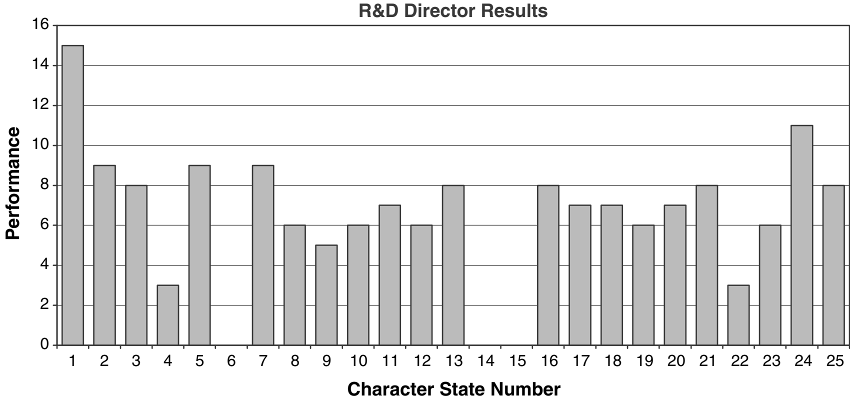

Figure 12 Simulation of company evolution based on R&D Director's opinion scores

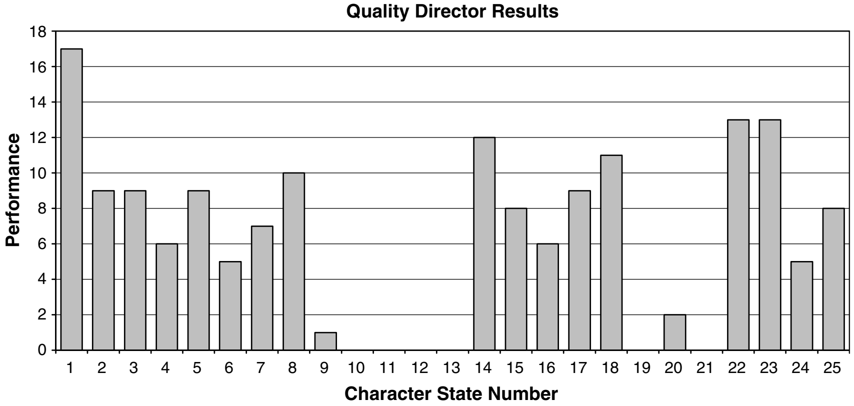

Figure 13 Simulation of company evolution based on Quality Director's opinion scores

balancing, operator rotation, operator flexibility, empowerment, and 24h working pattern), suggesting issues with workforce utilization perhaps. Two possible reasons are that the workforce policies negatively affect product quality or the Director prefers different policies like, for example, a return to more crafts skills.

On a more general note, there was good agreement between all (or most) of the decision-makers regarding the importance of several CSs with the following CSs exceeding 8 value units in most of the simulations: International quality standards (CS 1), standards for purchasing resources (CS 2), 100% inspection (CS 3), operator involvement in error detection (CS 5), 5Ss programme (CS 7), automated set-ups in machines (CS 16), ERP integrated with clients' ERP (CS 23), cooperation with suppliers (CS 24), and investment on R&D and equipment (CS 25). The CSs with the most problems (determined by their failure in at least two simulations) included corrective maintenance subcontracted (CS 6), which failed in three simulations and line balancing (CS 10) which failed in two simulations. The simulations in general, together with the Quality Directors opinions, also suggest that the workforce policies need further scrutiny as these had mediocre performances and rarely exceeded the 8-value unit mark.

Further research

Building on this work, current research has now turned to the next level of aggregation – networks of industrial organizations. We are focusing on aerospace supply chains for large commercial aircraft. In addition to developing benchmarking classification schemes based on evolutionary principles (resulting in a scheme similar to that shown in Figure 1), organizational and spatial models of the supply chain are being created. Six specific areas are of main concern to academics in this field: supply chain management; international and global issues; power relationships; lean and agile practices; learning and communication, and risk and resilience. Currently we are identifying scenarios to explore in the area of uncertainty and risk through establishing appropriate characteristics of the supply chains and their interaction among one another.

