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Innovation in manufacturing as an evolutionary complex system

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Abstract

The focus of this paper is on innovation in terms of the new product development processes and to discuss its main features. This is followed by a presentation of the new ideas emerging from complex systems science. It is then demonstrated how complex systems provides an overall conceptual framework for thinking about innovation and for considering how this helps to provide understanding and advice for the organisation of new product development in different circumstances. Three case studies are quoted which illustrate the application of these new ideas.

Keywords: Complexity; New product development; Uncertainty; Evolution; Discontinuity

1. Introduction

Today's challenges to manufacturing companies are the much fiercer competition in a global market characterized by more rapid change than experienced in the expansive post-war demand for consumer products.

This reality requires a strategy with a stronger emphasis on creativity and innovation than previously and on lean systems involved in mass production. Complex systems science concerns the transformation and evolution of systems over time and, therefore, we believe provides a natural framework for managing innovation and creativity in organizations. In this paper we set out to apply complex systems thinking as a holistic perspective to innovation processes as illustrated through three cases.

1.1. Simple improvements versus radical innovation

There is a distinction between simple improvement of existing products, and the appearance of a radical innovation. Veryzer (1998, p. 305–318) refers to radical new products in terms of customer benefits or in terms of technology as 'discontinuous' innovations. Thus when a discontinuous product is successful it can define a new industry and the product in the long run can then be transformed into ongoing continuous innovative products. He argues that although the product to be launched may appear as a radically new product to the users, it might have taken a long time to develop so that the development process itself does not appear to be dis-continuous to the people involved. In other words even with a revolutionary outcome the process leading up to the final product may actually be rather evolutionary. Likewise, a more hidden product change to the eye of the end user can be a real innovation.

1.2. Innovation, customer needs and risk

There is little input from customers or market research at the early stages of revolutionary or discontinuous products according to Veryzer (1998, p. 315). Which means the development is technology driven rather than market driven. However, Dalrymple and Parsons (2000, p. 222) have found that for technology driven products approximately only *one idea in seven* is successfully converted into a new product. Which explains Millier's (1999, p. 44–46) argument that 'devices' are the major causes of failure when launching innovations. Thus importantly, Millier defines a 'technical device' as something, which has been designed with scientific and technical rigour without concern for customer's needs. On the other hand for successful devices and these are the 'true' discontinuous products, it can be said that the products are leading the customers into new experiences and opening new needs they could not have been able to give adequate input about to the producers.

Whether a company commits itself to continuous or discontinuous innovation is a matter of strategic choice. Thus the most important innovation strategies related to performance according to Cooper (1996, p. 104–107) are orientation and commitment to new product programmes,

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descriptions of the nature of the new product and the technologies to be employed. He found that the 'high impact firms' involved themselves in high risk, high technology and innovative and complex products. These companies are not significantly market oriented. However, the 'top performers' are proactive in identifying customer needs, and their products were innovative with an impact on customers and they had a strong technological focus.

1.3. Total quality concepts and innovation

A comparison was made by Pullman et al. (2002, p. 355–363) between two different approaches to the implementation of New product development (NPD) strategies. Firstly, *Conjoint Analysis* is traditionally used by marketers in prediction of market reactions to different design decisions. Secondly, Quality Function Deployment (QFD) is used by technical personnel in the process of adapting perceived customer needs into structuring the NPD process. The two approaches are seen as complementary when used together.

Japanese society is well known for its collectivist efforts within industry and between industry and government. This appreciation of the complex nature of knowledge distribution within organizations and between organizations gave rise to the total quality management concepts in Japan in the 1960s. Concurrent engineering became the answer for moving away from the inhibiting influence of scientific management applied to mass-production (Cristiano et al, 2000, p. 287–288) and QFD became functional means for concurrent engineering. Also essential to total quality management is the strong 'customer' focus. Du Gay and Salaman (1992, p. 619–624) presents the discourse of the 'culture of the customer' as an idea for deleting obstructive and expensive bureaucratic controls and to liberate entrepreneurship and be sensitive to market requirements. The model being that of a two-way customer relationship where everyone threat each other as customers.

Thus in terms of customer satisfaction, communication across discipline boundaries, reduces the NPD cycle time and design improvement. Cristiano et al. (2000, p. 298) see the role of QFD in assisting in this. Its weakness, they argue, lies in the considerable time it takes to make it function and, like Pullman et al. argued, its limitations for market forecasting, and that it could inhibit innovative creativity (Cristiano et al., 2000, p. 302).

1.4. Standard control versus emergence

At a more internally focused level Dougherty (1996, p. 425–429) argues that the whole organization must balance the tensions between standard control and emergence through freedom for creativity, and also that innovation is dependent on the ability to balance the outside–inside tension between market needs and technological potential. Thus her arguments attempt to bridge the gap between continuous and discontinuous innovations.

NPD teams freedom to influence the shaping of operational controls had a positive effect on performance (Bonner et al., 2002, p. 24). On the contrary, they found that project team influence over strategic direction had no significant influence on project performance. Top management intervention into team decisions and the degree of process control imposed on a NPD project both had negative effects on project performance.

