The Role of Innovation in a Consulting Engineering Firm

Science Dynamics
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1.0 Executive Summary

In an era when countries are searching for new forms of competitive advantage through technological innovation, the potential of the consulting engineering profession is usually overlooked. This is paradoxical, as engineering stands at the conceptual pivotal point between the processes of new idea generation and production. This positioning presents an opportunity to ensure that new products (both goods and services) are both market driven and well designed.

This paper reviews the engineering profession from two theoretical perspectives with the view to defining a strategy framework for integrating innovation processes into mainstream engineering activity. The paper uses general systems theory to depicts the conceptual environment of engineering practice and life cycle theory to construct a dynamic environment in which change can be anticipated and used for creating competitive advantage.

2.0 Introduction- the need for a theoretical framework

Although the literature on the management of innovation is quite extensive, it is generally recognised as lacking a comprehensive theoretical framework. By theory, we mean a succinct set of statements about the relationships between the basic components in a field of interest that are believed to be universal and which enable deductions about behaviour in particular cases. Without theory, analysis is of limited value and prediction is hazardous.

The discipline of strategic planning and management, which endeavours to provide theories about various aspects of the workplace is relatively new- in fact only a few decades old. Unfortunately, due to its limited success in real situations, it has come under attack in recent years and managers are turning to less rational approaches to addressing increasingly complex and difficult circumstances[1].

To scientists, this attitude seems to be faint-hearted. The history of science is replete with failed or limited theories, but is also has its successes. Some successes have been the inspiration of rare genius, but most have been the result of persistent application by dedicated and relatively ordinary people.

Theory enables greater efficiency and effectiveness in the deployment of available resources towards desired goals. Without theory, we are left to guesswork, cut-and-try or bald assertion by enthusiasts or vested interests- none of which is renowned for its efficiency.

Efficiency in achieving organisational goals can mean superior competitiveness if one's organisation has a greater ability to formulate, comprehend and apply theory than one's competitors.

The following, then, is an attempt to provide a theoretical framework for the management of technology, illustrated by its application to the area of management consultancy. By *theoretical framework* we mean something slightly less presumptuous than a universal theory, but something that is a formalisation and systematisation of many observations that suggests the likely shape of a theory.

3.0 Basic Concepts

3.1 General Systems Theory (GST)

Any environment can be depicted as a system. By this we mean:

a collection of related elements with a purpose.

(See Fig. 1). Almost anything can be thought of as a system. In the case of consulting engineering we can envisage the firm as a system comprising elements in the form of people, buildings, equipment software and documentation which are related for the purpose of providing advice to clients on the efficient design, construction and/or maintenance of *their* systems. These elements, or subsystems can be thought of in turn as being comprised of smaller elements, connected to serve a particular purpose. (Fig. 2). Alternatively, the environment outside the organisation can also be considered as a system, with our consulting engineering company as just one of *its* elements.

3.2 Codified and Tacit Knowledge

Of central importance to this model is our knowledge of each of the elements and the relationships between them. In reality much is not known- sometimes because we simply haven't taken the effort to find out more, but often because the knowledge is not accessible. We call the elements that can be enumerated and described in detail together with the logic of their relationships with other elements codified *or explicit knowledge*. If we can see the results of the knowledge, but can't describe the elements and relationships, we call it *tacit knowledge.* Most real systems are a combination of tacit and codified knowledge.[2]

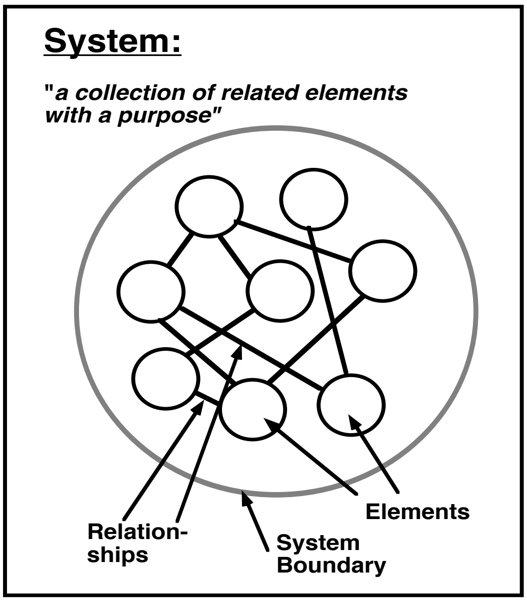


Fig 1: Definition of a system.