One such scenario, for example, concerns the fact that aerospace supply chains have been found to be most vulnerable during periods of change such as processes of improvement activities, pressure to reduce costs and outsourcing. The sources of risk can thus be related directly to the critical success factors (CSF) of cost focused decisions, quality/technical leadership, schedule delivery adherence and customer supplier relationships (Haywood and Peck, 2004). The critical success factors can therefore be seriously affected by incorporation of new suppliers from the customer's country. This could increase the geographical length of the chain which would slow down demand satisfaction and also mean replacing existing suppliers by less effective or less reliable suppliers which would decrease process qualities (Paliwoda and Bonaccorsi, 1994).

Suppliers who are selected on the basis of price only rather than selection based on quality of product and operations can also seriously affect delivery schedules and quality of product. Another source of risk occurs when there are only two suppliers of a high technology item. This makes the buyer vulnerable in situations where there are problems with one of them. Thirdly, at every tier in the supply chain the tendency is to look for risks only as far as the adjacent supply tier (Haywood and Peck, 2004). This limited strategic view inhibits the understanding of the whole chain. This again leads to a lack of supply chain quality assurance and a slow down of the responsiveness to deal with unexpected events. This problem is, however, arguably reduced with high-level selected suppliers with a total system responsibility. In these cases the airframe manufacturer and their long-term suppliers are sharing both the industrial and financial risk of a project (Giunta, 2000). Modelling scenarios and exploring hypotheses like these will hopefully reduce management uncertainty.

Conclusions

The past and present research outlined above attempted to draw together the foundations of a new evolutionary framework and methodology that can be utilized to reduce uncertainty and risk in the management decision-making process. The main benefits of the evolutionary model was found to be through the insights provided into the outcomes of interactions between practices and technologies, the decision-making process, commitment issues, and risk, uncertainty and unpredictability in management. The simulations tested the internal harmony of organizations and demonstrated how new practices emerge and perform relative to others. Through these interactions, successes and failures are quite often logical in terms of one characteristic replacing a similar characteristic, but are also sometimes illogical and quite surprising indicative of a high degree of unpredictability. This unpredictability highlights the limited capacity of foresight, and in some aspects, precaution. It is these scenarios that the indirect and somewhat subtle interactions influence the fates of unrelated CSs.

It was demonstrated that innovations behind organizational transformations, in different spheres in the organization (for example, quality, supplier, and workforce policies), can have unexpected and disastrous consequences on either production or the overall internal consistency or harmony of the organization. The model, through simulating these processes, stable solutions, and potential consequences, both in the short- and long-term, can be an aid to management in decision-making, in terms of reducing uncertainty. Fully exploring the consequences could also have an overall impact in reducing, for example, the timescales involved in major organizational transformations. The research into the diversity of management decision-making is particularly revealing. In cases like this, the model can give the modeller more of an insight into potential conflicts and different opinions and possible reasons. The model can produce an infinite number of evolutionary runs, producing different solutions and highlighting different areas of opportunity or concern. Different variables may be manipulated, such as the starting value (commitment), or different character combinations explored, both of which may to lead valuable answers for management.

Research in this new field and information and tools that it would generate would be valuable for industrial organizations. It can facilitate a reflection of the possible innovations, new ideas, disrupting technologies, and threats and opportunities that they face. The tools could arguably provide practical assistance in seeing options and in assessing their benefits and costs. The new evolutionary framework may identify threats to their longer-term survival, and in addition lead to choices of innovations and changes that have greater efficiency and cheaper running costs in the future. The ideas emerging from complex and evolutionary systems thinking have caused considerable excitement, but not as yet a great many practical results. The research reported here is a promising step in this direction.

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