1.5. Decision making and innovative processes

Negotiation of ideas and practices can traditionally be implemented differently. The collectivist culture of the Japanese facilitates the feeding of the functional groundwork into the final decisions to be made at management level, whereas the individualistic culture of the US facilitates a decentralized decision-making by engineers at functional levels (Cristiano et al., 2000, p. 292). Souder and Song (1998, p. 210) found in the US that decentralization was beneficial during creative NPD stages, and that management involvement was appreciated by personnel in the early NPD stages only.

Whether there is decentralized freedom for creativity or more orderly freedom within a collectivist tradition, the importance of freedom in innovative processes is evident. For Miettinen (1996, p. 51) showed that a particular invention was not the result of any rational decision-making. Instead, it arose as a vision evolved from two hypothetical ideas, which came about through the effects of several unanticipated developmental processes, and also that research and know-how made the idea formulation possible and not just pure luck. These observations are supported by the arguments by Mintzberg and Waters (1990, p. 5) suggesting that decisions involve commitment to action while there are actions taken where no decisions have been made.

Rather decisions can be a constraint in innovative processes (Dougherty, 1996, p. 428) as in the case where some managers not directly part of the NPD process exercise power through deciding to hold back essential resources to the process.

1.6. Idea diversity and evolutionary learning

At the level of interactions between functional groups, Olson et al. (2001, p. 266–269) found that the dependency between different functional departments varied across NPD stages. Thus for innovative projects, cooperation between marketing and R&D during early project stages, between marketing and operations during later project stages, between R&D and operations during later project stages were all positively related to project performance.

At individual level Salter and Gann (2003, p. 1309–1316) found that the immediacy and usefulness of face-to-face interactions and on the spot sketches were essential in solving problems and creating innovative ideas in the case of a world-wide engineering design company. Although these designers were heavy users of electronic information systems these lacked this immediacy.

The above evidence supports our argument that exchange of knowledge and collective learning between individuals and at the boundaries between functional departments are important for change and essential for innovation. However, for innovation to take place, the learning has to become expansive. That is, team members have to keep questioning existing models of products, practices or technologies, analysing them and destructively rejecting the old, collectively renegotiating and forming new models and testing these in a continuous cyclic activity (Blackler et al., 1999, p. 8; Engeström, 1999, p. 2–3; Engeström, 2001, p. 1).

1.7. Routines of adaptive improvements

In line with Dougherty's previously mentioned principle of balancing between market needs and technological potential, for a long-term strategy focus would be like Bessant et al. (2001, p. 67–76) argue that a company needs to establish routines of 'continuous improvement' and that through these evolutionary learning processes they are thus better prepared to do 'new things' and be innovative. Nijhof et al. (2002, p. 675) argues that this strategy of 'continuous innovation' is needed for a company to be at the forefront of its business and that in a very successful Canadian/Dutch company they looked at, there were not overall plans for innovations as employees were encouraged to present ideas, which if found workable by management, these employees were given freedom and responsibility to concentrate on and to develop the innovation

Summary
Product innovations are evolutionary processes and can either continuous (smooth evolution) or discontinuous, when qualitative change occurs at a new branching.
Innovations give new experiences to customers and open new needs and are characterized by high risks.
QFD is an improvement beyond scientific management but as a rigid system can inhibit innovative creativity.
There is tension between standard control typical of scientific management and freedom for emerging creativity.
There is tension between top-down decision making typical of mass production and decentralized decision making.
Innovations are characterized more by evolving ideas than rational decision making.
The importance of collaboration between R&D and marketing at early project stages, between marketing and operations and R&D and operations at later stages.
Collective expansive learning for innovations as opposed to top down ideas.
Innovation is dependent on routines for adaptive improvements.

1.8. The problems and limits of old approaches to NPD

The limits and problems when dealing with discontinuous, radical innovation are the approaches successfully used for mass production where rigid systems guide the processes. Creative innovation processes need to draw on a diversity of ideas available among those affected by the new product development.

Standard control, top down decision making, focus on decisions rather than the evolution of ideas and too rigid QFD systems inhibit this.

In this chapter we have tried to describe some of the very valid points made in the literature relevant to the discussion of the paper. In the next chapter, we wish to propose an integrative conceptual framework provided by complex systems thinking which allows these different approaches and observations to be seen within a single theoretical framework. The above approaches from the literature will be applied to three NPD cases in chapter three from a complex systems thinking perspective. However, let us first describe the basic ideas that have emerged concerning complex systems.

2. Complex systems thinking

Let us briefly summarise complex systems science, and what it has to tell us about the evolution of products and the companies that produce them (Allen, 2001a,b, 2002; McCarthy, 2003; McCarthy et al., 2000). Traditional science was built on the idea of the mechanical system, typically the planetary system. Newton demonstrated that for such systems simply knowing the law of interaction between the elements allowed accurate prediction into both future and past behaviour. The lesson was so impressive that the ideas dominated science for several hundred years. But in some ways there was always a problem. Prediction in mechanical systems was only possible provided that the system did not 'change'. The motion of the earth round the sun was predictable, but not how the solar system started or how it might end. In effect, these systems were not systems open to flows of energy and matter. In 'open systems' a wholly new set of phenomena were observed in which structure could spontaneously appear and the qualitative features and elements of a system could change. What it showed was that 'evolution' is more general than 'mechanical' system dynamics. Mechanical systems are 'special cases' of evolving systems, where for a time, qualitative, structural change does not occur.

One of us (Allen, 1988, 1994a,b, 2000), has shown that open systems can only be represented as mechanical, systems dynamics, under certain restrictive assumptions that essentially eliminate creativity and innovation. This is shown in Fig. 1.