The common name for systems that are principally codified knowledge is *technology*. A common name for systems that are principally tacit knowledge is *art*. An important part of the scientific process is the transformation of tacit knowledge into codified knowledge. That is, technology is the result of the application of scientific processes to the elements.

The process of identifying and specifying the boundaries, elements, purpose and relationships of a system can be a useful exercise in itself. It is the first step in formalisation We frequently tend to overlook some components of a system and/or not think of them as an integral part of the system.

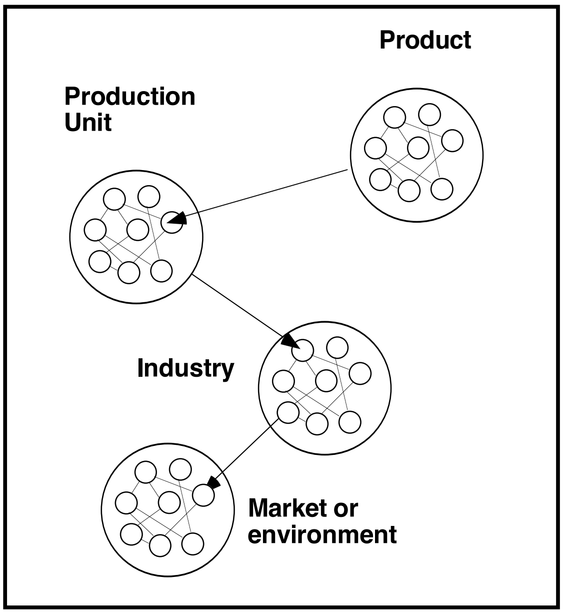


Fig 2: The 'nesting' of systems.

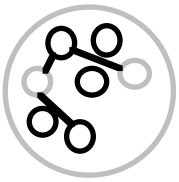
Sometimes we don't reflect deeply enough on the relationships between the elements and too infrequently do we pause to think what the purpose of the system is meant to be. Of course it can mean anything we like- just that we need to question the elements and relationships and what they could or should be to fulfil that particular purpose.

3.3 System Configuration- a Pattern Emerges

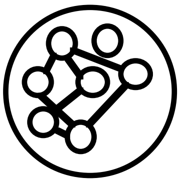
The capacity of a system to fulfil its purpose is very much determined by the systems configuration. By *configuration* we mean the particular pattern of relationships between the elements and the nature of those relationships. The pattern that we are interested in is the existence or absence of strong relationships between particular elements. In most practical systems, not all elements have direct relationships to all other elements. In other words, when a particular element performs an operation, it does not directly affect every other element, although it may eventually affect other elements through the consequences of its effect on elements with a direct relationship. For example, not everyone uses the photocopier in the office; the CEO only communicates with junior staff through executives and managers.

Of course, the more elements in a system, the greater the number of possible configurations. However, we find that in most viable or practical systems there are a limited number of basic patterns or configurations. These are displayed in Fig 3. In summary, the basic set of system configurations can be described as:

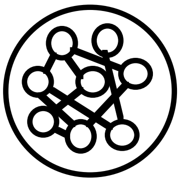
- pre-organisational



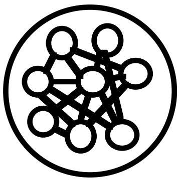
- early formation



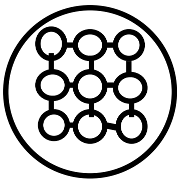
- experimental



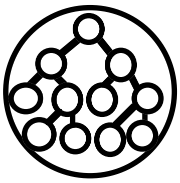
- entrepreneurial



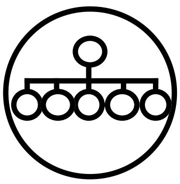
- matrix



- hierarchical



- corporate



- degenerate

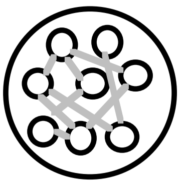


Fig 3: A taxonomy of archetypal systems.

