INFORMAL BOUNDARY-SPANNING LINKS AND NETWORKS IN SUCCESSFUL TECHNOLOGICAL INNOVATION

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Doctor of Philosophy

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SUMMARY

The sources of ideas embodied within successful technological innovation has been a subject of interest in many studies since the 1950s. This research suggests that sources external to the innovating organisation account for between one and two-thirds of the inputs important to the innovation process. In addition, studies have long highlighted the important role played by the personal boundary-spanning relationships of engineers and scientists as a channel for the transference of such inputs. However, research concerning the role and nature of personal boundary-spanning links in the innovation process have either been primarily structurally orientated, seeking to map out the informal networks of scientists and engineers, or more typically, anecdotal.

The objective of this research was to reveal and build upon our knowledge of the role, nature and importance of informal exchange activity in the innovation process. In order to achieve this, an empirical study was undertaken to determine the informal sources, channels and mechanisms employed in the development of thirty five award-winning innovations. Through the adoption of a network perspective, the multiple sources and pluralistic patterns of collaboration and communication in the innovation process were systematically explored. This approach provided a framework that allowed for the detailed study of both the individual dyadic links and the morphology of the innovation action-sets in which these dyads were embedded.

The research found, for example, that the mobilisation of boundary-spanning links and networks was an important or critical factor in nineteen (54%) of the development projects. Of these, informal boundary-spanning exchange activity was considered to be important or critical in eight (23%). Economic exchange theory was shown to provide only a partial explanation of the incidence of such informal exchange activity. Indeed, informal exchange behaviour was found to be linked more closely to the membership of the dyads and the social structure in which they were embedded.

Key Words: Innovation Process, Sources of Ideas, Personal Links,
Informal Exchange Activity, Communication Channels.

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> "It's just Eeyore," said Piglet. "*I* thought your Idea was a very good Idea."
>
> Pooh began to feel a little more comfortable, because when you are a Bear of Very Little Brain, and you Think of Things, you find sometimes that a Thing which seemed very Thingish inside you is quite different when it gets out into the open and has other people looking at it. And, anyhow, Eeyore *was* in the river, and now he *wasn't*, so he hadn't done any harm.
>
> A.A. Milne *The House at Pooh Corner*, 1928

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CHAPTER ONE: INTRODUCTION

1. The Origins and Sources of Technological Innovation

The origins and sources[1] of technological innovation have been a subject of interest in many studies since the 1950s. Early concerns focused on the utility of basic science[2] to technological innovation (Carter and Williams 1957, Sherwin and Isenson [Project Hindsight] 1967, Illinois Institute of Technology [TRACES] 1968, Battelle Memorial Institute 1973, Gibbons and Johnston 1974) and the importance of sources external to the innovative firm (Myers and Marquis 1969, Achilladis *et al* [Project SAPPHO] 1971, Langrish *et al* 1972). However, whilst this research suggested that external sources account for between 34% (Gibbons and Johnston 1974) and 65% (Langrish *et al* 1972) of the inputs important to the innovation process, evidence of the utility of basic science to technological innovation was mixed[3].

TABLE 1.1: A Summary of Studies Illustrating the Importance of External Sources to the Innovation Process

Study	% of Important Inputs Derived Externally
Myers and Marquis (1969)	48
Utterback (1971)	47
Langrish *et al* (1972)	65
Gibbons and Johnston (1974)	34

Variations in the importance of external sources to the innovative firm have been identified between industrial sectors[4] (Carter and Williams 1957, Myers and Marquis 1969, Easingwood 1986, Sowrey 1989), between product and process innovations[5] (Baker *et al* 1985), between large and small firms[6] (Allen *et al* 1983), between the idea-generation and problem-solving stages of the innovation process[7] (Myers and Marquis

1969, Utterback 1971, Allen 1977), and between *basic* or *radical* innovations, and major and minor improvements, termed *re-innovation*[8] (Hippel 1976, 1977a, Spital 1979, Rothwell and Gardiner 1985, Shaw 1985,1993, Rothwell 1986).

A diverse range of external sources have been found to contribute to the development of successful innovation, including academia, government research laboratories, suppliers, competitors, users, consumers and distributors. Studies have shown users, in particular, but also suppliers and competitors as playing an important role in the innovation process (see Conway 1993a and 1993b for a review of the literature). Research has even shown the continuing significance of the independent inventor as a source of innovative ideas leading to successful innovations in larger firms (Enos 1962, Jewkes *et al* 1969, Udell 1990, Whalley 1991). However, cross-sector studies (*e.g.* Langrish *et al* 1972) have suggested the limited importance of academia as a source of ideas and information.

Contrary to expectations, research as early as the 1960s (FBI 1961) revealed that external sources, such as research associations, and licensing and technical knowhow agreements, for example, were as important to innovators with in-house R&D as to those without. That is, external sources are an important complementary source of scientific and technical information rather than a substitute for indigenous innovative activity. Indeed, Freeman (1991,501) argues that "the successful exploitation of imported technology is strongly related to the capacity to adapt and improve this technology through indigenous R&D". And this is as true at the national level as at the firm level. In addition, Cohen and Levinthal (1989,569) suggest "that R&D not only generates new information...[but] also develops the firm's ability to identify, assimilate, and exploit existing knowledge from the environment", what they term the *two faces* of R&D. This view receives support from a number of studies including Rothwell *et al* (1974), Rosenberg (1990), Pavitt (1991) and Gambardella (1992).

TABLE 1.2: A Summary of Studies Illustrating Variations in the Dominant Locus of Innovative Activity Between Sectors (Adapted from Hippel 1986)

Study	Industrial Sector	% of Innovations Developed by:		
		User	Manu	Other
Enos (1962)	Petroleum Processes	43	14	43[a]
Knight (1963)	Computer Innovations - performance - radical	 25 33	 75 67	
Hollander (1965)	DuPont Process Innovations	67	33	
Freeman (1968)	Chemical Processes	70	30	
Berger (1975)	Engineering Polymers	0	100	
Boyden (1976)	Plastics Additives	0	100	
Hippel (1976)	Scientific Instruments - Basic Innovation - Major Improvements - Minor Improvements	100 82 70	0 18 30	
Hippel (1977a)	Semiconductor and Electronic Subassembly Manufacturing Equipment - Basic Innovation - Major Improvements - Minor Improvements	 100 63 59	 0 21 29	 16[b] 12[b]
Lionetta (1977)	Pultrusion Processing	85	15	
Spital (1979)	Scientific Instruments - Major Improvements - Minor Improvements	 50 17	 50 83	
Vanderwerf (1982)	Wire-stripping and Connector Equipment	11	33	56[c]
Vanderwerf (1984)	Industrial Gas Equipment	42	16	42[d]
Vanderwerf (1984)	Thermoplastics Equipment	43	14	43[d]
Shaw (1985)	Medical Equipment	53	47	
Voss (1985)	Applications Software	32	68	

KEY: [a] Attributed to independent inventors/research companies.
[b] Attributed to joint user-manufacturer developments.
[c] Attributed to connector suppliers.
[d] Suppliers accounted for around 80% of these innovations.

Research has also highlighted variations in the locus of innovative activity between industrial sectors (see Table 1.2 on previous page for a summary of research findings). That is, in some instances external sources not only provide a large proportion of the inputs into the innovation process, but are in fact the dominant innovators within an industry rather than the commercialising organisations or manufacturers. Users have been shown to play a significant role in the innovation process within the oil industry (Enos 1962), the chemical industry (Freeman 1968), the semiconductor, scientific instruments and electronic sub-assembly industries (Hippel 1976,1977a), and the medical equipment industry (Shaw 1985, 1993). Whilst studies in the materials industry (Corey 1956, Peck 1962), and subsequent investigations of the industrial gas, thermoplastic and wire-preparation equipment sectors (Hippel 1988, Vanderwerf 1990) have highlighted the importance of suppliers as a source of innovation.

It has been hypothesised that the observed variations in the locus of innovative activity across industries could be explained by differences in economic incentives (Hippel 1982,1988, Vanderwerf 1992). Other factors may include variations in the locus of *state-of-the-art* expertise and the nature of technology within a sector. Shaw (1985,290), for example, in his study of medical equipment innovations in the UK noted the dominance of the user in the development of basic innovations and major improvements. This he believes "should be expected where *state-of-the-art* clinical and diagnostic knowledge resides with the user, and the user has a high probability of deriving *output-embodied* benefit from the innovation".

2. The Sources of Technological Innovation Stimulus

A number of studies since the 1960s have also attempted to determine the nature and source of the stimuli leading to the initiation of successful innovation (Peplow 1960, Baker *et al* 1967, Myers and Marquis 1969, Utterback 1971, Rothwell *et al* [Project SAPPHO II] 1974, Baker *et al* 1985).

An innovation may be said to be *means-stimulated* or *need-stimulated* (Utterback 1971). These terms are synonymous with the concepts of *technology-push* and *market-pull*[9]. Myers and Marquis (1969) subdivided need-stimulated events further into market, production and administrative factors. The stimulus for a given innovation may be seen to arise from within the innovative firm or to originate externally, often from a customer and sometimes articulated as a specific product idea rather than a general need.

Research has indicated that between two-thirds and three-quarters of innovations are need-stimulated (see Table 1.3 below for summary of findings), and that there is a positive correlation between need-stimulated innovation and commercial success (Utterback 1971, Rothwell *et al* 1974).

TABLE 1.3: A Summary of Studies Illustrating the % of Innovations Stimulated by *Need* versus *Means* (Adapted from Utterback 1974)

Study	% Need-Stimulated	% Means-Stimulated	Sample Size
Carter and Williams (1957)	77	27	137
Baker *et al* (1967)	77	23	303*
Myers and Marquis (1969)	78	22	439
Utterback (1971)	75	25	32
Langrish *et al* (1972)	66	34	84

KEY: * Ideas for new products and processes.

Variations may however exist between industrial sectors and between types of innovation. A study by Baker *et al* (1985) in the USA, for example, found that customers were more likely to suggest new product projects than new process projects, whilst this situation was reversed for in-house R&D personnel. While Utterback (1971), in his investigation of the scientific instrument industry in the Massachusetts area, found that external sources accounted for approximately 55% of both the means and need-stimulating inputs to the innovation process.

3. <u>The Mechanisms or Modes of Transfer of Ideas and Information</u>

The innovation literature also reveals a strong interest since the early 1960s in the *mechanisms* of idea and information transfer. The primary focus in the 1960s centred upon the mapping out of the communication patterns of scientists and engineers, and the identification of the principle mechanisms by which these actors received ideas and information (Menzel 1962, Bernard *et al* 1963, Shilling and Bernard 1964, Allen and Cohen 1969, Allen 1969,1970,1977, Rosenbloom and Wolek 1970). The 1970s saw a shift in emphasis away from this interest in more general inventive activity, to the concern of identifying those mechanisms employed to transfer ideas and information in the development of specific innovations (Myers and Marquis 1969, Utterback 1971, Langrish *et al* 1972, Gibbons and Johnston 1974).

This body of research has identified a number of mechanisms for the transference of ideas and information across the organisational boundary, including: the hiring of new staff, termed *boundary-crossing* (Aldrich 1979); the use of scientific and technical journals, and trade publications, termed *formal* literature (Allen 1977), and in-house publications, termed *informal* literature (Allen 1977); formally established meetings and conferences; field-tests; and informal person-to-person modes of communication such as telephone or corridor conversations, correspondence and visits. Kelley and Brooks (1991) dichotomize these mechanisms into *active*, referring to those modes of transfer involving personal interaction, and *passive*, referring to textual material.

Burns (1969,12) has argued that "the mechanism of technological transfer is one of agents, not agencies; of the movement of people among establishments, rather than the routing of information through communication systems". This view has received some empirical support, most notably from Langrish *et al* (1972) in their study of innovations that had gained the Queen's Award for Industry in 1966 and 1967. In this study they found that the major mode of transfer was via a person joining the company, accounting for 20% of the key ideas obtained from external sources. In addition, studies by Roberts and Wainer (1971) and Roberts (1969), concerning spin-offs from research at MIT, found that the displacement of academic staff was crucial to the success of technology transfer to the commercial sector.

In addition, Katz and Allen (1982,7) in their investigation of the *Not Invented Here (NIH) Syndrome*[10] found that performance increased in stable project groups of up to 1½ years tenure, remained steady for a time, but noticeably declined after 5 years. They argue that this is because stable project teams become "increasingly cohesive over time and begin to separate themselves from external sources of technical information and influence by communicating less frequently with professional colleagues outside their teams", such that it begins to become "increasingly complacent about outside events and technology developments" and "to believe it possesses a monopoly of knowledge of its field".

However, a number of other studies have indicated the importance of personal boundary-spanning contacts and formal literature, particularly in relation to idea-generation rather than problem solving, where internal sources are more important (Myers and Marquis 1969, Utterback 1971, Allen 1977). The role and incidence of so-called *boundary-spanners*[11] are discussed in section 4 of Chapter 2. In their study of 567 innovations across five industrial sectors, Myers and Marquis (1969) found that boundary-spanning contact accounted for 30% of the inputs that evoked the idea for the innovation and 17% of those inputs that expedited the solution. Formal literature accounted for 7% and 6% of the inputs, respectively. In addition, Utterback (1971) found that 44% of the means and need-stimulating inputs, and 28% of all inputs to the 32 innovations studied, arose from external discussion: formal literature accounting for 15% and 13% of inputs, respectively.

Research by Hippel (1976,1977a,1977b) of manufacturer-user relationships placed most emphasis on *multiple and continuous* interaction, while Shaw (1985,290) notes that the "dominance of personal contact...within a very efficient informal and formal networking system", in relation to his study mentioned earlier.

An interesting study by Menzel (1962) on the information-gathering behaviour of biochemists, chemists and zoologists in an American university, revealed a variety of unplanned mechanisms through which ideas and information came to light accidentally in informal discussion. These mechanisms are discussed in section 5.2 of Chapter 2. A further study of 430 engineers and scientists within a large American electrical corporation by Rosenbloom *et al* (1964), found that in one-third of the instances where useful technical information was obtained from outside an individual's division, the acquisition had occurred by chance. These studies reinforce the importance of personal contact and discussion in the innovation process.