Complex systems thinking shows us that evolution and co-evolution are to be expected in real systems that survive in a changing environment. This implies both quantitative

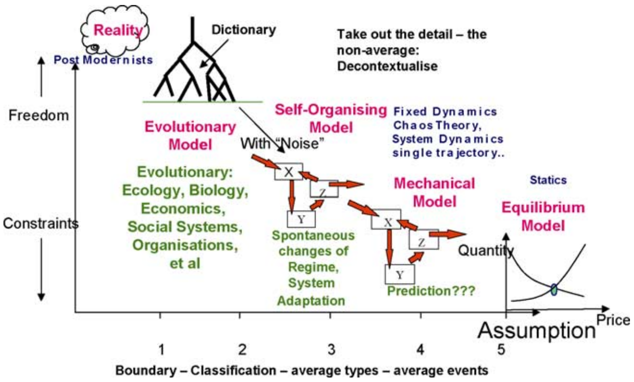


Fig. 1. A clear, mechanical picture is obtained from a naturally creative reality by making successive simplifying assumptions.

and qualitative change. Qualitative change occurs at moments of instability, also known as bifurcations in 'solution space' when, some new aspects or elements appear and grow in the system, re-structuring it, invading new dimensions and leading to emergent properties and attributes. Mechanical systems of linked process do exist where systems' models are useful and their fixed structure is not incorrect. However, different mechanical systems are separated by the moments of instability during which an initially insignificant item, entity, behaviour or concept appears and then grows in the system leading to qualitative and structural changes as shown in Fig. 2.

2.1. Innovation and evolutionary complex systems

In general system dynamic models, and engineering processes are fixed representations of systems that are designed to perform a particular job This is quite correct when we are modelling a production process, for example, that has a pre-defined sequence of operations that need to be carried out in order to achieve a given end. However, the problem of defining a new product is different. Of course, in the case of a minor improvement of a pre-existing deign, the series of actions may well be entirely clear, and have a deterministic outcome. But if a new design is required, and a radical innovation is involved, then this can no longer can be represented as a deterministic system. Instead, it must be seen as an evolutionary, complex system in which future structure will be created. In Fig. 1, this means that the assumptions of average behaviour of typical elements that lead to a deterministic system do not hold, and therefore, cannot be made. Because of this, radical innovation and the development of really new products corresponds to the evolutionary processes of the left-hand side of Fig. 1, where new dimensions and attributes can emerge in real time as a result of the interaction of the agents.

In summary then, when the design system is such that the input (customer specification, etc.) produces a predetermined outcome product, then we are in the realms of system dynamics and process and we do not have radical innovation. This corresponds to a 'non-branching' part of evolutionary history when current structure and design holds. However, when there is internal freedom in the design system, the system can be 'unstable' with respect to perturbations such as new ideas or daring concepts, and these can take off and create a new branch of evolution. The new branch will have new attributes and possibilities that will emerge, and this will correspond in retrospect to a 'radical innovation'.

The innovation is radical then the 'jump' the system makes is really dependent on contingent and contextual elements that cannot necessarily be known beforehand. The ideas that will be explored, and the order in which they may be raised are entirely contingent on the experience of the person called in to deal with the problem. In addition it will depend on how the conversations 'go' and on how various participants 'feel' as it happens. So, in reality, the complex system instability corresponding to a radical innovation in the NPD process is not pre-existent and fixed, but instead is 'constructed' in creating the new product.

2.2. Knowledge beyond instabilities

The lesson of complex systems tells us that in considering the performance of a new design, it is important to distinguish two different aspects of performance:

- The dimensions, qualities and attributes of the product/service
- The quantitative values that these have

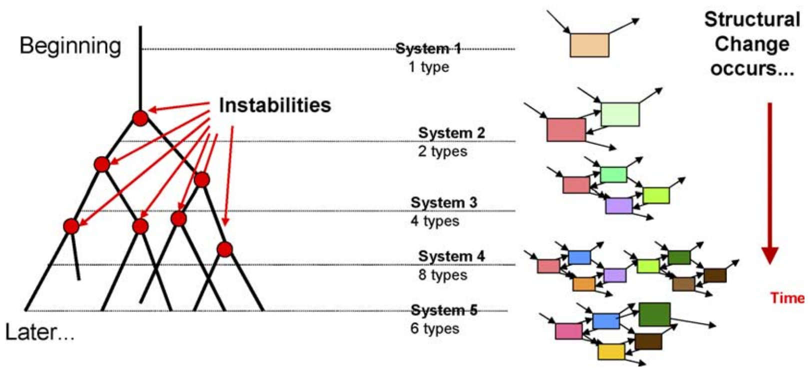


Fig. 2. A complex system is one in which successive 'mechanical' systems are created, with emergent properties and attributes. Instabilities mark radical innovations.

These two quite different aspects of performance have not been clearly separated in much previous work, although approaches such as QFD (Griffin, 1992; Cristiano et al., 2000) recognise the issue by mapping the dimensions of customer 'need' down into the design and production processes that can deliver them. Typically, we have a four-stage mapping:

1. Hierarchy of customer needs onto technical requirements
2. Technical requirements onto the critical part characteristics
3. The critical part characteristics onto the critical process parameters
4. The critical process parameters onto the production planning matrices

In this way the NPD 'process' is taken from customer needs, to Product Planning and Design (the Quality Matrix), to the Part Deployment Matrix, to the Process Planning Matrix and on to the Production Planning Matrix. This is also the case for Conjoint Analysis, a method that tries to understand the predicted demand from customers for a product with a different 'mix' of the dimensions they seek.