Most people will quickly identify with these configurations and recognise that their organisation compares closely with one of them.

Importantly, these configurations are relevant to all kinds of systems, not just work-related organisations. They relate equally well to the "design" of artefacts or equipment or technology and also to other social structures. In fact all purposive systems seem to fit into one of the patterns and curiously, many non-purposive systems seem to fit too. (see Hurst and Zimmerman[3])

The important implication of configuration is that some configurations are better suited for achieving certain purposes than others. For example, in organisations, the “experimental” and “entrepreneurial” configurations are better suited to innovation than the hierarchical and corporate. Alternatively, the latter two are better suited to mass production than the former two[4].

3.4 Life Cycles

Not only do we find that most systems seem to conform to the above eight configurations, but we also find that systems seem to evolve in their configuration in the same way. We are familiar with the life cycles of living things, where change occurs from young and disorderly through vigorous growth to stable maturity and eventually senescence.

The configuration of systems rarely remains static for long. Configuration means the type of elements in the system, and the patterns of their interactions and relationships (See, for example, Mintzberg, 2009). While infinite variations of configurations of human activity systems are possible, the types of variations, and the sequence of stages in which those variations occur, frequently follow familiar patterns. This pattern is called the *system life cycle*, as the same patterns can be frequently observed in living things (Utterback, 1978).

In broad outline, systems that follow a life cycle pattern start small and disorganised, but with a new purpose, with some new elements and relationships, but most derived from existing systems. With time, systems grow in size and complexity, and show more order in their configuration. Also, with time, subsystems tend to coalesce and redundant features and functions tend to disappear. Importantly, a networked, "entrepreneurial" stage is later followed by a hierarchical, "mature" stage. Rather than stabilising at an apparently optimum (mature) configuration for their purpose, systems tend to become even more complex. This mature stage is followed by either a stage of re-simplification (revitalisation), or a slide into fragmentation. Sometimes, but not always, there is a degree of rejuvenation before the final decline. System "death" could be defined as a loss of purpose together with a loss of purposeful relationships between the elements.

Fig. 4 depicts the typical stages of a system life cycle. Different systems analysts interpret these changes by varying numbers of stages, from three to 20, with most using about eight, as in the present case. These are

- Information
- Invention
- Innovation
- Take-Off (or Diffusion)
- Shake-Out
- Maturity
- Revitalisation
- Decline

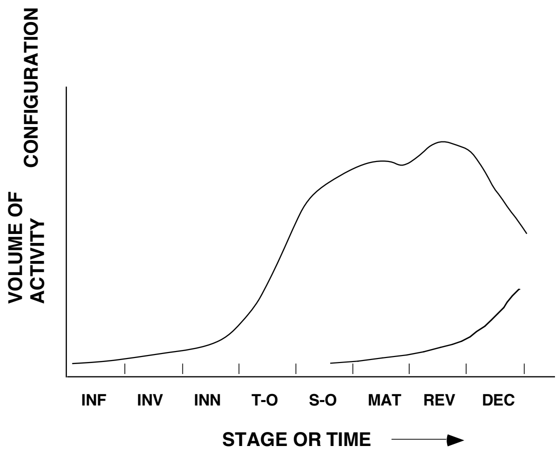


Fig4: The stages of a basic life cycle.

An important aspect of system life cycle theory is that the configurations of the various stages in most systems, and the sequence of configurations, are fairly predictable. Also, the choice of configuration (if choice is possible) will, to a large extent, determine the dynamics of the system (Mintzberg, 1990). This enables us to understand the system and at least remove a large element of the surprise that often accompanies the shift in configuration of systems. (Fig 5.) Even with this limited power of prediction, it may be possible to intervene to change the sequence, or capitalise on the changes.

Examination of multi-levelled systems will often show that each level is at a different life cycle stage. Much of the dynamism of systems emanates from the interaction between the different system levels, which can be viewed as a struggle for ascendency of purpose and form. Again, as the interaction between systems and subsystems at different stages follows similar patterns, we are able to make general statements about a particular system once it has been characterised.