4. The Channels or Modes of Linkage with External Sources of Ideas

In his review of the literature, Freeman (1991,500) noted that empirical studies of innovation since the 1950s had demonstrated "the importance of both formal and informal networks, even if the expression *network* was less frequently used", and that "multiple sources of information and pluralistic patterns of collaboration were the rule rather than the exception". In this paper, Freeman also attempts to classify the various patterns of collaboration or what he terms *categories of network* relevant to innovation (see Table 1.4 overpage). Whilst this classification is essentially a list of dyadic or triadic relationship forms between organisations, DeBresson and Amesse (1991,364) argue that "because interactions between firms...are iterative and broad in content, time and space, what matters is the complete set of relationships". Hence these categories can be seen as components of the overall network of an organisation.

With reference to a number of studies undertaken since the mid-1980s on the changing patterns of collaboration in the last decade or so, Freeman (1991,507) argues that:

> "In quantitative terms there is abundant evidence of a strong upsurge of various forms of research collaboration [categories 1-5 in Table 1.4], especially in the new generic technologies...involving extensive international collaboration as well as national and regional networks. There is also ample evidence of a *qualitative* change in the nature of the older networking relationships which have existed for a long time [categories 6-8 in Table 1.4]."

TABLE 1.4: The Modes of Linkage Between Innovating Organisations and External Sources of Ideas in the Innovation Process (Freeman 1991).

Category Number	Mode of Linkage
1	Joint Ventures and Research Corporations.
2	Joint R&D Agreements.
3	Technology Exchange Agreements.
4	Direct Investment Motivated by Technology Factors.
5	Licensing and Second-Sourcing Agreements.
6	Sub-contracting, Production-Sharing and Supplier Networks.
7	Research Associations.
8	Government-Sponsored Joint Research Programmes.
9	Computerised Data-Banks and Value-Added Networks for Technical and Scientific Interchange.
10	Other Networks, including Informal Networks.

Freeman (1991,507) also notes that while computerised data banks and computer networking [category 9 in Table 1.4] provide entirely new and potentially important forms of research collaboration, "in-depth studies of the experience of data banks and value-added networks are still few and far between". Freeman (1991) does however cite a small number of interesting studies, including: Bar and Borrus (1989), who review the use of various forms of computer networking in innovative US companies; and Kooij (1990), who looks at the role of computer networking in the Japanese system. In addition, Webster (1993) examines the issues associated with EDI in relation to other forms of collaboration, in particular, supplier networks (category 6 in Table 1.4).

In relation to the last category in Table 1.4, a number of studies have indicated the importance of informal person-to-person communication channels and networks to the innovation process (*e.g.* Johannisson and Peterson 1984, Leonard-Barton 1984, Lawton-Smith *et al* 1991, Kreiner and Schultz 1993, Shaw 1993). However, this research has been typically anecdotal in nature. This view is supported by Freeman (1991,500-502), who argues that "although rarely measured systematically... informal networks [category 10] are extremely important, but very hard to classify and measure".

In addition, whilst research in the 1960s and 1970s frequently utilised the network concept to map out the communication patterns of scientists and engineers (Allen 1970,1977, Frost and Whitley 1971), the 1980s and early 1990s have seen the application of the network metaphor almost exclusively at the organisation-level (*e.g.* Hakansson 1989, Hagedoorn and Schakenraad 1992). Contemporary interest has thus focused largely upon the analysis of formal networks of innovating organisations within and between industries, regions and nation states (see DeBresson and Amesse 1991, and Freeman 1991, for a review), at the expense of informal networks at the level of the individual. Yet, as Freeman (1991,503) argues:

> "Behind every formal network, giving it the breath of life, are usually various informal networks...Personal relationships of trust and confidence (and sometimes fear and obligation) are important both at the formal and informal level...For this reason cultural factors such as language, educational background, regional loyalties, shared ideologies and experiences, and even common leisure interests, continue to play an important part in networking. An appreciation of these sociological factors in both formal and informal networks is a necessary complement to narrower *economic* explanations."

This view is acknowledged by others, including Lundvall (1988), Bianchi and Bellini (1991), and Saxenian (1991).

5. The Research Problem

The existing innovation literature has thus demonstrated unambiguously the importance of external sources in the development of successful innovation and highlighted the vital role of informal boundary-spanning interaction between individuals in this process. There is also a recognition that sociological factors are an important but neglected aspect in the analysis of formal and informal relationships and networks. However, as Freeman (1991) notes, there is a need in the literature for a more systematic analysis of the informal mechanisms, channels and networks employed in the innovation process to supplement existing studies.

This research is therefore intended to build upon the preoccupations of earlier studies - the identification of external sources, the nature of information transferred, and the modes of transfer and linkage (*i.e.* mechanisms and channels) - to focus upon the characteristics of the informal boundary-spanning relationships (their origin, nature, and underlying structure, for example), and the morphology of the networks identified, since DeBresson and Amesse (1991,371) argue that "innovation networks need a typology".

The research problem is to combine an approach which engages with the "multiple sources of information and pluralistic patterns of collaboration" (Freeman 1991,500), with one which reduces this complexity to a level of analytical manageability. In order to address this issue, the social network literature was drawn upon heavily (*e.g.* Mitchell 1969, Boissevain 1974, Laumann and Pappi 1976). This led to the adoption of the concept of *action-nets* as the framework for analysis. A action-net is the set of dyadic relationships "isolated in terms of a specific short-term instrumentally-defined transactional content" (Mitchell 1969,40): which in this research project refers to the inputs into the development process of specific innovations. This framework allows for the study of both the individual links, between source and recipient of such inputs, and the overall form or morphology of the action-set network.

6. Review of Chapters

This chapter has attempted to provide a concise and structured precis of the innovation literature concerning: the sources of ideas and information in the innovation process; the sources of innovation stimuli; the modes of transfer (mechanisms) of ideas and information; and the modes of linkage (channels) with external sources. From this discussion, a *niche* was identified for further investigation.

The following two chapters draw heavily upon network theory, with reference to the sociology, organisational sociology, and social anthropology literatures. Chapter 2 focuses initially upon the properties of dyadic relationships, such as *intensity*, *reciprocity*, *structure* and *multiplexity*, and the nature of *transaction content*. The focus then shifts to a more detailed discussion of *cognitive* transaction content before reviewing the concepts of *boundary-spanning*, *boundary-crossing*, and the role and incidence of *boundary-spanners* and *gatekeepers*. The chapter closes with a discussion of *link-pins*, *bridges* and *liaisons* as distinctive types of links between actors, noting the potential strategic importance of such *weak-ties* to the innovation process. Chapter 3 moves on to discuss the structural characteristics or morphology of networks, such as *size*, *density*, *stability* and *centrality*. The concepts of *partial-networks*, *action-sets*, *focal-nets*, *transaction* and *attribute-defined networks* are also introduced. There then follows a review of the literature concerning the social organisation of scientists, engineers and entrepreneurs.

The methodological aspects of the research are reviewed in Chapter 4. Of particular interest in this chapter are the issues relating to the selection of the sample of innovations studied; the setting of the boundary of analysis in the construction and mapping-out of the action-set for each innovation; and the problems involved in identifying weak-ties. The chapter closes with a discussion of the three elements of qualitative data analysis (data reduction, data display and conclusion drawing), in relation to this study.

Chapter 5 provides a brief introduction to the innovations investigated in the study: indicating the nature of each innovation, the innovator and the innovation award received.

The subsequent three chapters discuss the findings of the research project. Chapter 6 presents the results in relation to the role, locus and *exchange value* of the identified boundary-spanning inputs into each of the developments investigated. The following chapter then focuses on the role, nature and *exchange value* of the informal boundary-spanning activity in these projects. Chapter 7 then presents the findings with respect to the nature of the identified boundary-spanning dyads, and attempts to explain the incidence of informal exchange. The emphasis then shifts in Chapter 8, from a focus on transaction content and dyads, to that of networks. The chapter first presents the results concerning the morphology of the constructed action-sets, and then analyzes the incidence and importance of strategic links and the types of *attribute networks* that they link the innovator to.

Finally, Chapter 9 summarises the findings of the study and discusses their implications for the management of innovation, with particular emphasis placed on the management of critical, personal boundary-spanning links. The chapter concludes by identifying various opportunities for further research arising from the research.

Notes

[1] Although used synonymously in much of the innovation literature, a distinction is made here between the terms *origin* and *source*. *Origin* refers to the original locus of an input into the innovation process, whereas as *source* refers to the direct source from which an organisation obtained that input. Studies such as Project Hindsight (1967) and TRACES (1968), discussed below, did attempt to trace the origins of technological innovation. However, the majority of innovation studies have attempted only to identify the sources rather than the origins of ideas leading to technological innovation (*e.g.* Myers and Marquis 1969, Utterback 1971, Langrish *et al* 1972).

[2] A common distinction is made here between *basic science* and *applied science*. Basic science refers to research undertaken with no specific application in mind, and is sometimes known as *fundamental science*, *phenomenon-orientated science*, *non-mission-orientated science* or *undirected research*. In contrast, applied science is viewed as mission-orientated research.

[3] A number of attempts were made in the late 1950s to early 1970s to determine the utility of basic science to innovation. Two studies of particular note are Project Hindsight (Sherwin and Isenson 1967) and TRACES (Illinois Institute of Technology 1968),

undertaken in the USA. The former, sponsored by the Department of Defence, studied the science and technology employed by the department in the development of 20 post WW II weapon systems. The results of Project Hindsight suggested that undirected research played a very minor role in innovation, accounting for only 0.3% of R&D events. The latter, sponsored by the National Science Foundation, partially in response to the results of Project Hindsight, attempted to trace the key historic events which contributed towards 5 major technological innovations. TRACES found that 70% of all key events identified were *non-mission research events*. These contradictory results were largely due to the time horizon employed in these studies, with TRACES extending the time horizon further back. A follow up to TRACES (Battelle Memorial Institute 1973) supported the results of the original study.

[4] For example, studies of innovation in consumer goods (Sowrey 1989) and the services sector (Easingwood 1986), found that external sources were less important than for industrial goods, accounting for 32% and 35%, respectively.

[5] For example, a study by Baker *et al* (1985) in the USA, found that customers were more likely to suggest new product projects than new process projects, whilst this situation was reversed for in-house R&D personnel.

[6] For example, a study by Allen *et al* (1983) of 102 small firms in three countries (Ireland, Spain and Mexico), across 8 industrial sectors, found that 83% of all technology was acquired from external sources. This is far higher than indicated in the studies summarised in Table 1.1, which include a spread of SMEs and large firms.

[7] For example, a study by Myers and Marquis (1969) of 567 innovations, found that the major input in 414 of the cases had been the input which expedited the solution, while in 153 of the cases it had been the input that had evoked the basic idea for the innovation. Of these major inputs, 29% and 50%, respectively, were sourced externally, with multiple sources accounting for 11% of major inputs in both cases.

[8] Rothwell and Gardiner (1985) whilst recognising that users can play a major role in basic innovation within certain industrial sectors (see Table 1.2 for examples), emphasise the crucial role of the user in what they term *re-innovation*, that is, the improvement of product performance following its first commercial launch.

[9] The term *technology-push* refers to the case of innovation stimulated by invention or technological discovery, whilst the term *market-pull* refers to innovation stimulated by the realisation of a market need (Schmookler 1966).

[10] The *Not Invented Here Syndrome* is defined by Katz and Allen (1982,7) as "the tendency of a project group of stable composition to believe it possesses a monopoly of knowledge of its field, which leads it to reject new ideas from outsiders".

[11] The term *boundary-spanner* refers to individuals whose communication activities transcend the boundaries of the organisation of which they are a member.

CHAPTER TWO: DYADIC RELATIONSHIPS

1. Introduction

Rogers and Kincaid (1981) argue that most social research to date has tended to treat social relationships, if at all, as attributes of individuals or groups, rather than taking the interpersonal relationship as the focus of analysis. This research is intended to address the issue directly by establishing the analysis of relationships as a central theme.

The principal objective of this chapter is to provide a detailed discussion of the characteristics, or what Aldrich (1979) terms *dimensions*, of dyadic relationships. A dyadic relationship is simply the linkage between two actors. It is generally acknowledged in the network literature that "a single transaction between actors...does not make a tie or a network linkage. Instead a sequence of exchange activities must take place over time" (Johannisson and Peterson 1984,2).

Depending on the unit of analysis, the two actors of a given dyad may be organisations, individuals, or virtually any other aggregation of individuals. At the organisation-level of analysis, terms such as *joint venture* and *collaboration* are employed to describe the relationship (Aldrich 1979, Auster 1990). At the level of the individual, *role relations*, such as employee and friend, are better able to describe the link (Boissevain 1974). The characteristics of dyadic links discussed below, are as relevant at the individual-level of analysis as at the organisation-level, although different literatures directed towards different levels of analysis may utilise different terminology to describe comparable dimensions.

Although Auster (1990) argues that networks should not be viewed simply as *portfolios* of dyads, the analysis of individual dyadic links is an important step in the study of networks. This approach is supported by Rogers and Kincaid (1981,127) who contend that "the shift from the predominant use of individuals as units of analysis, toward network analysis, usually begins with dyads as units of analysis. But realisation of this potential has been relatively rare". This chapter is thus intended to establish a more systematic approach to the analysis of dyads in order to realise this potential.

This chapter draws heavily on a variety of literatures: sociology (*e.g.* Merton 1957, Blau 1964), organisational sociology (*e.g.* Evan 1965, Aldrich 1979), social anthropology (*e.g.* Barnes 1954, Mitchell 1969, Boissevain 1974), and to a more limited extent, social psychology (*e.g.* Berg and Clark 1986). In so doing, a rich description of the dimensions of dyads has been constructed.