The key issue is that while the performance requirements of potential customers are multi-dimensional with particular thresholds of 'acceptability', the performance 'output' that any particular design may deliver in these multiple dimensions is a complex coupled function of the component parts and of their particular configuration. This means that we are attempting to explore the multi-dimensional performance of a possible design (particular components and configurations) corresponding to a particular point in the multi-dimensional space of its characteristic qualities, features and attributes. Different designs will in fact be characterised both by being different 'performance' points in this space, and also by sitting in different 'bundles' of dimensions that correspond to their particular qualities, features and attributes. This means that comparison between designs involves both qualitative judgement about the different features generated and also the comparative 'values' of the performance in those dimensions. Also, NPD based on either QFD or Conjoint Analysis will not be very new since it will be concerned with the dimensions that are already known to customers. This does not allow us to explore 'beyond the bifurcation' in the domain of radical innovation.

Neither does all this tell us whether the actual company trying to design a new product can actually produce this design nor more realistically whether it is particularly suited to do so. In other words, simply using QFD or conjoint analysis to try to factor in customer desires into the process ignores the question of the suitability of this design for the particular skills and capabilities of the company. Complex systems thinking tells us that it this double ended dialogue of possible capabilities with possible needs that really will determine what happens. Neither innovation-push nor demand-pull alone will work in reality. Success will go to those companies whose strategy succeeds in linking the two.

Complex systems science tells us that going beyond the bifurcation is going into the unknown. When we change a design, we may be unable to predict the impact on performance, or perceived performance, as there may be emergent attributes, or discontinuities in the values of the existing attributes. Firstly, several performance attributes may depend on the single parameter. There may be difficulties in the manufacturing process that are not apparent. There may be emergent properties for the product that only manifest themselves in use by customers, and these we cannot anticipate. In short, even for small design changes the only way that we can be sure about its performance will be AFTER we actually build it, sell it, and customers use it. So, complex systems science tells us that each time a really new product is called for, really what will emerge is not predictable.

In real time, there will be some particular modifications or new ideas tested, and a programme of performance tests set up to explore what improvements or problems are. However, what will actually happen is not that all possible modifications and test will be considered (as optimisation would require), but instead, ideas will be tried out in a somewhat unpredictable order, and only a limited number of trials will be envisaged, because of cost limits. This is a process of 'satisficing' not optimising (Fig. 3).

In reality, the actual performance of a new design cannot be fully known. Both the dimensions of comparison and the values generated by a particular design are generally a non-linear function of the details of its components and of their relative configuration (the concept). We can also use the terminology of 'ambiguity' for the dimensions of performance, and 'uncertainty' for the quantitative values that are generated within the particular dimensions of the design. This means that there have to be tests for the performance in each dimension, and also that there will always be some quantitative experimental uncertainty in any particular test result in a given dimension. There will always a level of 'residual ambiguity' even after the most thorough regime of testing. In the end, radical innovation 'success', beyond the bifurcation, will be

Fig. 3. This shows a continuous improvement cycle that should be centred around the strategy (desired identity) of the company.

a matter of the capacity to imagine new concepts and designs to be 'tested', and the ability to make good judgements about the degree of ambiguity and uncertainty that must be accepted in a competitive market place.

The NPD process consists of the generation of new ideas, and criteria for their evaluation, testing and selection, so as to identify one that is 'good enough'. It is hardly surprising that this fits into an 'evolutionary' view that complexity suggests. Clearly also, the criteria of evaluation should reflect the needs of potential customers and the 'trade-offs' that they would make between different quantities of different qualities, and also the production/delivery capabilities of the company, together with the expected costs and profits and the trade-offs in these, involved in supply different possible quantities of different qualities. This is, therefore, the background to our understanding of the NPD process as a complex system of decision-making by the actors involved.

Different performance dimensions, viewed by either the potential producer or consumer, are coupled within the 'structure' of the product. They are not capable of 'independent' change. More strength may definitely require more weight, for example. The attributes have 'values' that are coupled, and any design change that aims to modify one characteristic may well change several others. This means that we must search in a multi-dimensional 'rough landscape'. Instead of having a smooth optimisation surface to climb, there is a rugged set of hills and valleys, within which even a single design modification can take the performance to an entirely new set of values (Fig. 4).

The NPD process is really about the interaction of this landscape of 'potential supply' with the corresponding landscape of 'potential demand'. This second landscape really expresses the trade-offs that potential customers have concerning the different dimensions of performance that might be offered. These might be relatively smooth functions except for thresholds of unacceptability. The designer, or more correctly the NPD actors, need to know the dimensions of the qualities of the different possible designs, the performance values achieved in these, and very importantly, how these will be perceived by potential customers.

How well can the designer know the degree of success that the new product will encounter? If all aspects of the product could be tested and a measurement provided, then it would be possible to know perhaps through conjoint analysis, how the trade-offs would operate, and what market share or profits would be. However, the producer can only test the performance properties that he already knows, which are also measurable, and as we know from complex systems thinking any new structure such as a new design or product will have emergent properties and attributes for some customers, and this could be good or bad. Furthermore, aspects such as style and overall attractiveness may be impossible to anticipate. They might be indicated by using test markets or consumer panels or may only emerge with use and with a wide variety of customers. A better approach would be to engage with the potential customer and interact closely in exploring what could be done and what they might value or require.