The confluence of GST and LCT has come from several, apparently independent directions. Abernathy and Utterback (1978)[5] and others have started from a "product life cycle" approach, whereas Sterman (1985)[6], Nakayama (1987)[7] and Roobeek[8] (1987) and others have developed social life cycle theories based on Kuhn's (1970)[9] "paradigm" model.

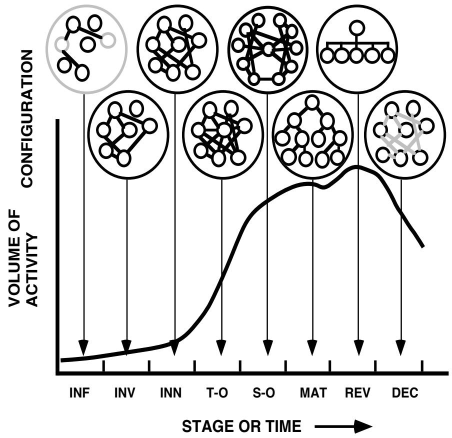


Fig 5. The positioning of archetypal systems on the life cycle.

4.0 Application to the Engineering Consultancy

Having established the general conceptual tools for analysing products, organisation and their environment, we can now look at the particular case of a consulting engineering firm.

There are a number of 'products' produced by the firm. The main one is reports based on monitoring and testing produced by a system comprising instruments, software and people, together with the machine being inspected. (This is important). All of these elements may have originated on different life cycles - the machine may be of a new or mature design, the instruments may be novel or mature, the engineers may be young or very experienced in this area and the 'software' may be a well known procedures manual on a new piece of analytical software as an adjunct to the instrumentation. As a 'product' it maybe novel or mature.

There are, therefore, a number of possible scenarios for development. Let us assume or the moment that a fairly novel problem has arisen and assume that the elements deployed in the process of the consultancy are at various stages of maturity- that is, some are mature and well codified (such as off-the-shelf equipment) and others partly codified (such as how to conduct the measuring process, and some are mainly tacit (such as the interpretation of output information). The process would then be to measure as many variables as practicable, process them by as many ways as resources permit and use whatever experience and knowledge available for interpretation. The results of this process (or the use of this 'product') might be to provide advice or repair and maintenance of the machine.

With time, given enough similar situations, the processes comprising this service can become codified and proceduralised. The certification of procedures, such as quality assurance through ISO standards is an example of standardisation or routinisation of procedures.

One might question where the innovative dimension resides in this situation. *Innovation* needs to be distinguished from *competitive advantage*, as a company may be competitive without obvious product innovation by being able to guarantee that its procedures are more uniform and reliable than its competitors. To some degree this ability will have a tacit dimension, called experience or skill, whereby the engineers know how to repetitively perform substantially codified but complex tasks correctly and efficiently. The innovative product in this situation is at the larger scale of the *total process*. Such "products" are competitive, by virtue of the difficulty of reproducing them when they embody a lot of tacit knowledge. This "service system" is in fact a kind of technology. However, by not being able to readily copy this system, competition is likely to remain limited.

In any real engineering service one sees the evolution of greater "mechanisation", or the transformation of tacit knowledge into codified knowledge. The sequence may be as follows: At first, data derived from measurements may be manually recorded and then repeated analytical steps are listed, followed by the algorithms related to these steps also being listed for ready computation. The algorithms may then be linked and embedded in computer code, so that the gathered data only needs to be entered into the computer and the partly aggregated results interpreted by the experienced engineer. The reading of dials on probes can be replaced by the digital output from the probes being directly entered into the computer. With time, more of the engineer's tacit knowledge can be codified, leading to more powerful and complete analysis and perhaps diagnosis of the system under inspection. The prescribed corrective action may also be embedded in the same system so that a fully automated control system is established.

This process may "freeze" at some stage, or continue to evolve. The human linkages may remain for a number of reasons:

- There may not be enough similar cases analysed to justify the investment in codification.
- The life cycle of each service may be too short to justify the investment.
- Competitive advantage may be more easily maintained by keeping some of the system knowledge only in the heads and bodies of the engineers.
- The company lacks the necessary skills to analyse the processes so that they may be efficiently codified.
- The company may be comfortable in the blend of people and technology and simply not wish to further systematise its services.
- The company may not have control over the codified knowledge (IP) of all of the elements, thus blocking system consolidation.