2. The Characteristics of Dyadic Relationships

There are three elements of dyadic links that may be studied: the actors, their inter-relationships, and the *transaction content* that flows between them. A total of fourteen characteristics of dyadic relationships, incorporating these three elements, are identified and discussed in this section; their degree of importance varies. Among the most salient for the purposes of this research are the *nature* and *exchange value* of transaction content, and the *nature*, *formalisation* and *multiplexity* of links. In addition, many of the characteristics are inter-connected, for example, *standardisation*, *formalisation* and *intensity*. These factors allow a *snap-shot* to be taken of a dyad, at a given point in time. By taking many snap-shots, one is able to establish a picture of how the relationship has developed and changed over time.

2.1 Actors

2.1.1 Spatial and Sociometric Proximity of Actors

In their synthesis of a wide range of network research, Rogers and Kincaid (1981,298) argue that "a general theme emerging...is that individuals tend to be linked to others who are close to them in physical distance and who are relatively homophilous in social characteristics". This is known as the *homophily principle* (Rogers and Bhowmik 1971) and is discussed more fully in section 6.1 of this chapter. Following on from Zipf (1949), who argued more generally that all human behaviour is guided by the principle of minimising total action to achieve certain goals, Rogers and Kincaid (1981,298) postulate that "both spatial and social proximity can be interpreted as indicators of *least-effort*".

2.1.2 Unit of Analysis of Actors

The actors in a given dyad may be individuals or virtually any aggregation of individuals, such as a group, an organisation, a community, or even a nation-state (Fombrun 1982). However, it was noted in section 4 of Chapter 1 that in recent years there had been an over representation of research at the organisation-level in the field of innovation, at the expense of studies at the level of the individual. Indeed, Auster (1990,80) argues that "much more attention should be paid to the relationship of individual ties to inter-organizational linkages".

2.2 Links

2.2.1 Nature of Relationship

A dyad may be described in terms of the nature of the *bond* (Hakansson and Johanson 1990) or *tie* (Kanter 1972) which maintains the relationship between the two actors. Kanter (1972) describes three types of ties between what she terms *committed communities* (networks): *instrumental-ties*, through which mutually rewarding economic exchanges can be operationalised; *affective-ties*, through which satisfying emotional sentiments, such as friendship, can be evoked; and *moral-ties*, where a *code of fairness*, *social-banking* and reciprocity, are the main binding forces.

Hakansson and Johanson (1990,462) argue that "interaction between firms develops overtime...[and] as a consequence of interaction, bonds of various kinds are formed by the parties". They classify these *organisational bonds* into five categories: *technical* *bonds*, related to the technologies utilised by the organisations; *knowledge bonds*, related to the knowledge of the organisations about their business; *social bonds*, related to personal confidence and trust between individual members of the organisations; *administrative bonds*, related to the administrative procedures and routines of the organisations; and *legal bonds*, in the form of contractual obligations between the organisations. Hakansson and Johanson (1990,462) argue that "these bonds create lasting relationships between the firms". Technical, knowledge, administrative and legal factors not only help bond organisations together, they also provide a framework for the social bonding of individuals between organisations. Cunningham and Homse (1984,17) argue that "social bonds between organisations are an important element of many successful [formal] relations".

Each of the various types of bonds described above may be related to one of the two basic organising principles of Tonnies (1955), which are: *gemeinschaft*, where actors feel that they belong because they are of the same kind or *sociometrically* close (see 2.1.1 above); and *gesellschaft*, where bonds are considered voluntary and therefore based on some rational pursuit of self interest.

2.2.2 Intensity of Relationship

The intensity or strength of a link is indicated by the degree to which the actors honour obligations or forego personal costs to carry out obligations (Mitchell 1969, Aldrich 1979), as well as the frequency of contact over a given period of time (Aldrich 1979, Tichy *et al* 1979). Thus, this dimension is composed of the degree of commitment and the frequency of interaction. Certain types of links, such as kinship ties, are intrinsically strong and therefore do not require the same intensity of interaction to be maintained over long periods of time (Aldrich 1979, Aldrich and Whetten 1981, Tichy 1981).

However, Lincoln (1982,28] argues that while "inter-organizational ties are merely aggregates of boundary-spanning inter-individual (or positional) ties", it must be recognised that:

> "Strong inter-organizational links are possible which are not reducible to rates of inter-personal contact. Two companies may have a close trade relationship in which a high volume of resources is exchanged, but that exchange is unaccompanied by a significant flow of cross-organisation personal relations."

In general, as Levine (1972) notes, strong inter-organisational ties usually also imply the existence of frequent inter-personal ties between the respective organisations.

2.2.3 Degree of Dependence

The degree of dependence of one actor on another varies according to the content exchanged or transmitted via the dyadic linkage (Auster 1990). Aldrich (1979,118-119) argues that "a major consequence of competition for scarce resources, is the development of dependencies of one organisation on others in its environment". The concept of dependence was originally developed in the early 1960s, in the context of explaining power in inter-personal relations (Emerson 1962, Blau 1964), and was extended in the late 1960s to embrace inter-organisational relations (Thompson 1967, Jacobs 1974). This dimension is discussed further in this chapter in section 4.2.1.

In summing up the salience of dependence in the analysis of inter-organisational relations, Aldrich (1979,273) argues:

> "A condition of dependence is the most important relation between organisations because of its potential impact on a dependent organisation's activities... However, dependence is not usually at stake in most inter-organisational transactions, and thus it is necessary to consider more mundane aspects of everyday transactions and relations."

2.2.4 Nature and Degree of Trust

Closely allied to the nature of dyadic relationships, is the question of *trust*. Dodgson (1993) citing Sako (1991, 377), defines trust as "...a state of mind, an expectation held by one trading partner about another, that the other will behave in a predictable and mutually acceptable manner". Sako (1991) distinguishes between three types of trust:

contractual trust, where each partner adheres to agreements and promises made; *competence trust*, concerning the expectation of a trading partner performing its role competently; and *goodwill trust*, referring to mutual expectations of open commitment between trading partners.

A number of studies have shown the importance of high levels of trust for effective inter-firm relationships (Jarillo 1988, Lorenz 1992). Indeed, Lundvall (1988,52) argues that to overcome the inevitable uncertainties in jointly developed product innovations "mutual trust and mutually respected codes of behaviour will normally be necessary".

Dodgson (1993,13-14) provides three main reasons why high trust facilitates effective inter-firm links: the first relates to the nature of the cognitive transaction content exchanged where high trust exists, "it is often tacit, uncodified, firm-specific and commercially sensitive...Furthermore, it is often *proprietorial*"; the second factor relates to the time-scale of successful inter-firm links. "Trust facilitates continuing relationships between firms...it is only within a long-term horizon that reciprocity in collaboration can occur"; and the third reason relates to the high management costs of such linkages. "Selecting a suitable partner and building the dense communications paths through which tacit and uncodified information can be transferred has considerable management costs, both real and opportunity". In this context, a lack of trust on either side would jeopardise the return on the investment in a relationship.

Once again, even though the literature here is essentially discussing trust between organisations, it is equally as relevant to the nature of trust between individuals. The importance of friendship and trust for the disclosure of information has been demonstrated by a number of studies, both in the business world (*e.g.* Cunningham and Homse 1984, Saxenian 1985,1991, Hakansson and Johanson 1990) and outside of this context (Berg and Clark 1986, Miell and Duck 1986).

2.2.5 Multiplexity

At the level of the individual, multiplexity identifies the degree to which two actors are linked by multiple role relations (Tichy *et al* 1979). This view is supported by Boissevain (1974,28-29), who argues that:

> "The social relations that link people derive from the many different activity fields in which each participates. They are in fact role relations...Each person plays many different roles; neighbour, husband, employee, football club member, and so on. By virtue of each he comes in contact with particular sets of people who share with him a particular activity or interest...Many of the people in a given activity field also play roles on other activity fields. Each is thus sometimes in touch with the same people in different capacities."

It is also argued that the greater the number of role relations linking two actors, the stronger the link (Tichy *et al* 1979). On this point Boissevain (1974,30) contends that:

> "There is a tendency for single-stranded relations to become many-stranded if they persist over time, and for many-stranded relations to be stronger than single-stranded ones, in the sense that one strand role reinforces others."

This is also supported by Hakansson (1989,115), who in his study of the technological interaction behaviour of 130 Swedish companies, highlighted the fact that "people on both sides [of a link between two firms] can gradually build up confidence and trust in one another, and in this way an important social element enters the interactions". However, Barnes (1969,75) argues that "relationships between persons in tribal society are typically multiplex...whereas in urban society they are typically single-stranded". Between these two extremes of society there exists many intermediate types, such as the rural semi-industrial society of Bremnes in Norway (Barnes 1954).

The terms *overlap* and *redundancy* are sometimes used as synonyms for multiplexity (Tichy *et al* 1979, Tichy 1981), though Auster (1990) argues that such terms are less useful because they do not capture the differences that exist in the various linkages between two actors.

2.2.6 Formalisation of Relationship

Aldrich (1979,273) notes that "traditional theories of bureaucratic structure emphasize the importance of formalisation in stabilising activities and ensuring continuity in staff behaviour", and thus contends that "formalisation of relations between organisations has similar consequences".

Aldrich (1979) distinguishes between, what he terms, *agreement formalisation* and *structural formalisation*. The former refers to the extent to which a transaction between two organisations is given official recognition and administratively or legislatively sanctioned. A link between two organisations is considered formalised where it is embodied in a written contract. In his study of non-contractual relations in the US, Macaulay (1963) found that many business contacts were not formalised, and that contractual conditions were often ignored in business transactions by employees. In attempting to explain this phenomenon, Macaulay (1963,63) argues that:

> "Contract and contract law are often thought unnecessary because there are many effective non-legal sanctions...At all levels of the two business units [in a given transaction] personal relationships across the boundaries of the two organisations exert pressures for conformity to expectations. Salesmen often know purchasing agents well...buyer's engineering staff may work with the seller's engineering staff to solve problems jointly...top executives of the two firms may know each other. They may sit together...[on] committees. They may know each other socially and even belong to the same country club."

The latter term refers to the degree to which an intermediary organisation coordinates the relationship between two or more organisations. Aldrich (1979), citing Simmel (1950), argues that adding a third-party usually changes the nature of a relationship.

2.2.7 Underlying Structure of Relationship

Auster (1990) argues that it is important to have an appreciation of the basic underlying structure of a linkage between actors when analysing relationships and networks. The underlying structure of a linkage may be determined along two dimensions: its *symmetry*, and the *horizontal* versus *vertical* nature of the relationship. The *symmetry* of a relationship refers to the flow over time of transaction content between two actors through a given linkage. The underlying structure of the link is termed *asymmetric* or *unilateral*, where the flow is one-way, and *symmetric* or *bilateral*, where the flow is two-way. Asymmetric linkages tend to imply some form of inequality in the power relations between two actors. On this point, Tichy (1981,228) notes that "affective relationships tend to become symmetric overtime (Homans 1950), whereas influence frequently remains asymmetric". Boissevain (1974,34) argues that:

> "Equality or complementarity in the flow of items exchanged is an indication of equality in terms of power or prestige between the actors. Where there is asymmetry in the flow over time, there is very often a difference in status and power between the actors. This transactional account, in book-keeping terms, is thus an important measure of the quality of a link."

The term *reciprocity* is frequently used to refer to the degree of symmetry in a given relationship (Aldrich 1979, Tichy *et al* 1979). In addition, Aldrich (1979) makes a further distinction, between what he terms *resource reciprocity* and *definitional reciprocity*. The former refers to the flow of transaction content between two actors, whilst the latter refers to the extent to which the terms of reference of a relationship are mutually agreed upon. Definitional reciprocity is closely allied to *clarity of expectations* (Tichy *et al* 1979).

At the organisation-level, linkages may also be classified as either *horizontal* or *vertical* (Porter 1985, Auster 1990). Horizontal linkages refer to exchanges between organisations producing similar products, processes or resources. This type of linkage has also been termed *commensalistic* (Aldrich 1979). Vertical linkages in contrast, refer to exchanges between organisations at different stages of the production and distribution chain. Vertical linkages can in turn be classified as either *backward* or *forward*, referring to linkages with organisations at an earlier or later stage of the transformation process, respectively.

2.2.8 Origin of Relationship

This dimension refers to the identification of the events leading to the origin of a linkage. It is intended to incorporate factors such as the context in which the relationship originated, the initiator of the relationship, and whether a third-party was involved in the process. Kreiner and Schultz (1993) for example, note the importance of serendipity in the emergence of personal relationships, from their study of informal collaboration in the Dutch biotechnology industry.

2.2.9 Motives behind Relationship

Giddens (1979) points out that the functional significance of networking does not qualify as a convincing explanation of its occurrence. In addressing this issue, Kreiner and Schultz (1993,201) argue that "one must determine the motives and perspectives of the actors who reproduce such patterns". Thus, the motives behind the initiation, nurturing, continuation or decline of a dyadic linkage is also an important and interesting factor to analyze. This view is supported by Rothwell (1991). There may also exist variations in the motives of the actors within a relationship and these motives may vary during the life of the linkage (Auster 1987, Buckley and Casson 1988). In addition, actors may have more than one motive activated at any given time.

2.2.10 Standardisation

Aldrich (1979,277) contends that "just as internal standardisation of procedures smooths bureaucratic operations and promotes efficiency, so the standardisation of external relations is sought by cost-conscious administrators". Aldrich (1979) makes a distinction between what he terms *unit standardisation* and *procedural standardisation*. The former refers to the extent of similarity between individual units of transaction content exchanged between two actors, whilst the latter refers to the degree of similarity over time in the procedures employed in the exchange process.

The intensity of interaction in a dyadic link has a positive effect on standardisation, because of the larger investments involved in the linkage (Litwak and Hylton 1962). Organisational size also has a positive effect on standardisation (Blau 1972).

2.3 Transaction Content

2.3.1 Nature of Transaction Content

Kadushin (1966) refers to *transaction content* as the *flow* between actors, to emphasize both the dynamic nature of networks and that something is passing through a relationship. Tichy *et al* (1979) distinguish between four types of transaction content, that is, the nature of what is exchanged between actors: *expressive* transaction content, the exchange of friendship between actors; *instrumental* transaction content, the exchange of power and influence between actors; *cognitive* transaction content, the exchange of data, ideas, information, or knowhow, between actors; and finally, *objective* transaction content, the exchange of goods, money, technology or services, between actors. While this typology is very useful for classifying transaction content, the term *objective* is confusing and thus for the purposes of this research project will be replaced by the term *material*.