The real issue at the heart of NPD is the origins of true innovation. Clearly, marginal improvements and 'hill-climbing' are merely rational extensions of the present, but a new product and the perception of its emergent property requires a creative step that is not foreseeable. It happens if there is 'openness' to some new ideas and to a creative dialogue between the designer and the potential user. This appears to be the key element in creating really new products that are actually desired by their customers.

The NPD process of the constituent companies therefore underpins the large-scale evolutionary process of the sector. It is therefore important for any particular company to maintain its ability to have a creative NPD process, so as to maintain its relative position in the sector. If the sector is more 'creative' than the company in question then it will eventually be eliminated. In the longer term survival of a company depends on its ability to be as creative in its product development as the sector, and equally the sector

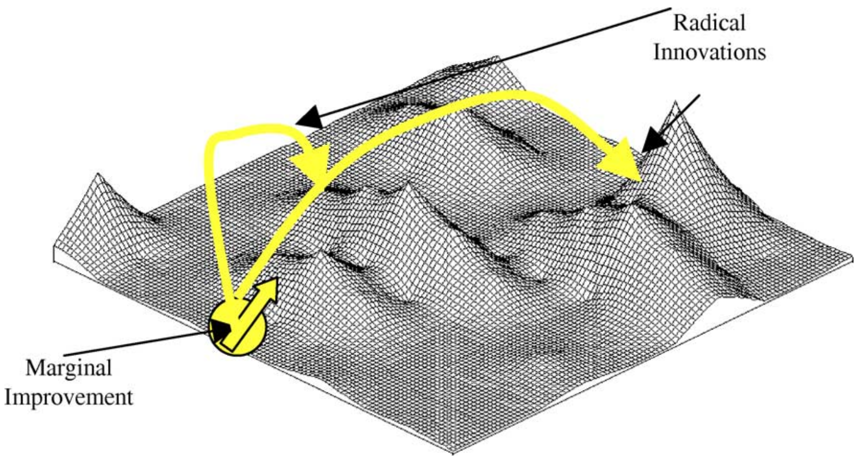


Fig. 4. Here we show only two dimensions, but in fact the performance landscape is really multi-dimensional and rugged.

will maintain itself through the competing creativities of its constituent companies.

3. Case illustrations

In this chapter we will try to demonstrate the usefulness of complex systems thinking to the understanding of innovation in terms of NPD activities, as these are evolutionary and creative processes with unpredictable outcomes .

Boundary interactions at moments when these ideas are put into practice, at points of bifurcation, are when change in design can be experienced. This can only occur within the NPD activity when the fluctuations within it is triggered by the tensions between different voices such as between existing design ideas and perceptions of environmental realities reach a level where change has to take place for the customer to be satisfied. And this is where real innovations may occur. However, with these three producers being as close to their customers as they are and totally dependent on their customer's world views, these companies were exploring opportunities in terms of technologies and markets only within small and familiar parts of the landscape. They were adapting incrementally only to the perceived changes that they, their competitors and customers made to what appeared to them to be a clear and rational part of a larger landscape. In that sense their innovative efforts would be less than when experiencing a larger and more rugged landscape

Due to their close relationships with old customers, it can be argued that because of their lack of external exploration they kept themselves much within the knowledge of their past only. The companies had medium to high success rates and were of low impact as their new products did not differ much from existing products in terms of technology and newness to the market

Co-evolution within	Adaptation
Immediate and familiar landscape	Less innovative effort
Larger and rapid changing landscape	More innovative effort

Marketing mix				
	Products	Place	Promotion	Price
Company A	Series of mechanical parts for cars	Worldwide	Close relationship with old customers	Negotiated
Company B	Substructures for aircrafts	Worldwide	Close relationship with old customers	Negotiated
Company C	One off complete mechanical solutions	Locally in UK	Close relationship with old customers	Negotiated

3.1. Co-evolution

All three companies that we studied were producing highly customized industrial products. None of the companies was engaged in defining a new industry.

Company 'A' was producing mechanical parts for the car industry worldwide, Company 'B' was producing parts for the aircraft industry worldwide and company 'C' was producing complete mechanical devices for UK customers.

They were all rather part of an industry wide development in terms of their respective fields. Their eventual innovations were at the level of detail rather than being ground breaking and were part of stepwise continuous processes, which were building on their joint experience with their customers from product to product. In that sense the companies never gave their customers new experiences, as they were totally customer-dependent in terms of ideas and what the customer wanted to be made.

More holistically, through the interaction between the customer and the producer in the three cases, the customer in presenting their externally informed ideas is actually inviting the producer into their environment or reality and allowing the producer to co-evolve with them and their environment. The environment they can potentially influence through their new products. In this way these producer–customer-environment relationships can be seen more holistically in terms of being an open world provided they are properly connected where energy can be exchanged in the form of ideas between them across their imaginary boundaries. What matters then is how the producer is able to respond to these different levels of environmental demands.

3.2. Sustainability

In terms of technology, although these three companies offer neither high impact new products nor real newness to market, they have all still survived within their market niches so far.