However, the trend to "mechanisation" or automation seems to be inexorable, leading to the dictum:

Yesterday's idea is today's software is tomorrow's hardware

Even if the whole system does not consolidate into a single technological artefact (Hardware), there will be a trend towards larger and larger "clusters" of elements within the total system envelope. (Fig 6.) Either in its totality or in part, the system will trend towards the "ideal" configuration of the "revitalisation" (or corporatist) stage, where integration is maximised with minimum subsystem redundancy and all elements and relationships codified. This is the "dream" of "high technology."

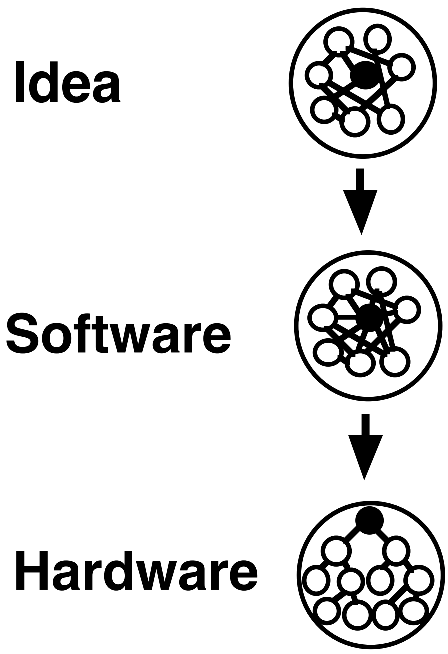


Fig 6: The systemic transformation of ideas into products.

In the early 1980s a British report observed a similar process happening with academic consultants. (Bullock, 1983)[10]. The consultancy started with a "product" of advice based on careful measurement and with time and repetition the product became more formalised or systematised eventually leading to an embodiment of the service in a device. This process was called a "soft entry path", as it enabled the academic to enter a market with very little capital to accompany his or her personal knowledge and skills and progressively increase the embodied component of the service. This compares with the traditional "hard entry path" where market entry is based on the capital intensive development of intellectual property. This same process happens to some extent in all service-oriented industries, as described in the next section.

6.1 The Supplier-User Relationship Model

The model[11] as illustrated in Fig 7 is most clearly depicted as a sequence of interactions or relationships, unfolding over time, between two groups:

- Suppliers (or technical problem-solvers); and
- Users (of the supplied solutions to improve their businesses).

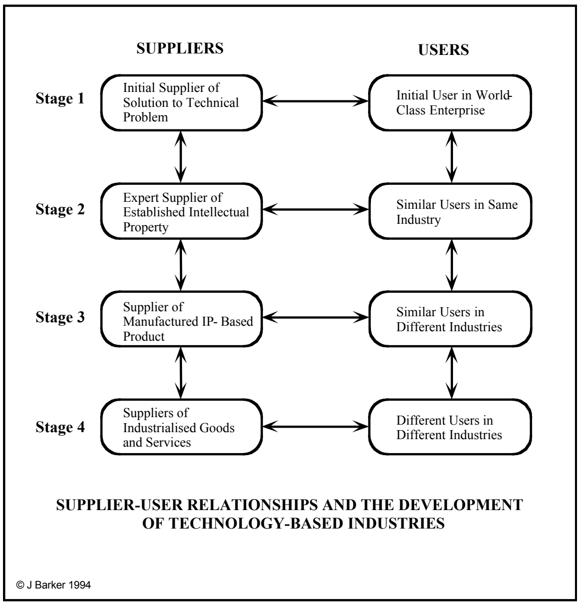


Fig. 7: The Supplier-User Relationship development model.

1. In Stage 1 a major company identifies a problem in its production chain for which an off-the-shelf solution does not exist. A solution is required to enable the company to maintain or improve its international competitiveness. Although production problems are often resolved in-house, external expertise is sometimes required to solve the problem. A problem-solver (called a 'supplier') is identified and contracted to work on the problem. The solution to the problem is new knowledge, in the form of either a new, patentable product (intellectual property), or, more commonly, know-how (intellectual capital). The relationship between suppliers and users is highly interactive in this first stage and the 'solution' is in a form that is useable only by the user-company.