Dyadic relationships and networks of exchange can be categorised according to their transaction content. Indeed, Fombrun (1982,281) contends that four categories of network can be distinguished in which "the flow through the network is primarily expressive, instrumental, cognitive, or objective". This corresponds directly with the typology of transaction content referred to above. Fombrun (1982,281) also argues that "for the purposes of analysis, the first step of the network researcher is to distinguish clearly among these networks".

2.3.2 Exchange Value

This dimension refers to the perceived value of the transaction content, both received and transmitted, by each of the actors in a given dyad. The value of the transaction content may be measured as discrete units within specific exchange events, or as the cumulative value of exchanged units within a series of exchange events over time.

2.3.3 Standardisation

It was noted above in section 2.2.10, that standardisation occurs along two dimensions: firstly, in terms of the unit of exchange (unit standardisation), and secondly, in terms of the procedures employed in the exchange process (process standardisation]. Aldrich (1979,277-278) argues that:

> "unstandardised units create uncertainty and thus could affect the distribution of power within organisations if boundary-spanning units take advantage of their position as uncertainty absorbers...unstandardised transactions persist because there are no effective environmental criteria selecting against them."

It is highly likely that technology, such as electronic-data-interchange (*EDI*) and computers, will increasingly bring about unit standardisation, in particular, but also procedural standardisation (Webster 1993).

3. Cognitive Transaction Content

3.1 Classifying Information and Knowledge

3.1.1 Tacit and Codified Knowledge

The term *tacit knowledge* has been employed in the innovation literature to encapsulate knowledge of methods, techniques, and designs, which are difficult to articulate, and thus to communicate and codify (Collins 1974). To this may also be added, knowledge of where to locate other required knowhow, of how it may be retrieved and interpreted, and of who may be able to help in this process. Thus, tacit knowledge may encompass not only *knowhow*, but also what Rogers and Kincaid (1981) have termed *knowwho*, and what may be termed *knowwhere*. Senker (1992,3) describes tacit knowledge as "heuristic, subjective and internalised knowledge", which needs to be "learned through practical examples, experience and practice". This notion is implicity supported by Burns (1969), who argues that technological knowledge is the property of people rather than documents.

Tacit knowledge and skills form a major component of what Rubenstein (1980) terms the *imbedded technology capability (ITC)* of an organisation, alongside specific knowledge embodied in materials, products, processes and systems.

By contrast, *codified* or *articulated* knowledge may be transferred using formal and systematic language. This term is used to encompass knowledge of general principles and laws of science, technology and engineering. These principles and laws are articulated in great detail within manuals and textbooks (Senker 1992).

However, Senker (1992) warns that the distinction between tacit and codified knowledge must be treated with caution, quoting Polanyi (1969,144), who notes that:

> "These two are not sharply divided. While tacit knowledge can be possessed by itself, explicit [codified] knowledge must rely on being tacitly understood and applied. Hence all knowledge is either *tacit* or rooted in *tacit knowledge*."

In addition, there are various routes through which tacit knowledge may become codified. For example, codification may result from conducting research; as a consequence of automation, perhaps through the use of expert systems; and to a more limited extent, through the patenting process. Senker (1992) distinguishes between *science push* and *technology pull* codification. The former referring to blue-sky research with the purpose of increasing understanding, the latter, to the exploration by scientists of phenomena and problems arising within industry.

A number of studies have identified tacit knowledge as an important component of the knowledge employed in the innovation process (Rosenberg 1976,1982, Dosi 1988, Senker 1992, Senker and Faulkner 1993). Freeman (1991,502-503) goes even further, to argue that:

> "It is now very generally recognised that in the technology accumulation process within firms and other organisations, tacit knowledge is often more important than codified formal specifications, blue-prints etc."

Senker and Faulkner (1993,2) also note the continuing importance of tacit knowledge "despite the growing codification of knowledge in the twentieth century through the growth of R&D and in automation".

3.1.2 Data, Information and Intelligence

Fuld (1991) contends that much of corporate America has accepted the concept of *business intelligence*, with many of the *Fortune 500* companies having already established so-called *intelligence* departments and built databases dedicated to competitor or market intelligence, for example. However, Fuld (1991,12) argues that:

> "Understanding the difference between intelligence and information is essential to success. Data, information, and intelligence are three distinctly different parts of the same concept. Corporations that do not distinguish among the three parts are the ones whose managements call for intelligence and instead receive a flood of data."

Fuld (1991) views data as raw, unconnected pieces of information, which form the basis for all intelligence. Each piece of data taken separately might appear meaningless, but together represents information. When this information is analyzed in a broader context and with the benefit of personal experience, this value-added information becomes intelligence.

3.1.3 Classifying Innovation Inputs by their Role

Very few studies of innovative activity have seriously attempted to classify the identified inputs with respect to the role they perform in the innovation process. Langrish *et al* (1972), for example, in their study of Queen's Award winning innovations, classified the sources of the key inputs and the mechanisms through which they were channelled, but did not identify the role to which these were employed. While studies such as those of Myers and Marquis (1969) and Utterback (1971), classified key inputs only in terms of whether they were *stimulating* or *problem-solving* inputs. That is, inputs that either evoked the idea for a given product, or expedited a solution in realising that product.

Steward and Conway (1993,6) advocate a more systematic approach to the classification of inputs into the innovation process, akin to the that adopted by Shaw (1993), suggesting that inputs should be:

> "...classified according to whether they contributed, or led directly to the original *impetus* for the innovation project, induced by either a need or means-stimulated input; the original *concept* of the innovation itself; to the *features* and functionality that added flesh to this concept; or the *solutions* that translated this into a commercialisable product or process."

For some innovations, the impetus and concept may be stimulated by the same input. A customer-need articulated in the form of a product idea may both provide the original impetus for the innovation as well as the original concept.

3.2 Innovation as an Ensemble of Cognitive Inputs

Innovation should not be viewed as resulting from a single idea, but from a *bundle* or *ensemble* of ideas, information, technology, codified knowledge and knowhow, which may or may not be embodied within the product or process. In their cross-sector study of thirty innovations developed by UK firms, Gibbons and Johnston (1974) identified a total of 887 units of information employed in resolving technical problems during their development. To a large extent innovations should also be viewed as building upon existing science and/or technology embodied within previous generations or alternative applications of the product or process. This is inherent in the approach of TRACES I (Illinois Institute of Technology 1968) and TRACES II (Battelle Memorial Institute 1973), and supported by Myers and Marquis (1969,59), who argue that "technical change, is to a significant extent, based on the cumulative effect of small incremental innovations".

Previous research has also clearly demonstrated that new ideas seldom appear fully formed and articulated from a single source (Myers and Marquis 1969, Utterback 1971, Allen 1977, Allen *et al* 1983). Allen *et al* (1983,201), for example, found in their study of technological change in 102 SMEs in Ireland, Spain and Mexico, that:

> "Bits and pieces of what eventually becomes a new idea arrive from a variety of sources...The individuals who introduce the new idea to the organisation, integrate these messages and in that may make their own creative contribution to the process."

These "bits and pieces" have been termed *units* (Gibbons and Johnston 1974), *inputs* (Myers and Marquis 1969, Utterback 1971), and *messages* (Allen *et al* 1983).

However, it has been common for innovation studies to identify only *the* most important input into the innovation process (*e.g.* Myers and Marquis 1969). Whilst studies such as that of Langrish *et al* (1972), identified only the key ideas underlying their sampled innovations. In contrast, Baker *et al* (1967) collated large numbers of messages prior to categorising them as *best* or *good.*

3.3 The Proliferation of Knowledge and Ease of Data Access

Many authors have documented the so-called *information explosion*, fuelled by the dramatic rise in the number of scientists and engineers, and supported by rapidly expanding R&D budgets in the post-war period (Licklider 1966, Allen 1977,6-7, Badaracco 1991,20-28). Indeed, scholars in the emerging fields of bibliometry and scientometry have revealed the exponential growth in scientific articles, journals and books during the past two centuries. This rapid expansion of knowledge is not confined to science, but is also a prominent feature of technological endeavour. Allen (1977) even contends that the problem is more serious in technology. Since not only has it become extremely difficult for engineers to keep pace with the *state-of-the-art* in the many fast growing technological fields, but they must also, at least partially, keep abreast of and absorb scientific information to maintain technological progress.

Badaracco (1991,25) argues that "these efforts and expenditures create not only more, but also increasingly specialised knowledge". He notes that whilst in the mid-1940s there were only 54 scientific specialities, by the mid-1970s this had risen to 900. No doubt this number is considerably higher today. Badaracco (1991,25-26) contends that of these specialities:

> "Some were the result of increasingly fine distinctions in established fields, but others reflected the creation of new specialities. Knowledge proliferates further when scientists and engineers combine branches of knowledge...Just as new knowledge creates new technology, so new technology creates new knowledge."

The fusion of existing technologies often produces new technologies and products. The scientific genealogy of the video-recorder, for example, shows that it descended from a number of technological and scientific advances, including: magnetic and control theory, electronics, chemistry and materials science.

The technology for storing, communicating and retrieving information was launched on its trajectory well over 100 years ago, but dramatic advances in computer-processing and telecommunications since the early 1980s, have enabled the rapid dissemination of the burgeoning knowledge-base. With this in mind, Rogers and Kincaid (1981,343-344) argue that:

> "Perhaps in recent decades *knowhow* was a major factor in the effectiveness of individuals in their daily lives. But at present the information explosion, facilitated by the widespread mass-media and by recent advances in communication technology (especially of the interactive sort), has created an information environment in which almost every individual possesses more knowhow than he can cope with. Such information overload is often handled by the structuring of interpersonal network links by individuals. *Knowwho* thus begins to replace *knowhow* as one of the main determinants of individual effectiveness."

4. Organisational Boundaries and Boundary-Spanning Activity

4.1 The Organisational Boundary

4.1.1 Defining the Organisational Boundary

The establishment of an *organisation* implies that a distinction has been made between members and non-members. That is, some individuals are admitted to participate in the activities of the organisation, whilst others are excluded (Weber 1947). Modern organisations typically define organisational members contractually. However, Cole (1970) argues that in an earlier age, membership was often ascribed on the basis of ethnicity, kinship or wealth.

Aldrich (1979,4) defines organisations as "goal-directed, boundary-maintaining, activity-systems". Maintaining this boundary, by distinguishing between members and non-members, involves the establishment of an authority empowered to admit some and exclude others. The ability of the organisation to control its boundaries is critical for the maintenance of its autonomy (Aldrich 1979).

However, Lincoln (1982,27) questions the need for separate theories, terminology and research techniques for examining inter- and intra-organisational structures and processes, arguing that:

> "If [organisational] boundaries are hard, objective facts, then links across them might be thought to have a very different quality from links within them. But if boundaries are vague, permeable and shifting, perhaps there is no reason to treat inter-organizational relations separately."

In such an approach, an inter-organisational tie would simply be seen as just another network link that happens to span what the observer views as the organisational boundary.

4.1.2 The Organisation and Boundary-Crossing

A number of authors have argued that the only effective mechanism of technology transfer is through the movement of people between organisations (Burns 1969, Price 1969, Allen 1977). This displacement of labour is sometimes termed *boundary-crossing*. As noted in section 3 of Chapter 1, Burns (1969,12) contends that "the mechanism of technological transfer is one of agents, not agencies", whilst Allen (1977,43) argues that "ideas have no real existence outside of the minds of men...Consequently, the best way to transfer technical information is to move a human carrier".

This view has received some empirical support. Langrish *et al* (1972), in their study of innovations which had gained the Queen's Award for Industry in either 1966 or 1967, found that the major mode of transfer was via a person joining the company, accounting for 20% of the key ideas obtained from external sources. Further evidence is supplied by Roberts and Wainer (1971), in a study of the effective transfer of space technology from quasi-academic institutions to the industrial sector. This research revealed that the only successful mechanism of transfer had been via the displacement of the scientists themselves. With this is mind, Allen (1977,43) argues that:

> "A certain amount of turnover [of engineers] may be not only desirable but absolutely essential to the survival of the technical organisation, although just what the optimum turnover is for an organisation is a question that remains to be answered."

Bonora and Revang (1993) note the growing importance of knowledge as a resource and the emergence of what has been termed the *knowledge-intensive* organisation, as distinct from capital or labour-intensive organisations. Knowledge-intensive industries would include, for example, the computer and biotechnology sectors. Since much of the knowledge and ideas are held within the brains of engineers and scientists in such knowledge-intensive industries, Bonora and Revang (1993,193-194) argue that:

"...these human beings, in many cases...hold the very essence of the firm captive...the mobility of this primary resource becomes a key element when discussing strategies for the storage and/or protection of knowledge...Thus, the mobility of knowledge workers gives them power."

As a result of this situation, Bonora and Revang (1993) argue that organisations have two sets of generic strategies open to them to contain the mobility of their knowledge workers: to reduce the dependence on individuals by *building* knowledge into the organisation, through the diffusion of knowledge among organisational members, the abstraction of knowledge and skills, and the institutionalisation of knowledge; and to build exit barriers for knowledge workers, through mechanisms such as high wage rates (*material-based* exit barriers) and the creation of what Coleman (1988) has termed *social capital* (*social-based* exit barriers).

4.1.3 The Organisation and Boundary-Spanning

The term *boundary-spanning* is used to refer to those linkages that transcend the boundaries of a given focal organisation unit. Whilst the term b*oundary-spanner* refers to those organisational members who are involved in boundary-spanning activity. Unlike boundary-crossing, boundary-spanning activity involves the flow of transaction content to and from the organisation, rather than the flow of personnel. The degree and form of boundary-spanning activity varies according to a variety of organisational and environmental factors which are often inextricably linked (Aldrich 1979).