Company A is mass-producing parts for regular customers. Although they are focusing on at least keeping a high market share and in that sense having some control over their future, maintaining their relative position in their sector, they are still highly dependent on their old customers for survival.

New product explorations by companies B and C are characterized by joint efforts with their customers and thus they can hope to survive as long as their relationships with these customers are good and their customers also survive. But their rather fixed or too adapted behaviour aimed at satisfying a contemporary niche market does not give them potentials to survive (Allen, 2001a,b,c, p. 155) in a rapid changing market. Thus at the same time as this is a risk-averse approach it is a vulnerable approach due to the high dependency on a few customers.

All three companies are highly specialized and are not exploring outside their niche markets, which can of course be argued to be the case of companies with long and embedded traditions and little input from the wider environment

Sustainability within	Adaptation
Immediate and familiar market	Risk-aversive approach
Larger and rapid changing market	Visionary approach

3.3. Quality assurance, control versus creativity

Company A employs QFD but there is no evidence that they are using any form of conjoint analysis. Their innovation, however, is in their effort to periodically improve their standard products. These standard products are all customer specific.

Company A was focusing strongly on the culture of the customer in terms of strong team working and team decisions where everyone becomes each other's customer. In that sense the company both philosophically and practically is successful in deploying their total quality assurance.

Their quality consciousness is reflected as a combination of formal communication through written reports and formal decisions in terms of reviews at different stages, and informally through a strong focus on face-to-face communication and team decisions throughout the whole NPD process. This acknowledgement by management of the importance of diverse opinions in enhancing creativity, letting discussions move freely and allowing final decisions to emerge illustrates that the company as such is prepared to respond to the market in whatever way the decision process leads it, as long as this corresponds to customer demands in the end. Thus unpredictability is to some degree reduced as team decisions are the prevailing ones, which then gives consent and some collective direction to individual actions, through a focus on a common object in terms of a vision.

Company B is an ISO 9000 company and although this reflects a corporate intention of total quality management the company is not successful in deploying total quality assurance. That is although management customer relationships seemed to be strong, it is admitted that the company is having integrative problems in terms of the transfer of knowledge and meaning. Employees are invited to meetings where management make decisions in order that they shall 'hear the message'. Yet, still in general the implementation of the decisions do not turn out as intended by management, who argue that this is because people are not committed enough. Thus even small changes to the implementation by the employees could make the outcome difficult to predict. This lack of connectivity between management and employees inhibited any collective effort in the NPD processes.

A conclusion could, therefore, be that management's unitary impositions through top down decision making and expectancy of average and orderly behaviour is not realistic and in so doing are actually inhibiting designers' creative potential and thus promoting a lack of responsible attitudes and lack of interest amongst employees. It is again this lack of ability within the company to facilitate the creation of collective objects as visions evolving from people's different perspectives being given a voice and coming together.

The small company C does not employ any form of conjoint analysis, QFD or any advanced formalized techniques or practices but they did relatively well in the exchange of knowledge at their level due to an open and inclusive culture within their small company community. That is they rely heavily on informal communication throughout the whole NPD process, internally as well as externally with its customers. The company is old-fashioned in terms of technology at the same time as it is post-modern in its appreciation of non-average behaviour. This company does not follow any simple recipe but has a more intuitive and common sense approach to challenges, where human interactions and ideas have freedom to move according to the different contexts. Small decisions were made by the project engineer while decisions on serious matters were made on the spot by the project engineer and the very experienced MD

	Approach	Expected outcome
Collective efforts	Decentralized decision making	Creativity
	Communication of ideas and perspectives	Creativity
Unitary efforts	Centralized decision making	Average behaviour
	Top down ideas and perspectives	Average behaviour

3.4. Strategies and imagination

Company A expressed a clear vision of the future and a strategy for the future in terms of market share and in their periodic improvement of their standard designs within the framework of clearly defined customer needs This continuous improvement strategy can be argued to be the company strength. However, the periodic revision of design can be argued to be reflected in their approach to strategy where the company works with the world as it is and where changes are made risk-aversively in small steps only.

Company B's management was not satisfied with their strategic planning ability and they also had problems in communicating a corporate vision of the future internally in their organization. Employees' feeling of uncertainty regarding the future made many of them leave the company. Thus major strategic decisions had problems in both being implemented and absorbed throughout the networks of employees in the firm. This made management's intentional attempts to adapt to the future even more unpredictable than necessary.

Management's top down approach to strategy could be argued to artificially inhibit the heterogeneous voices of company B in influencing more exploratory search and in creating some wider sense of ownership in the mutual understanding of the company's future. As company B had a very close relationship with their customers it could also be argued that they were simultaneously applying a careful step-by-step approach to strategy externally, but that this was not successfully transmitted internally in their organization as already discussed above.

Company C, a small local firm were explicitly having a non-strategic approach as they did not use any defined strategy to give them direction. Also they invested little in NPD and operated in their existing local markets only. This can be argued to be a rather 'adaptive' approach to strategy as the company by behaving in this way is letting the environment decide.

For all three companies more creative approaches to strategy would be to have the confidence to deliberately go beyond present knowledge and try and have the capacity to imagine a future through new concepts that can be presented convincingly to customers. This is where it can be argued that more exploratory actions within these companies would be needed in general and in the case of company B specifically where management should be more inclusive in their employee relationships

Strategy implementation	Externally	Internally
	Convince market	Employee appreciation and commitment through inclusive dialogue

3.5. Diverse capacity versus lean systems

The way a company organizes its work is a combination of strategic choice and evolution.