2. In Stage 2, by solving the problem, the supplier has gained experience and has developed a 'product' that may be of value to other companies in the same industry with the same problem as the first company. Thus, further sales of the 'solution' or product may ensue, with the supplier gaining experience, and growing on the proceeds of these sales. The 'product' at this stage is usually in the form of 'consulting services'- a combination of codified and tacit knowledge, as described earlier as being typical of engineering services. Interactive relationships tend to be strongest between the initial supplier and the expert supplier who 'packages' the knowledge in a form that can be readily used industry-wide.

3. In Stage 3, the supplier identifies companies in other industries who may also have use for the same or similar products. The growing market for the 'product' enables it to be developed into a standardised form as manufactured hardware or software.

4. In Stage 4, the supplier has gained experience, reputation and a range of products. At this stage the supplier may realise the potential to diversify, having developed a range of skills and experience that may be saleable individually, as well as collectively in a 'product'. By this final stage the supplier has usually attracted competitors as well as collaborators, and what may have started out as a one-on-one relationship between a supplier and a user has evolved into a host of new companies that not only maintain the competitiveness of the original major industry, but also create new products for other industries - in other words, a new industry has been born.

An important aspect of this model is that the elements on the left side can be viewed as the stages of technology development as new knowledge is first formed into a service, then a product, followed by a company then an industry. The process of knowledge flow and development down the left side is generally called *technology transfer*. The elements on the right side can be viewed as the development of the market for new knowledge from a first, discerning customer to a widespread market. This development is often called *market diffusion*. The arrows that connect both the vertical and horizontal flows are double-ended, indicating that the flow of knowledge in both directions is important.

6.2 An Example

The remote sensing industry in Western Australia is now significant and flourishing. It began many years ago in the form of air-borne photogrammetric interpretation of aerial maps and photos for agriculture and mining. With the advent of satellite imagery and spectrally selective sensing in the 1980s, further opportunities emerged for more sophisticated analysis, bringing benefits to mineral exploration, agriculture and environmental monitoring in the State. Local scientists, originally from CSIRO, Curtin University and the State Government have been able to develop new techniques and technologies that have been adopted by commercial companies to serve both local and international markets. What started as a modest technical service to local major industries has now become a major export of technical products and services in its own right. The willingness of local mining companies and government land-management agencies to use these services has been crucial in the development of this export industry in Western Australia and elsewhere.

6.3 Relevance of the model to consulting engineering

Consulting, by definition, is a service based on expert knowledge. It is problem solving which is principally the application of the results of previous practical experience and codified knowledge related to similar problems, as depicted in Stage 2 of the model. Traditionally, consultants, particularly in engineering, based their problem solving on 'mature' knowledge that was embodied in codes of practice and handbooks. Increasingly, consultants are working closely with researchers and sometimes the consultant is the researcher working in this modality. Sometimes the problem calls for solutions based on the tacit knowledge of the researcher (ie contextual knowledge that has not been codified in publications), but more often the knowledge has not yet diffused from publications into general practice. Thus, a close relationship is required between the researcher and the consultant to ensure that the available knowledge is transferred. Given the relative novelty of the knowledge in these situations, it is likely that new problems requiring further research will arise with some clients. The close relationship between consultant and researcher can therefore work in both directions- the researcher providing further codification of the results of previous research and the consultant providing new research opportunities to the researcher. This may result in further improvement to the knowledge set of the consultant, or new opportunities for other consultants. In the model, all relationships are depicted by two-way arrows, signifying that knowledge from any stage can, in principle, be transmitted to the previous or subsequent stage.

Consultants are, therefore, potentially in a pivotal position in the development of new knowledge-based products. Having a large client base (compared with most researchers), they can identify recurring problems for which satisfactory solutions do not yet exist. This 'awareness' can be viewed as 'market' information for the development of new knowledge based products so long as the consultant can transfer this knowledge to a Stage 1 problem solver. The emergence of 'engineering science' a discipline is a reflection of the growing need for intimate connections between research and practice in many areas of economic activity.