In contrast to scientists, the vast majority of engineers or technologists are employed by organisations with well defined missions. Such mission-orientated organisations demand of their engineers a degree of identification unknown in most scientific circles. Allen (1977) argues that this organisational identification works in two ways to exclude these engineers from the informal communication channels that transcend the organisational boundaries. Firstly, the engineer is inhibited by the requirement that he must work on problems that are identified as of interest to the organisation. Secondly, the engineer is obliged to refrain from disclosing the results of any research undertaken, in order that the organisation may gain from its investment. Allen (1977,41) concludes that "both of these constraints violate the rather strong scientific norms that underlie and form the basis of the *invisible college*". This in effect, results in what he terms *enforced localism* in the communication patterns of engineers. However, more recently some have argued that the division between *scientific community* and *technological activity* is fading (Rappa and Debackere 1992, Debackere *et al* 1994). This is discussed in sections 6.1.2 and 6.2 of Chapter 3.

Hall (1992,135) argues that "sustainable competitive advantage results from the possession of relevant capability differentials. The feedstock of these capability differentials is intangible resource". Hall (1992) employs the term *intangible* resource to encapsulate an array of assets, such as patents, trademarks, data-bases, reputation and trade secrets, and people dependent resources, such as networks of personal relationships, organisational culture and knowhow. The view that personal relationships and organisational alliances should be considered as an important intangible resource, is supported by Saxenian (1991,430), who contends that:

> "A network of long-term, trust-based alliances with innovative suppliers represents a source of advantage for a systems producer which is very difficult for a competitor to replicate. Such a network provides both flexibility and a framework for joint learning and technological exchange."

However, although economic benefits can be realised through boundary-spanning activity, the trading or sharing of proprietary information outside the organisation entails the risk that the information transfer behaviour of boundary-spanners may not be in accordance with the interests of their organisation. Mansfield (1985) argues that the rapid diffusion of technology via informal boundary-spanning channels, is one of the reasons why many firms have difficulty in appropriating benefits from their innovation. Such *leakage* may result because boundary-spanners are guided by purely personal objectives (Rogers 1982) or misguided by the insufficient availability of managerial information to enable well-informed decisions to be made (Schrader 1991). While Hamel *et al* (1989) argue for measures to restrain informal boundary-spanning activity, Schrader (1991) suggests the adoption of mechanisms to induce desirable information transfer behaviour, such as financial incentives and the internal dissemination of organisational information.

4.1.4 The Shifting of Organisational Boundaries

The boundaries of an organisation are not firmly fixed and may shift over time, often in response to changes in the environment. However, whilst some environmental factors may impose shifts in the boundaries of an organisation, others will facilitate such changes to increase the effectiveness of the organisation. Aldrich (1979,5) contends that:

> "When the boundaries of an organisation become blurred for an observer, it is probably a sign of change in the relative power of the organisation *vis-a-vis* its population. The boundary-maintaining process becomes visible on those occasions when it is severely tested."

Depending on the situation an organisation faces, there are a range of boundary-maintaining strategies open to its leaders or administrators, from expansion to contraction. The organisation may, for example, expand its boundaries to incorporate individuals from competing organisations or from a turbulent or troublesome environment (Aldrich 1979).

The potential of inter-organisational systems such as EDI for the promotion of closer organisational collaboration, for example, has been well documented in recent years (Skagen 1989, Konsynski and McFarlan 1990). However, evidence of the realisation of this potential remains thin on the ground (Webster 1993). This is partly explained by Clarke (1992), who suggests that the potential of EDI is contingent upon factors such as the type of goods or services that are exchanged.

Clarke (1992) distinguishes between what he terms the *passive* and *strategic* implementation of EDI. In the former, EDI is employed to reduce internal costs with little or no changes in the boundaries of the interacting organisations. In the latter, EDI is consciously utilised by one or more of the partners as a tool of corporate strategy. It is in this second scenario that information and communications technology is likely to affect the boundaries of the organisation. In this context, Webster (1993,19) argues that "the study of power-dependency relationships is critical to an understanding of the changes taking place in organisational boundaries - of whether they are broken down, simply maintained, or invaded".

4.2 The Environment and Boundary-Spanning

4.2.1 The Environment and the Nature of Boundary-Spanning

A number of studies from the early 1960s to the early 1970s were able to show a positive relationship between a higher dependence on other organisations for resources (excluding a parent organisation), and a lower formalisation and standardisation of organisational structure (Burns and Stalker 1961, Pugh *et al* 1969, Hasenfeld 1972, Haas and Drabek 1973). Thus, one would expect a greater incidence of informal boundary-spanning activity for organisations which are more dependent on other organisations for resources. This view is supported by Aldrich (1979,122), who argues that:

> "As inter-organisational dependence increases, organisations tend to display a more flexible and open structure, characterised by less formal and standardised procedures, greater decentralisation of decision-making, and decreased impersonality of relationships."

With the proliferation of scientific and technical specialities (Badaracco 1991), noted earlier, the likelihood of inter-organisational resource dependence has notably increased, such that Prahalad and Hamel (1990) contend that even those with the largest technological resources can develop only a narrow range of core competencies.

In addition, research has also indicated that organisational structure is influenced by environmental uncertainty (Dill 1958, Lawrence and Lorsch 1967, Duncan 1972) and that the most salient feature of organisational environments today is their rate of change (Terreberry 1968). These studies suggest that environmental uncertainty is likely to increase the incidence of informal boundary-spanning activity. Indeed, Aldrich (1979,124) argues that:

> "As organisations are confronted with increasing environmental uncertainty due to instability, hetergeneity, or turbulence, more flexibility is observed in their structures and activities...Under such conditions, there is some evidence that organisations tend to be more effective if they are more decentralised and specialised, and less formalised and standardised."

From this research, it is possible to conclude that the incidence of informal boundary-spanning activity and the *specificity* of boundary-spanning roles, are likely to vary, at least in part, with variations in the environment.

4.2.2 The Environment and the Number of Boundary-Spanners

The number of formally designated boundary-spanning roles in an organisation is partially dependent on: organisational size (Aiken and Hage 1972); the direct impact of environmental pressures (Aldrich and Herker 1977); and as a result of the interaction between the technology employed by the organisation and its environment (Thompson 1967).

Aldrich (1979,263) argues that "boundary-spanning roles are expected to proliferate when organisations are in concentrated, heterogeneous, unstable, and lean environments". Following the principle of *structural isomorphism*, Thompson (1967,70) contends that environmental heterogeneity evokes more boundary-spanners and roles as organisations "seek to identify homogeneous segments and establish structural units to deal with each".

4.3 The Two-Step Process of Information Flow

The evolution of local *languages* and *coding schemes* within an organisational unit aids internal information processing requirements, but also hinders its ability to acquire and interpret information from external sources. The impedance caused by errors in interpretation of external messages is termed *semantic noise* (Bar-Hillel and Carnap

1953). However, Allen (1977,139) also argues that:

> "Of course, the coding schemes are less exclusive than most languages. There is a great deal of overlap among the coding schemes of different organisations operating within the same culture. On the other hand, the non-overlapping areas, however small, can potentially operate to produce semantic noise, and they can be even more troublesome because it can go undetected."

Tushman and Katz (1980,1072) argue that one way to overcome this paradox, is through gatekeepers "who are capable of understanding and translating contrasting coding schemes". Indeed, Allen (1977,148) argues that contact between the average engineer or technologist and the world outside of his organisation "occurs most effectively through the gatekeepers in a two-step or multi-step process".

The notion of a *two-step* process of information flow, was first identified in the 1950s in a study of voter decisions during the 1940 US presidential election campaign (Lazarsfeld *et al* 1948). This study revealed that the average voter was not directly influenced by information on the radio or in the newspapers, but indirectly via a key subset of voters or *opinion leaders*. In the 1960s, opinion leaders were also found to be influential in the diffusion of a variety of innovations, examples include: the propagation of such agricultural innovations as hybrid seed corn (Rogers and Shoemaker 1971); and the introduction of a new drug to a community of physicians (Coleman *et al* 1966). In both of these studies, the opinion leaders were found to be highly exposed to both written and personal sources of information from outside of their immediate community. Thus, the opinion leaders were acting as gatekeepers to the flow of new technology and information from one community to another.

4.4 The Role and Nature of Gatekeepers

A number of studies of the communication behaviour of scientists and engineers in the 1960s and 1970s have indicated the critical role of a small number of key individuals in linking the laboratory with its external environment (Allen and Cohen 1969, Allen 1970,1977, Holland 1972, Chakrabarti and O'Keefe 1977, Tushman 1977, Katz and

Tushman 1979, Tushman and Katz 1980). These key individuals have been termed *gatekeepers*, *key communicators*, *communication stars* and *linking-pins*. However, the term *gatekeeper* appears to be the most commonly employed today.

Katz and Allen (1982,16) define gatekeepers as "those key R&D professionals who are both high internal and external communicators and who are able to effectively transfer external ideas and information into their project groups", while Tichy (1981, 229) views a gatekeeper as "a participant who controls the flow from one section of the network to another".

Aldrich (1979,249) argues that gatekeepers or boundary-spanners fulfil essentially two types of function: information processing and external representation, and that "boundary roles link structures and activities [within a given organisation] to environmental conditions in the form of buffering, moderating, and influencing external events". Our principal interest here, lies in the information processing function of the key boundary-spanning individuals or gatekeepers.

Gatekeepers are considered the primary linking mechanism of the organisational unit to external sources of information (Tushman 1977). By virtue of their strategic position, they are exposed to large amounts of potentially relevant information. Studies have indicated that gatekeepers have a significantly greater readership of professional and scientific literature, and maintain longer-term relations with experts in a broader, more diverse range of fields outside of their immediate working environment, than the average researcher (Allen 1970,1977, Tushman 1977, Katz and Tushman 1979, Tushman and Katz 1980). Thus, gatekeepers are likely to account for the vast majority, though certainly not all, of the boundary-spanning activity of their organisation. This control over information is a powerful resource (Pettigrew 1972).

In addition, gatekeepers also provide the main line of defence against information overload through the communication channels of the organisation, acting as information *filters* (Aldrich 1979). Where there exists ambiguity and uncertainty in the information they receive, gatekeepers act as *uncertainty absorbers*, drawing inferences from the perceived facts and transmitting only the inferred information (March and Simon 1958). They may also generate or sustain internal variation by channelling information about external developments to relevant parts of their organisations (Aldrich 1979). Finally, gatekeepers may work to reduce the communication boundary between their organisational subunit and external areas, by directing, training and coaching the external communications of their work colleagues (Tushman and Katz 1980).

From a study of work-related verbal communication of 345 professionals within the R&D facility of a large American corporation, Tushman and Katz (1980,1083) found that the importance of the gatekeeper role was contingent upon the nature of the work of the organisational unit. They conclude that:

> "This research suggests that direct peer contact, contact mediated by gatekeepers and contact mediated by the hierarchy are alternative mechanisms by which subunits can be linked to external information areas. Each mode of information transfer seems to be appropriate under certain conditions...Gatekeepers are most important in development projects; units whose task is locally defined yet where the technology employed is changing...The importance of gatekeepers is, however, tempered by the existence of alternative media for extra-organisational information. As research projects are unencumbered by external communication boundaries, direct peer contact seems to be the most effective way to access external professional information. While gatekeepers exist in research projects, they function here as a complement to direct external communication."

5. Informal Boundary-Spanning Activity

5.1 The Role, Importance and Incidence of Informal Exchange

Burns (1969,14-15) argues that "technological transfer is still envisaged as the passage of disembodied *ideas and methods*, endowed with some quasi-independence...from one state of existence, or from one mileau...to another". It is for this reason that studies concerning the mechanisms and channels of technology transfer and exchange are important. As noted in Chapter 1, innovation studies have long highlighted the importance of informal boundary-spanning contacts (Menzel 1962, Bernard *et al* 1963, Shilling and Bernard 1964, Myers and Marquis 1969, Utterback 1971, Allen *et al* 1983, Hippel 1987, Schrader 1991, Lawton-Smith *et al* 1991, Kreiner and Schultz 1993). Indeed, research by Hippel (1976,1977a,1977b) and Shaw (1985,1993) of user-innovation placed most emphasis on *multiple and continuous* interaction.

The notions of personal contact and multiple and continuous interaction, indicate the importance of informal exchange activity within *personal relationships* between individuals. Freeman (1991,503) goes further, contending that "behind every formal network [of relationships], giving it the breath of life, are usually various informal networks". Whilst Hamel *et al* (1989,136) argue that management may set the legal parameters for exchange behaviour, "but what actually gets traded is determined by the day-to-day interactions of engineers, marketers, and product developers". This view is supported by Cunningham and Homse (1984,1-2), who argue that:

> "Personal contacts are the lifeblood of supplier-customer relationships. They are the vehicle of communication, not only of factual information but of ideas, impressions, attitudes, commitment, integrity, and sometimes of commercial or technical information provided only to the trusted or privileged...They allow problems [between suppliers and customers] to be resolved and crises avoided, they can lower the social and cultural barriers which may otherwise prevent the exchange of product, money, services and expertise...individuals contribute to the *atmosphere* of the supplier-customer [organisation-level] relationship."

However, in a recent study of industry-academia links and knowledge flows in three emerging technologies - biotechnology, advanced engineering ceramics and parallel computing - Senker and Faulkner (1993) found evidence that variations exist between industrial sectors in terms of their relative use of personal contact and literature. They found, for example: that literature proved more important than personal contact in biotechnology; that personal contact was marginally more important than literature in ceramics; and that researchers in parallel computing relied far more on personal contact than on literature. Myers and Marquis (1969) also noted variations in the modes of information transfer across the five industrial sectors of their US study.

Cunningham and Homse (1984) identify nine roles served by personal boundary-spanning interaction within customer-supplier relationships: *surveillance* of the performance of the organisation-level link, and that of third-parties; *communication* of resource bases of the two organisations; demonstration of organisation-level *commitment*; *distance reduction* in terms of geography, perceptions and culture; *problem-solving*; demonstration of organisation-level *crisis insurance*; *negotiation*; and *social bonding*. In addition, Cunningham and Homse (1984,14) found that "many personal contacts in the relationships studied were clearly problem-orientated".