Company A has formal systems for exchange of information where employees' ideas can be fed into an intranet system for sharing. Such a facility for sharing general knowledge is important. However, more importantly management emphasized their priority for frequent face-to-face interaction and freedom to enhance sharing of ideas and thus take care of immediate tasks.

Company B has also established formal systems for the exchange of general information. Nevertheless, company B was not good at exchanging knowledge across projects and they were not good at communicating within the projects and thus as expressed by management had to 'reinvent the wheel' too often. The company, in holding back on essential human resources to form lean structures to be cost effective, does not allow enough space and time for people to come together, to exchange experiences and knowledge for improvement. The company is thus a significant contrast to the continuous improvement or continuous innovation strategies recommended by Bessant et al. and Nijhof et al., respectively. It also contrasts the face-to-face interactions emphasized by Salter and Gann for innovative success. This lack of excess capacity limits the opportunity for exploration of design solutions and concepts within the company. A further consequence of these lean structures is that their exclusion of expansive individual and collective learning prevents innovation within the company from taking place. The company, so doing is separating opposing views, which if coupled could have triggered off synergetic solutions.

However, management in general is also about trying to reduce unpredictability through some control. However, in company B these ordering and control mechanisms are emphasized too strongly through the imposition of unitary meanings through centralizing decision-making. This again is in deep contrast to the established freedom and responsibility given to employees in a successful innovative company as pointed out by Nijhof et al. That is for company B management's top-down control attempts did not work, as employees had little commitment to schedules and company B thus had problems in delivering their products on time. A suggestion for such a case would be that through open, collective processes, where a diversity of perspectives is produced and where everyone takes ownership of collectively made decisions, the implementation of decisions be successful and the unpredictability of internal processes reduced.

Company C have no formal system for exchange of knowledge. As a rather small company it has the advantage of easy and informal exchange of knowledge internally in the company. Due to its size, however, it is suffers in terms of a lack of diversity of expertise as this is limited to the competence of the project engineer and the experienced MD when having to face unfamiliar design problems

	Outcome
Lean structures	Restricts continuous improvements and innovation
Diversity	Potential for synergetic solutions

3.6. Evolutionary learning

Diversity of experience and perspectives held by members of an activity can enhance collective learning for that community.

Company A are focusing on improving standard design and sharing new ideas. Simultaneously they constantly focus on their main competitors and what they are doing. Through their extensive teamwork it can be argued that they are facilitating co-learning.

In company B, knowledge transfer from project to project is not good, and successive people have to re-solve from scratch problems that should be familiar to everyone. That is it can be argued on one hand that workplace learning here is more about individuals becoming competent within established expertise and practices only. Thus, for the company as a whole the learning is not expansive. That is expansive in terms of individuals and groups going beyond present knowledge. They would do this by critically analysing present problems and ideas, then creating new models, testing these, reflecting on the results and creating new models in a cyclic continuous fashion. Thus, through conversations/dialogue vertically between management and employees and horizontally between people of different professional disciplines learning actually evolves in such complex systems.

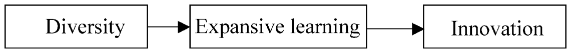
Company B with its restricted division of labour is encouraging average expertise only. In that sense the company is not exactly increasing its potential as a complex system with a capacity to approach the environment in several possible ways.

In company C when they encounter unfamiliar problems, they simply ‘look around’ to see if something similar has been designed before. In general they find something that they can easily adjust to their own purpose. Although they are very good at exchanging ideas with their customers it can be argued that their new product developments are very practical adaptations of old principles. There is no destructive rejection of old designs and hence the work can be characterized more as routine with hardly any expansive learning

	Outcome
Adaptation of proven principles and knowledge only	Competence within established expertise only
Critically analysing problems, create new models, test and reflect	Innovative capacity

3.7. Innovation and customer relationships

To create new ideas and solutions a diversity of perspectives need to come together in expansive learning cycles.



Although company A is very customer dependent, they apply their own interpretation of customer needs, like typically for the more innovative firms they involve the customer at later stages in their NPD processes only.

Rather typically for non-innovative companies referred to in the literature, both company B and C relied heavily on customer involvement in the early stages of their projects. Thus, as if they had used conjoint analysis their NPD would not necessarily be innovative as their products are based on dimensions already known to their customers. In that sense their improvements are marginal only.

Based on the same logic, high involvement with customers for high impact firms has been argued to be inconsistent with the freedom to be creative for innovation as the customer cannot give input to something that does not yet exist.

This argument holds well for consumer products. However, in the case of one off industrial products like in companies B and C the reality can be defined as totally different. That is for such industrial products there is likely to be product expertise in both the customer and producer communities and these slightly different expertise and perspectives might be complementary when brought together, and could enhance creativity and could thus produce positive synergies for innovation.

3.8. The firms as complex systems

In the context of seeing company A in terms of short-term sustainability and within an environment mainly consisting of its present competitors and customers, it is a complex system. For long long-term sustainability in a wider and more rapidly changing market it could probably be argued that it is not presenting itself to have the diversity required to respond to that environment in more than the ways it is presently doing.