7.0 The Place of Research in the Organisation

To some extent, innovation will occur quite readily and spontaneously in most organisations where skills and knowledge are valued. As indicated above, without planning and management, innovation may remain at the elemental or subsystem level, or be frustrated from achieving its full expression for a range of reasons. Given this "natural" drift of systems towards greater codification, the challenge of the enterprise is to manage the change in ways that suit its mission (ie "purpose") and agreed competitive strategies. The managed process of codification is essentially what we call *research and development*.

How to optimise this process is a vexing question and libraries contain many books and journals addressing the issue from many directions. In the context of this paper we focus on the organizational structural issues. Pierre Dussauge in his 1992 book *Strategic Technology Management* provides a detailed analysis of the different kinds of structures that enterprises adopt in their attempt to maximise the benefits of R&D[12]. Redolent of Burns and Stalker[4], he poses the problem thus:

How can the company simultaneously achieve efficiency in its existing operations (incremental change) as well as effective repositioning and innovation (radical change)? Differentiation of functions facilitates the maintenance of deep expertise and the generation of new knowledge but makes the fast and efficient transfer of technology or new ideas difficult at best. Integration of technical capabilities, however, has the inadvertent effect of overcommitting the organisation to the existing technological paradigm. (Dussauge p156)

Dussauge describes five generic structures that are employed by large technology- driven companies. They are:

- Intrapreneurship
- Skunkworks
- Matrix
- Independent Business Unit
- New Venture Department

He describes the structure, management, staffing and motivation in the context of the degree of differentiation within the organisation. The above list is from low to high differentiation, from little to great in the extent of new knowledge created and from intrinsic to extrinsic rewards for achievement. Although there are lessons to be derived from Dussauge's analysis for firms of all sizes, the focus, as usual in the literature, is on large companies. He draws examples from General Motors, Apple, IBM, Hughes Tool and du Pont. All of these companies are characterised by elaborate hierarchical structures with many division and levels. Very little is known about R&D in the Small to Medium-sized Enterprise (SME), probably because the Fortune 500 companies are more likely to sponsor management research than small companies.

Clearly, SMEs of, say, forty to fifty staff cannot have a hierarchical structure as elaborate as General Motors. However, small companies may still have a surprising degree of differentiation, and consulting organisations may be little more than co-located individuals, all doing their own thing. Combining this expertise to develop new products and processes may be as challenging as it is in General Motors.

It is most likely that the Consulting Engineering Firm, as an SME will have a moderate degree of differentiation, with a small groups specialising in different areas, offering somewhat different services to clients.

Does the manager allow an engineer with a good idea to form a "skunkworks", where he or she and several support staff work through the innovative process before returning to "normal duties"? How is the existing client base maintained during that time and how is the new product maintained after production starts. (It is important to recognise that product innovation does not, or should not cease after market introduction).

Or does the manager establish a separate R&D division, which picks up the ideas from other staff and expedites them efficiently through their greater knowledge of the processes of R&D? Again, the benefits of functional efficiency are offset against the problems, and therefore costs, of establishing and maintaining effective communication between this group of "wonks" and the "practical people" in the field.

Matrix management of research may be possible if the R&D can be viewed as one project amongst a number that a group may be engaged in. In this case the tasks are allocated and each may spend part of their time on the research project and part of their time in the field on other projects. Matrix management is renowned for its problems due to staff having more than one manager.

8.0 Conclusion

Viewing the world as a series of systems can help to identify and distinguish between the many active parts in a real situation. The distinction between tacit knowledge and codified or explicit knowledge can help give a sense of the goals of science and its practical form of R&D. Knowing that the constant quest for "understanding" (in the Western Philosophical sense of the word) through codification impels systems towards greater differentiation or "maturity" can provide some useful predictive capability.

In summary, there is no unique solution to structuring an organisation so that R&D is conducted efficiently and effectively. Further, none of these solutions is particularly durable within an organisation. Innovation, by definition, is disruptive of orderly processes and confronts the establishment with the inadequacies of its present way of viewing the world. However, being aware of the nature of the structure and dynamics of innovation can not only mitigate the anxieties that accompany inevitable change but also enable one to induce change in directions that will profit the organisation.

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