From his study of the extensive *informal knowhow trading* that occurs in the US steel mini-mill industry, Schrader (1991,168) argues that "the evidence suggests a positive link between informal information trading and a firm's economic performance". However, Hippel (1987,296) notes that "on an anecdotal basis...we have found informal knowhow trading apparently quite common in some industries, and essentially absent in others". This preliminary research found widespread knowhow trading among aerospace firms and wafer-board manufacturing mills, but rare or absent among powdered metals fabricators and producers of the biological enzyme *klenow*. In attempting to explain these variations in *informal knowhow trading*, Hippel (1987,300) contends that:

> "In general, one may say that informal knowhow exchange between rival and non-competing firms is the most effective form of co-operative R&D when (1) the needed knowhow exists in the hands of some member of the trading network and when (2) the knowhow is proprietary only by virtue of its secrecy, and when (3) the value of a particular traded module is too small to justify an explicit negotiated agreement to sell, license or exchange. Since much technical progress consists of small, incremental advances, the universe bounded by these three conditions is likely to be a substantial one."

5.2 <u>The Nature of Informal and Unplanned Mechanisms of Exchange</u>

Studies of the sources of innovation (Myers and Marquis 1969, Utterback 1971, Langrish *et al* 1972, Gibbons and Johnston 1974, Senker 1992, Senker and Faulkner 1993) have identified a number of mechanisms through which ideas and information transcend the organisational boundary. Of interest here are the informal person-to-person modes of communication and exchange. These mechanisms, which were identified in section 3 of Chapter 1, include: telephone and *corridor* conversations, correspondence, informal visits, and informal discussion on the *side-lines* of more formal meetings and conferences.

An interesting study by Menzel (1962), also mentioned in the first chapter, on the information-gathering behaviour of bio-chemists, chemists and zoologists in an American university, revealed four basic types of unplanned mechanisms through which ideas and information came to light accidentally: three involving informal personal interaction and one involving literature. These basic types were described as follows: in the course of contact for another purpose, a scientist informs a colleague of his current work or of some obstacle which is preoccupying him, and is rewarded with an item of information that becomes important to his progress; sometimes a scientist hears about new developments from a colleague, or frequently on an informal visit to a scientist in another laboratory, who volunteers the information while they are together for another purpose; frequently a colleague will deliberately seek out a scientist whom he knows to be interested in the matter, in order to convey to him some information that he happens to have heard; the scientist searches the literature for a particular item of information and in the process stumbles across another.

During this study, Menzel (1962,420) observed that:

> "...a good deal of the news comes to their attention in unplanned and unexpected ways, during activities undertaken on occasions sought out for quite different purposes, proves to be of considerable significance to them."

5.3 The Nature and Complexity of Informally Exchanged Transaction Content

From their study of industry-academia links in emerging technologies, mentioned earlier, Senker and Faulkner (1993,26) conclude that "we suspect that much of the knowledge transferred through personal networks is tacit, and our evidence is suggestive in this regard". Menzel (1962) in his study, discussed in the following section, also reveals the *tacitness* of much of the information transferred in unplanned ways during personal contact. In addition, Freeman (1991,502) argues that "informal networks are extremely important but very hard to classify and measure...just because of this difficulty it is essential to notice that they have a role somewhat analogous to *tacit knowledge* within firms".

However, it should not be assumed that simply because tacit knowledge tends to flow through personal contact, that this mechanism is not also a useful mode of transfer for other types of transaction content, such as codified knowledge or equipment and materials. On this point, Steward and Conway (1993,4) argue that:

> "It is extremely important to maintain a clear analytical distinction between network relationships and the type of knowledge being conveyed through these relationships...While there may be a strong connection [between channel and transaction content], this should not be assumed *a priori.*"

The complexity of a message is also likely to influence the mechanism of exchange employed. Indeed, Wolek (1970,233) argues that "the probability that a communication will involve interpersonal interaction between source and receiver varies directly with the complexity of the message communicated". This is because the flexibility of interpersonal communication allows the sender and receiver to adopt mutual coding schemes, to focus on uniquely relevant relationships and to vary the format of communication in order to tackle more complex messages (Committee on Information in the Behavioural Sciences 1967, Horowitz 1968, Wolek 1970).

However, McLaughlin *et al* (1965) also note that while the first impulse may be to ask somebody, when a precise answer is required, the first impulse may be instead to look it up in the literature. With this in mind, Wolek (1970,239) argues that since science is a structured body of knowledge, which "permits scientists to breakdown many ideas and observations into messages of low complexity", scientists may be expected to be less reliant on interpersonal communication than technologists or engineers.

5.4 Explaining Informal Exchange Activity

A number of theories have been forwarded in an attempt to account for the occurrence of informal exchange between actors. These theories may be broadly pigeon-holed as either economic or sociological explanations of exchange activity.

5.4.1 Economic Explanations of Informal Exchange Activity

Hippel (1987,297) argues that at the organisation-level, "it may be possible to explain both the presence and absence of informal trading of proprietary knowhow between rivals in terms of maximising the profits (rents) which firms reap from it". That is, firms are expected to behave rationally when exchanging information. From this perspective, informal exchange activity is viewed as *economic exchange*, or what has also been termed as *informal knowhow trading* (Hippel 1987, Schrader 1991), or *bartering* (Carter 1989, Kreiner and Schultz 1993).

With evidence from his study of informal knowhow trading in the US steel mini-mill industry, Schrader (1991) argues that employees are likely to trade information in accordance with the economic interests of their firms, with factors such as friendship of secondary importance. Others are more prudent. Hippel (1987,302), for example, argues that "it is clear that the benefits to individuals actually engaged in the trading may differ from those of the firms which employ them. But they do not necessarily differ". This more cautious line is supported by Carter (1989,162), who contends that "since knowhow traders must proceed with significant autonomy, some agency problems are likely...possible sources of conflict lie in the employee's loyalty to and aspirations in his broader professional community".

5.4.2 Sociological Explanations of Informal Exchange Activity

Uehara (1990,523-524) forwards two basic reasons why the exchange concept is attractive to both sociologists and social psychologists:

> "First, a vast part of social life is characterised by the giving and reciprocating of material and intangible items, from favours, courtesies, and ideas to concessions, cattle and money. Second, individual choice and decision-making... appear essential to explaining much of social interaction. In a vast part of social life, norms and roles guide but do not completely determine interactions...The exchange framework thus represents an attractive alternative to purely *normative* explanations of social behaviour."

However, *social exchange* differs from *economic exchange* in at least two fundamental aspects. Firstly, social exchange theorists are more interested in the reciprocity obligations created by exchange than the material outcomes of the activity itself, and the implications of exchange upon the solidarity of the group. Secondly, social exchange theorists acknowledge more fully the social complexity of exchange behaviour. They argue, for example, that exchange behaviour is invariably influenced by the membership of a given dyad (Berg and Clark 1986, Miell and Duck 1986), but also highlight the relationship between exchange dyads, social structure and group solidarity (Ekeh 1974, Emerson 1976). To illustrate this last point, Uehara (1990,527) argues that "indirect reciprocity leads directly to the conception of generalised rights and duties and, logically, to such higher-order concepts as *citizenship*". This phenomenon is termed *generalised exchange* (Ekeh 1974), or more commonly, *dual exchange*.

In conclusion, Cunningham and Homse (1984,17-19) argue that with respect to supplier-customer relations:

> "The myth of the purely rational and economically motivated buyer has long since been rejected. The individuals involved in the task of buying and selling are influenced by their personalities, attitudes, education and experiences, likes and dislikes...It is unlikely that social bonds between individuals override all other considerations in other than exceptional cases...[yet] social bonds may be the only significant factor left that differentiates one supplier from another."

6. Strategic-Links and the Strength of Weak-Ties

6.1 The Homophily Principle and Isomorphism

A basic research question in past investigations of the communication within dyads, has been the degree to which the similarity of two actors affects their interaction (Rogers and Kincaid 1981). Park (1924), for example, assumed a conception of interaction in which one individual classified another by age, sex, race and social type, and behaved towards them on the basis of these stereotypes.

The degree to which interacting pairs of actors are similar in certain attributes such as beliefs, values, education and social status, is termed *homophily* (Rogers and Bhowmik 1971). While the term *heterophily* is employed to refer to the degree to which interacting pairs of individuals are different with respect to certain attributes. In addition, Rogers and Bhowmik (1971) argue that homophily-heterophily can be conceptualised at two levels; the *subjective*, the degree to which each actor in a dyadic link perceives the other as similar or dissimilar in terms of certain attributes; and the *objective*, the degree of observable similarity or dissimilarity between the two actors. Past investigations have generally indicated that these two levels of conceptualisation are positively correlated (Bender and Hastorf 1950). In relation to patterns of communication, Rogers and Kincaid (1981,127) argue that:

> "The most fundamental principle of human communication is that the exchange of ideas most frequently occurs between transceivers who are homophilous... because more effective communication occurs when the transceivers are homophilous."

Indeed, Rogers and Bhowmik (1971,529) argue that "homophily and effective communication breed each other". Thus, in contrast to linear models of communication, Rogers and Kincaid (1981,63-64) also contend that:

> "Communication is defined as a process in which the participants create and share information with one another in order to reach a mutual understanding...In other words, communication always implies relationship...By means of several iterations

or cycles of information exchange, two or more participants in a communication process may converge toward a more mutual understanding...and come within the limits of tolerance required for the purpose at hand."

While Boissevain (1974,37) notes that when:

"...information, judgements, gossip and so on, is actually exchanged on a large scale, as often happens, for example, in a small village where every one knows each other, it tends to bring about homogeneity of norms and values."

This process of convergence of norms, values, beliefs and behaviour of actors that interact on a frequent basis over time, is sometimes referred to as *isomorphism*. Isomorphism is a constraining process that forces one unit in a population to resemble other units (DiMaggio and Powell 1991).

However, whilst similarities between actors are likely to promote communication, Rogers and Kincaid (1981,128) forward the proposition that "the information exchange potential of dyadic communication is related to the degree of heterophily between the transceivers". This is because ideas, influences or information that pass between *sociometrically distant* heterophilous actors, are likely to be more *unique* and *fresh* (Granovetter 1973). Rogers and Kincaid (1981,131) thus postulate that: (1) the degree to which communication dyads have overlapping networks is negatively related to their information exchange potential; (2) the degree of heterophily in communication dyads is positively related to their information exchange potential; and (3) the degree of proximity in communication dyads is positively related to their degree of homophily.

In reality heterophilous communication is more likely to occur between actors who have at least some attributes in common, whilst remaining essentially sociometrically distant. This view is supported by Rogers and Bhowmik (1971,532), who argue that:

"For maximum communication effectiveness, a source and receiver should be homophilous on certain variables and heterophilous on some variables relevant to the situation."

6.2 The Strength of Weak-Ties

The idea that human communication typically entails a balance between similarity and dissimilarity, and between familiarity and novelty, is encapsulated by the concept of the *strength of weak-ties* (Liu and Duff 1972, Granovetter 1973,1982). The *strength* is informational, and refers to the information exchange potential of the relationship, while *weak-ties* refers to the low intensity of interaction between two dissimilar or heterophilous actors. Thus, Rogers and Kincaid (1981,128) suggest that:

> "A new idea is communicated to a larger number of individuals, and traverses a greater social distance, when it is passed through somewhat heterophilous links ...rather than through homophilous links...*Weak-ties* enable innovations to flow from clique to clique via liaisons and bridges."

This view is supported by Aldrich (1979,99), who argues that:

> "Organisations with strong ties to a small set of organisations may have members who are involved in frequent interaction, but very little new information is generated as the same opinions are recirculated through the network. Organisations with weak ties to a large set of organisations, by contrast, may have members who see persons in any particular organisation only rarely, but there is a greater potential for new information being passed on. New information is more likely to be generated because interaction in loosely coupled networks is, by definition, between organisations that have quite a few non-overlapping ties to others and thus have access to different information sources."

In addition, Boissevain (1974,22) argues that:

> "...it is no coincidence that criticism often comes from outsiders...Their social and geographic distance give them perspective, it also ensures that they are less vulnerable to counter-pressures. Those who criticise from within the system are rugged individualists...or angry young men..."

One may conclude therefore, that these heterophilous or weak-ties are important, if somewhat fragile, strategic links for the innovating organisation.

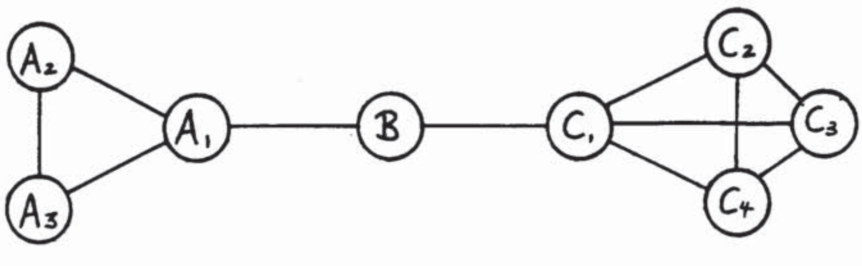
6.3 Classifying Strategic Links: A Typology

The weak-ties that link what have been termed *loosely coupled systems* (Weick 1976, Orton and Weick 1990) or *cliques* (Tichy 1981, Scott 1991), may be classified according to the number of *steps* between the original information transmitter and the final information receiver. A typology of three strategic link-types may be identified: *liaisons*, *bridges*, and *link-pins*.

6.3.1 Liaisons

A *liaison* link-type may be defined as an indirect link between two or more cliques in a network. In this instance the link is facilitated by an actor who is not himself a member of any of the cliques (Rogers and Kincaid 1981, Tichy 1981). The actor thus acts as an intermediary between two or more cliques, providing an indirect communication channel between them. This is exemplified by Figure 2.1, where actor B provides the liaison link between clique A and C via his direct link with A_1 and C_1.