Potentially, company B is a complex system but it lacks the connectivity between diverse perspectives and expertise and is thus not promoting expansive learning and creativity. Management choose too predetermined paths in terms of decision-making to be really innovative. Through management’s good relationship with its customer, company B can be seen to co-evolve with its customer. However, this knowledge transfer is suffering in being implemented thoroughly due to poor vertical communication in the company.

Thus in terms of its present work practices and lack of excess capacity, it can be argued that company B would not be able to respond to the apparently rapid changing world environment in more than one traditional way (Allen, 2001a,b,c, p. 150–152) and is thus not a sufficiently complex system.

Company C can be argued to be much in the same situation as company A in that within a short-term predictability horizon it is probably complex enough to sustain. However, if the company would be able to change and adapt to rapidly environmental changes could be down to people's imagination of changes in due course.

4. Case conclusions

The case illustrations above raise the question of whether QFD systems or ISO 9000 accreditation is enough to guarantee quality of products and success. As the three simple cases show, organizations in general and NPD specifically are more complex than these formal ordering systems can fully take care of. However, the intentions and philosophies behind these total-quality procedures and the culture of the customers' approaches are important as they are supposed to enhance a holistic view. But across the company, investment into such quality systems as training, understanding, adjustment to firm specific needs and time allowed for implementation of the systems are maybe the more important factors for success and that make them workable.

Rather as the application of complex systems thinking to three cases above clearly show, shifts of mindsets from that funded on mass-production and leanness to that of freedom for creative processes like NPD is needed.

Companies A and B have a rather processual step-by-step approach to strategy, whilst company C is more systemic in its approach in nurturing old customers.

None of the companies have an imaginative and creative approach to strategy. They are all very close to old customers and they do not go beyond responding to their demands. Thus any innovation is due to co-evolution with their customers.

Company A and C are enhancing the freedom to share ideas while company B's lean structures are inhibiting diversity to be connected.

Companies A and C focus on team decisions, while company B emphasizes top-down decision-making. In company A and C people are well connected into their activity networks, while in company B they function according to poorly connected activity networks emphasizing top-down control and thereby increasing unpredictability.

Companies A and C are facilitating co-learning. Due to lack of connected diversity company B is not facilitating expansive learning. And company C's more routine fashioned work is not really facilitating expansive learning necessary for making innovative products.

Companies A and C seem to have been complex enough to adapt well to their present situation.

Company B can be argued not to be complex enough to face future challenges.

In summary, we can say that B does not learn as well as A and C. It fails to discuss sufficiently the possible products, etc. and to iterate with customers, managers and engineers the possible problems, qualities, etc. This means that at every new product there is only marginal learning. A conversation could advance them several steps up the 'slope' of effective products. They are not learning more in the repetition of NPD whereas others that work with their customers are.

5. Conclusions

In this paper we have attempted to demonstrate the relevance of complexity science to innovation in terms of new product development processes. The key issue is that if a 'new product' is really 'new', then it automatically means that the designer or design team must go beyond a simple extrapolation of previous designs or products. Otherwise, this is merely product development not NEW product development. By stepping into the domain of the new, the NPD process is necessarily creative and not simply mechanistic. This means that the process at the initial time has different possible outcomes, and these will be explored to a greater or lesser extent by the NPD process. This process must therefore be one in which a new 'bundle' of components are discovered that give rise to a new set of performance attributes that satisfy the customer. This is why it is important that the customer and the design team interact sufficiently for the designers to show some of the possibilities, and for the customers to reflect on which new bundle of performance attributes is most attractive to them.

This means that potential new products are like different possible peaks in some multi-dimensional attribute space. The design team use underlying design concepts to decide on particular configurations of components that they think might deliver a satisfactory 'mix' of performance parameters. The customers will decide whether these are the right performance attributes, and also how much of which attribute they want at the expense of how much of which other. The trade-offs desired by the customer will depend on experience of the market, and of course can fail when some innovation is possible but has not yet been experienced. Similarly, the design trade-offs are a function of the underlying design concepts used, and these cannot be constructed by any deterministic process of marginal improvement. Design concepts, like having a car engine in the rear, putting the engine transversally and adopting front wheel drive, for example, are the results of creative flights of imagination, that cannot be anticipated by any 'incremental' process.

In evolutionary complex systems, new branches of evolution occur when the population of some new, deviant type, behaviour or strategy is amplified, and carves itself a place in the existing system structure (Allen, 1982). The structure as a whole is therefore characterized by a succession of temporary stabilities, separated by these instabilities. The temporarily stable structures we have called 'structural attractors', and the point is that which one of many that are probably possible happens to emerge at a given moments is not predictable. However, once a new structure does occur, it changes the probability of occurrence and of acceptance of any new deviant types, behaviours and strategies. This means that products, market sectors, markets and societies exhibit 'path-dependent' evolution, so that innovations that succeed change the future pattern of innovation occurrence and acceptance. The NPD process is at the 'sharp end' of this creative evolution, though risk aversion may well dictate very cautious decisions and designs, making most of NPD into Product Development and omitting the 'New'. While this seems risk averse and safe in the short term, clearly, in the longer term if other firms do innovate and create new products, new capabilities and embrace new technologies, then they will eliminate their more cautious competitors. Complexity science teaches us the generality of these conclusions, and can also help us set reasonable limits on how cautious, and how adventurous it is advantageous to be.

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