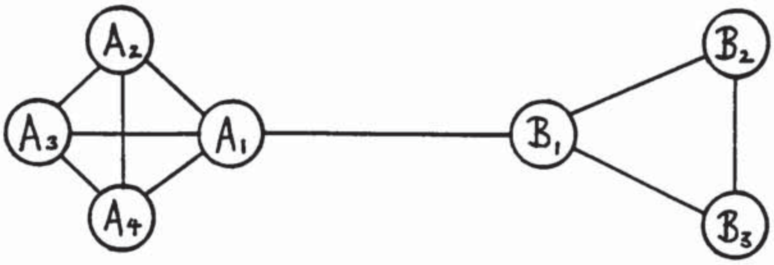
FIGURE 2.1: An Example of a Liaison



6.3.2 Bridges

In contrast, a *bridge* link-type represents a direct communication channel between two cliques by virtue of an existing relationship between an actor in each of the cliques (Granovetter 1973,1982, Rogers and Kincaid 1981, Tichy 1981). In Figure 2.2 the link between A_1 and B_1 provides the bridge between clique A and B.

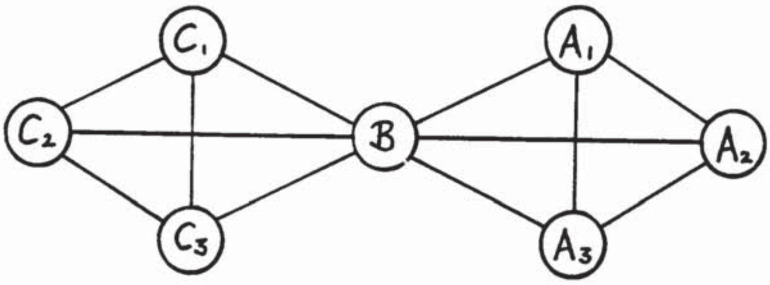
FIGURE 2.2: An Example of a Bridge



6.3.3 Link-pins

A *link-pin* is a network position rather than a link-type, since a link-pin represents an actor who provides a direct link between two or more cliques by virtue of their membership of each (Lincoln 1982). The link-pin node or position is the point at which one or more cliques may be said to *overlap* (Evan 1965). This is exemplified by Figure 2.3, where actor B provides the link-pin between cliques A and C.

FIGURE 2.3: An Example of a Link-Pin



7. Summary

This chapter provides the basis for a more systematic approach to the study of dyadic links, in order to realise their potential as a unit of analysis as identified by Rogers and Kincaid (1981). This task was approached by first identifying from a variety of literatures the *dimensions* of dyadic links, in relation to the three components of dyads: actors, links and transaction content. The subsequent sections then focused on more specific elements of dyadic links with respect to the innovation process: the classification of cognitive transaction content; the role, nature and incidence of boundary-crossing and boundary-spanning; and the role, nature and importance of informal exchange activity. The chapter then introduced the important concepts of the *homophily principle* and the *strength-of-weak-ties*, relating these to the notion of *strategic links* in the innovation process.

CHAPTER THREE: NETWORKS

1. Introduction

Relational data are central to the principal concerns of the sociological tradition, where the emphasis is upon the investigation of the *structure* of *social systems* (Marsden and Lin 1982, Scott 1991). However, there exists a spectrum of definitions for the term social system. According to Boulding (1985), the broadest possible definition of a system is "anything that is not chaos". Lundvall (1992) is more specific, viewing a system as constituted by a number of elements and the relationships between those elements. Further, Laumann and Pappi (1976,7) argue that:

> "...there exists a multiplicity of social structures in any complex social system that arises out of the many possible types of social relationships linking positions to one another."

Following on from this, Lundvall (1992,2) argues that a system of innovation:

> "...is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge...A central activity in the system of innovation is learning, and learning is a social activity, which involves interaction between people. It is also a dynamic system, characterised both by positive feedback and by reproduction."

Katz and Kahn (1966) and Weick (1969) argue that organisations too, can be viewed as social groupings with relatively stable patterns of interaction. However, Tichy *et al* (1979,507) contend that:

> "Such a model of organising, if it is to move beyond the metaphorical stage, requires a coherent framework and accompanying methods of analysis that are capable of capturing both prescribed and emergent processes."

Network analysis provides such a coherent framework, being concerned with the structure and patterning of relationships and seeking to identify both their causes and consequences. Indeed, Berkowitz (1982,vii) equates "network analysis" with "structural analysis". Fombrun (1982,280-281) argues that "network analysis is a powerful means of describing and analysing sets of units by focusing explicitly on their inter-relationships", which are "seen as *embedded* in a context that both constrains and liberates". In addition, Tichy *et al* (1979,510) contend that the framework provided by the network approach "makes it possible to compare and contrast formally prescribed and emergent relationships in a coherent fashion".

2. The Network Perspective

2.1 The Origins of the Network Perspective

The origins of the network perspective may be traced to the structural concerns of the British anthropologist Radcliffe-Brown and the German *gestalt* tradition of social psychology, principally associated with Kohler. Since this period, in the 1920s and 1930s, a diversity of strands have intersected, fused and once again diverged at various times. From this complex history, Scott (1991) identifies three main lines: the sociometric analysts (typified by Moreno 1934,1953), who produced a number of technical advances by adopting the methods of graph theory; the Harvard researchers of the 1930s (including Mayo), who explored patterns of interpersonal relations and the formation of *cliques*; and the Manchester social anthropologists of the 1950s and 1960s, in particular, Barnes, Bott and Mitchell. A diverse range of disciplines continue to contribute to the conceptual development of a network perspective, including: sociology, anthropology, political science and organisation theory (Tichy *et al* 1979).

Over the last thirty or forty years the network perspective has been adopted in a broad range of research areas, including: the study of influence in decision-making (Baldridge 1971, Wildavsky 1984); the diffusion of AIDS in the homosexual community (Klovdahl 1985); the diffusion of innovation (Coleman *et al* 1957,1966, Rogers and Shoemaker

1971); the sources of information concerning new jobs (Granovetter 1973); and the communication patterns of scientists and engineers (Allen 1970, Griffith and Miller 1970, Frost and Whitley 1971). For a review of the large number of applications of social network analysis see Mizruchi and Schwartz (1987), and Wellman and Bertowitz (1988).

2.2 Relational versus Structural Traditions

Rogers (1987) notes that there are two main research traditions of network research: *relational* and *structural*. Relational analysis evolved out of the Moreno-type network sociometry of the 1930s to 1950s. While scholarly interest in structural analysis was sparked by the development of *block-modelling* techniques by White and others at Harvard University in the mid-1970s (Boorman and White 1976, White *et al* 1976).

Relational network analysis essentially focuses on the pathways in networks and entails identifying the cliques of individuals among the members of a network. In this instance, two individuals are clustered in the same clique if they (1) interact directly with one another, and (2) share a high proportion of individuals in their personal networks. In contrast, structural network analysis focuses on patterns of similarity in relational configurations and entails identifying *blocks* of actors. Two actors are said to be *structurally equivalent*, and thus in the same block, if they have the same (or similar) pattern of relationships with other members of the system who occupy the same position (Boorman and White 1976, White *et al* 1976, Burt 1980,1982).

In this sense, Rogers (1987,11) argues that in the relational research tradition "structure emerges from communication among a set of individuals". This view is supported by Monge and Eisenberg (1987) who argue that in the relational approach structure grows out of persistent patterns of communication rather than structure prescribing how individuals should communicate. However, while Alba (1982,63) argues that "neither approach excludes the other...Indeed, they ultimately complement each other", Blau (1982) suggests that the relational approach is more useful in studying recently-formed systems and the structural approach more useful in studying well-established systems.

2.3 Mathematical versus Metaphorical Orientations

Morgan (1986,12) argues that the "metaphor is often just regarded as a device for embellishing discourse, but its significance is much greater than this. For the use of metaphor implies *a way of thinking* and *a way of seeing* that pervade how we understand our world generally". Morgan (1986) looks at a number of organisational metaphors, including the organisation as *machine*, *organism* and *brain*. In viewing the organisation as an organism, for example, the emphasis is placed on understanding the relations between organisations and their environments, while the brain metaphor draws attention to the importance of information processing, intelligence and learning. By using such metaphors to understand the complex and paradoxical character of organisational life, Morgan (1986,13) argues that "we are able to manage and design organisations in ways that we may not have thought possible".

The *network* as metaphor is also a powerful way of viewing organisations. It changes the imagery from a focus on pairs of dyadic relationships to one of "constellations, wheels, and systems of relationships" (Auster 1990,65) and of *webs* of group affiliations (Simmel 1955).

Scott (1991) notes that from the 1930s to the 1970s an increasing number of social anthropologists and sociologists began to build on Radcliffe-Brown's concept of *social structure* and, in doing so, began to take seriously the metaphors of the *web* and *fabric* of social life. As a result of this, from the 1950s a small group of specialists began to concern themselves with devising more formal translations of the metaphor. By the early 1970s an avalanche of technical work and specialist applications had appeared adopting a highly mathematical orientation. While the texts and sources of such social network techniques have, by and large, been produced by highly numerate specialists with a mathematical background, it is from these writing that the key concepts of social network analysis have emerged. Thus, network analysis methods, based on graph theory, clustering methods, and multi-dimensional scaling, have provided a means to move beyond just thinking of networks as a metaphor.

However, Rogers (1987,14) warns that "far too much, I fear, we admire mathematical elegance in our network tools and tool-makers, while largely ignoring what useful objects we can dig up with these tools". Indeed, Wellman (1983,156) argues that network analysis should be viewed "as a broad intellectual approach, and not as a narrow set of methods".

2.4 Networks and their Components

Auster (1990) stresses that networks should not be viewed as *portfolios* of dyadic linkages. Indeed, there is an assumption in the network literature that a network, like a system, is greater than the sum of its interacting parts. This potential for synergy is implied by DeBresson and Amesse (1991,364), who argue that "because interactions between firms...are iterative and broad in content, time and space, what matters is the complete set of relationships".

A network may be visualised as consisting of a set of *nodes* or *positions* occupied by actors, connected by *links* which represent the interaction between these actors. Ideas, information, goods, power and friendship, may flow through the network (see section 2.3.1 of Chapter 2). In principle such networks are *unbounded,* but the observer may for analytical purposes set suitable boundaries. The task of setting the boundary of analysis is discussed in the following chapter in section 4.

Mitchell (1969,2) defines social networks as:

> "...a specific set of linkages among a defined set of persons, with the additional property that the characteristics of these linkages as a whole may be used to interpret the social behaviour of the persons involved."

However, the network perspective is not only limited to studying the linkages between individuals, the nodes of a network can be virtually any aggregation of individuals such as a group, an organisation, a community, or even a nation-state (Fombrun 1982).

2.5 The Key Assumptions Underlying the Network Perspective

With reference to the network literature, the key assumptions underlying the network approach may be summarised as follows: (1) actors attempt to establish links to acquire resources or information concerning their environment, co-ordinate competitive inter-dependence, or reduce competitive uncertainty and thereby increase their power (Pfeffer and Salancik 1978); (2) action is viewed as intentional. Thus, ties between actors are established, maintained, or broken because of their perceived value (Cook 1982); (3) networks represent interconnected flows of resources and resource dependencies (power relations) between actors. This flow and its causes and consequences are the focus of network analysis (Pfeffer and Salancik 1978, Aldrich 1979, Cook 1982); (4) networks are dynamic, their configurations shift and change as actors attempt to gain or balance power by redistributing resources (Cook 1982); and finally (5) that the network, like a system, is greater than the sum of its interacting components (Aldrich and Whetten 1981, DeBresson and Amesse 1991)

2.6 The Visual Representation of Networks

A review of the network literature reveals the existence of a wide variety of approaches and styles to depict the relationships between a group of actors or artifacts. However, Steward *et al* (1993,1994a) synthesize this variety into a typology of three generic approaches employed in the representation of networks: tabular or matrix depictions, typical of the mathematical orientation of network analysis (*e.g.* Auster 1990,74); graphic depictions (*e.g.* Auster 1990,75 and Allen 1977,154); and a hybrid of these two generic approaches to network depiction (*e.g.* Allen 1977,156).

Steward *et al* (1994a,191) argue that the graphic approach not only "allows for easier and quicker assimilation of the data than the tabular form", but is "also able to provide information concerning the nature of the relationship...and the direction of flow...without too much visual distraction or additional cognition by the viewer". However, Steward *et al* (1994a,191) also note that "unlike geneticists, chemists, architects and cartographers, for example, social network analysts do not employ a set of recognised conventions in their pictorial representations". In response to the resulting lack of consistency in the network literature in relation to the graphic representation of network components, Conway and Overton (1994) and Steward *et al* (1994b) provide a palette of graphic options and suggest their usage for encoding both quantitative and qualitative data concerning nodes, links and transaction content.

3. The Characteristics and Morphology of Networks

This section identifies the main structural dimensions along which networks may be analyzed and compared, and highlights a number of the important network configurations and actors that network research has revealed. The purpose here is to provide clarity in what Auster (1990,68) has called the "terminological jungle" of network literature.

In studying networks of relationships, the interest for the researcher may lie with the structural or morphological features of the network itself and its implications for social behaviour (Barnes 1954, Bott 1955) or focus on the flow of content through the network (Coleman *et al* 1966, Rogers and Shoemaker 1971). Networks should be viewed as dynamic structures (Aldrich 1979, Aldrich and Whetten 1981, Cook 1982, McPherson *et al* 1992, Kreiner and Schultz 1993), with the structural dimensions of the network varying over time along side changes in the network configuration and actors. In addition, Boissevain (1974) argues that "it has been demonstrated that there is a certain feedback between values and norms and the structure of transactional relations", and that "values influence the structure of interaction, thus ultimately of the network in its morphological as well as transactional aspects".

3.1 The Characteristics of Networks

In the previous chapter a number of characteristics of dyadic relationships were identified, in order that individual dyads may be analyzed and compared with each other and over time. It is also necessary to determine a number of structural dimensions along which networks of relationships may be analyzed and compared. This view is supported by Boissevain (1974,45) who argues that:

> "Size, density, degree of connexion, centrality and clustering are all statements about the theoretical possibility of a person to interact. In the same way multiplexity, transactional content, directional flow, frequency and duration of interaction are indicators of the possible importance of various links. Together they help establish a statistical portrait of the form and content of a persons network."

3.1.1 Size

This dimension simply refers to the number of actors participating in the network (Tichy *et al* 1979, Auster 1990). However, the potential size of the network under investigation is most often dictated by some arbitrary boundary set by the researcher. In addition, the number of actors within that boundary which are actually revealed to the researcher will depend on a number of factors, including the methods employed for data collection.

3.1.2 Density

The density of a network refers to the "extensiveness of the ties between elements [actors]" (Aldrich and Whetten 1981,398). That is, the number of actual linkages in the network as a ratio of the total number of possible linkages. Aldrich and Whetten (1981) note that this dimension can be operationalised in one of three ways: (1) as the number of *holes* in the network, that is, the number of missing links; (2) as the extent to which one actor influences another, such that values are assigned to links on the basis of the influence of one actor over another; and (3) as the distance between actors, such that the number of *steps* between two actors is inversely related to the strength of the relationship. This dimension is also sometimes termed *connectedness* (Tichy *et al* 1979, Rogers and Kincaid 1981). However, Boissevain (1974,37) argues that "It must be stressed...that network density is simply an index of the potential not of the actual flow of information". Boissevain (1974,40) also argues that:

> "There is obviously a relationship between size and density, for where a network is large the members will have to contribute more relations to attain the same density as a smaller network."

In addition, network density tells us nothing of the internal structure of the network itself and as Boissevain (1974,40) points out "...networks with the same density can have very different configurations".

Tichy (1981) extends this network dimension by referring to: *organisational density*, the proportion of members of a given organisation who participate in a given network; *occupational density*, the proportion of all of the occupations of a given organisation who participate in a given network; and *vertical density*, the proportion of hierarchical levels of a given organisation encompassed in a given network. Occupational density and vertical density may be related to the network dimension of *diversity*.

3.1.3 Diversity

This network characteristic refers to both the number of different types of actor, which may be measured along a number of dimensions (Auster 1990), and the number of different types of linkage, in a given network (Burt *et al* 1983). Whilst the former is particularly relevant to *transaction-defined* networks as opposed to *attribute-defined* networks (see section 4.2 of this chapter for a definition of these two network terms), the latter is applicable to both types of network.

3.1.4 Stability

Tichy *et al* (1979,508) define this dimension as "the degree to which a network pattern changes over time". Auster (1990) expands on this, by referring to the frequency and magnitude of change of the actors and linkages in a given network. Auster (1990) also argues that stability will vary between sectors, with office equipment and computer industry networks, for example, being more fluid than those in more mature industries, such as automobiles. The sources of network stability are discussed later in this chapter.

3.1.5 Openness

This network dimension is defined by Tichy *et al* (1979,508) as "the number of actual external links in a social unit". That is, the number of links between a given network and other networks. Tichy (1981) extends this to ask whether the participants in a given network are cosmopolitans or locals.

3.1.6 Centrality

Tichy *et al* (1979,508) define this network characteristic as "the degree to which relations are guided by the formal hierarchy". More commonly, centrality is defined as the proportion of the sum of relations within a network that involve a given actor (Burt 1980). This view is supported by Aldrich and Whetten (1981,399), who note that "the more points that can be reached and the shorter the aggregate distance to these points, the higher the centrality of a point".

3.1.7 Reachability

This network characteristic has been defined as the number of links separating two actors in a network (Aldrich and Whetten 1981, Tichy 1981), but also, the average number of links between any two actors in a given network (Tichy *et al* 1979).

3.1.8 Visibility

This network dimension refers to the degree to which uninvolved observers can determine who participates in the network (Tichy 1981). However, since, "network analysts search for *deep-structures*, regular patterns beneath the often complex surface of social systems" (Wellman 1983,157), Rogers (1987,8) argues that "the social structure revealed by network analysis is generally invisible to the participants in the system of study". One would expect this to particularly be the case for studies of informal or social networks.

3.1.9 Integration and Proximity

In relation to personal networks, Rogers and Kincaid (1981) define *integration* as the degree to which the members of an individuals network are linked to each other, and *proximity* as the degree to which two actors have overlapping communication networks.

3.2 Configurations of Networks

3.2.1 Clusters and Cliques

The densely inter-connected regions in networks are often termed *clusters*. In addition to prescribed clusters such as work-groups and committees, Tichy (1981) identifies two types of emergent clusters of special interest: *coalitions* and *cliques*. Coalitions are viewed as temporary alliances, akin in *action-sets* discussed in section 4.2, while cliques are long-lived and pursue a broader range of purposes. Warner and Lunt (1941,110) see the clique as "an intimate non-kin group", varying in membership from two to thirty or more. This view is supported by Scott (1991,20) who defines a clique as "an informal association of people among whom there is a degree of group feeling and intimacy and in which certain group norms of behaviour have been established". In addition, Tichy (1981,228) argues that cliques "are the smallest clusters, and they generally form to meet the expressive and affective needs of organizational members".

In terms of graph theory, Scott (1991,117) defines the clique as a "subset of points in which every possible pair of points is directly connected by a line and the clique is not contained in any other clique". In addition, Scott (1991) notes that in graphs where only reciprocal relations are considered, the cliques that are detected are termed *strong cliques*. Where asymmetric links are also considered, Scott (1991) notes that subsequent analysis results in the identification of what are termed *weak cliques*.

In relation to the dynamism and flexibility of cliques, DeBresson and Amesse (1991,371-372) argue that:

> "Contrary to initial intuition, it is not the density of internal relationships that provides dynamism...On the contrary, close-knit clique relationships between partners in a network, while they allow for resilience in the collaboration, are resistant to change. Cliques are typical of cartels and stable oligopolies, not dynamic networks of innovators. Quite the opposite, weak ties have a more dynamic effect (Granovetter 1973). Incomplete graphs open to outside linkages seem to represent the more dynamic networks."

Indeed, Aldrich and Whetten (1981,388) argue that "a loosely joined system reaps the benefits of size and specialization of function, and remains flexible enough to cope with a wide range of contingencies". As such, loosely joined or coupled systems are able to adapt more readily to changes in complex and dynamic environments. In addition, Aldrich (1979,99) argues that:

> "Organisations that are part of large, loosely coupled information networks are more likely to have members exposed to news concerning innovations than in small, tightly coupled networks."

Aldrich (1979,99) also notes that "social movements often generate a large, loosely coupled information network within which information spreads rapidly". However, Aldrich and Whetten (1981,388) point out that there are also disadvantages to loosely coupled systems, through the "inevitable increase in communication delays and ineffectiveness across the entire system".

3.2.2 Radial and Interlocking Networks

In their work concerning the diffusion and communication of innovation through personal networks, Rogers and Kincaid (1981,347-348) distinguish between what they term *interlocking* networks and *radial* networks. Here they define interlocking networks as those "in which an individual interacts with a set of dyadic partners who interact with each other", and radial networks as those "in which an individual interacts with a set of dyadic partners who do not interact with each other". Thus, interlocking networks can be seen as synonymous with cliques and, in contrast to radial networks, are dense and highly connected.

FIGURE 3.1: An Example of a Radial Network

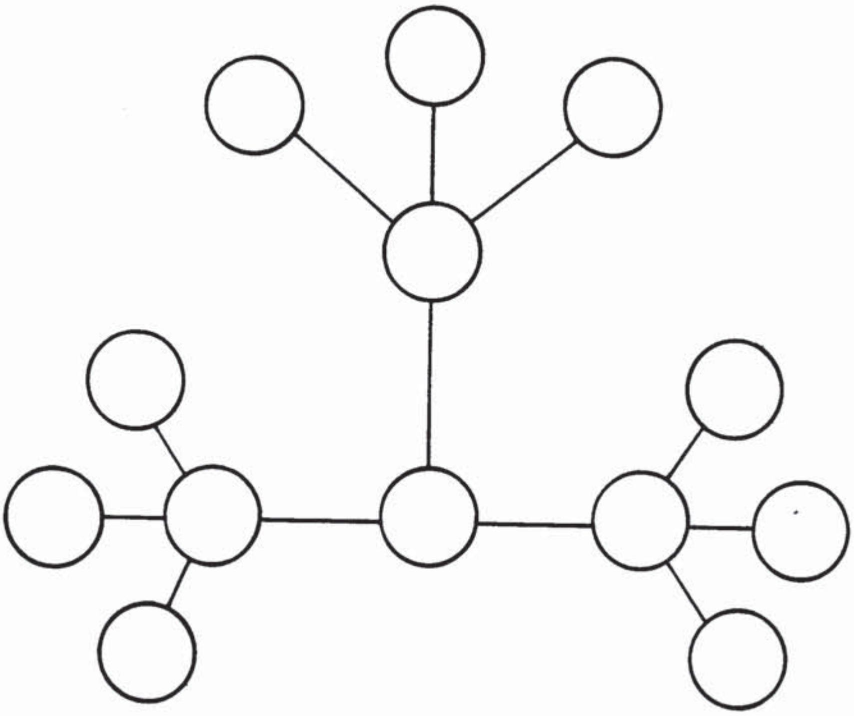
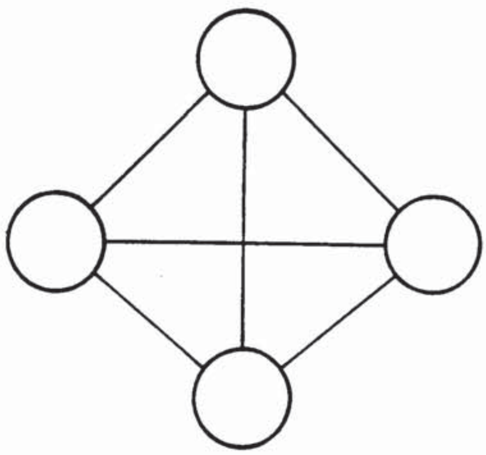


FIGURE 3.2: An Example of an Interlocking Network



With respect to the innovative capacity of these two types of networks, Rogers and Kincaid (1981,136) argue that

> "...interlocking personal networks are more numerous than radial networks. The reasons for this tendency toward integration in personal networks may be the same as those facilitating the homophily principle...Unfortunately, the ingrown communication patterns in interlocking personal networks discourage the exchange of new information with the environment beyond the personal network. Interlocking personal networks lack openness...[and] may simply facilitate the pooling of ignorance among the individual members."

3.3 Key Networking Roles

In addition, to the key networking roles introduced in the previous chapter (gatekeeper, liaison, bridge and link-pin) two further roles will be briefly discussed: those of the *star* and the *isolate*. In the network literature a *star* is defined "as the individual with the highest number of nominations [links]" (Tichy *et al* 1979,508) and as "a participant who has many relationships with other participants" (Tichy 1981,229). In sharp contrast, Tichy (1981,229) defines an *isolate* as "a person who has no relationships to others", or in the words of Tichy *et al* (1979,508), an actor who is "uncoupled from the network".

4. The Focus of Analysis in Studying Networks

4.1 The Total Network versus Partial Networks

Mitchell (1969,12) conceptualised what he termed the *total* network of a society as "the general ever-ramifying, ever-reticulating set of linkages that stretches within and beyond the confines of any community or organisation". As a result of this, Mitchell (1969) argues that the researcher must always select particular aspects of the total network for attention, what he termed *partial* networks. This process of selecting partial networks for further study is commonly termed *abstraction* (Scott 1991). The network literature reveals two approaches to the selection of network actors, which should be employed by researchers in combination: the first focuses on rules of inclusion based on the attributes and/or participation of the actors themselves, termed the *definitional* focus (Laumann *et al* 1983); the second relates to the manner in which the abstraction is *anchored* or *centred*, which may be around a particular actor or group of actors, for example (Scott 1991). This may be termed *nodal-anchoring*. These two approaches to abstraction are summarised in Table 3.1 overpage.

TABLE 3.3: Approaches to Abstracting Partial Networks			
Definitional Focus		**Nodal-Anchoring**	
Network Type	**Description**	**Network Type**	**Description**
Attribute Network	Inclusion rule based on specified attributes of the actors themselves.	Socio-Centred Network	Focus of analysis centred on group of actors within network.
Transaction Network	Inclusion rule based on actor participation in specified relationship.	Ego-Centred Network	Focus of analysis on centred around single actor within network.
Action-Set	Inclusion rule based on actor participation in specified event.	Action-Centred Network	Focus of analysis on group/single actor involved in event.

4.2 Abstraction and Definitional Focus: The Rules of Inclusion of Actors

Laumann *et al* (1983) identify three sets of components, or what they term *definitional foci*, for establishing the rules of inclusion of actors in a network: actors, relations and activities. In establishing the *partial network* to study, network analysts may select one or more of these three sets of components in which to *anchor* the abstraction. However, Laumann *et al* (1983,22) argue that "the choice of a definitional focus is of importance in that it fixes certain features of the network while leaving the remaining features free to vary". With respect to the stipulation of inclusion rules based on two or more of these sets of components, Laumann *et al* (1983,24) also argue that:

> "While this may lead to theoretically elegant definitions of memberships, it also has a major weakness, in that it reduces the number of problematic features to be explained given knowledge of network structure".

The first and most commonly employed definitional focus is the use of an inclusion rule based on some attribute or characteristic of the actors or nodes in the network under investigation. This approach would thus focus on what have been termed *attribute* networks. Fombrun (1982,280) defines attribute networks as those that link actors who share a commonality. Thus, good examples of this approach in the innovation field are provided by a number of studies of networks of scientists (Crane 1972) and engineers (Allen 1970,1977, Frost and Whitley 1971).

The second definitional focus often adopted is that of selecting actors on the basis of their participation in some specified type of social relationship. In contrast to the first approach, this method focuses on what have been termed *transaction* networks. Fombrun (1982,280) defines transaction networks as those which focus on the exchanges that occur among a set of actors. Transaction networks may thus be considered to be akin to *exchange* networks. Since transaction content may include affect, power, information and goods (Tichy *et al* 1979), as discussed in section 2.3.1 of Chapter 2, transaction networks may be seen to encompass friendship networks, influence networks, communication networks and economic or exchange networks. A good example of this approach is provided by Kreiner and Schultz (1993), in their study of the formation of informal collaboration networks in the Danish bio-technology sector.

The third definitional focus which is sometimes utilised by network analysts, is that of adopting an inclusion rule based on some event or activity. In this approach, participation in the event or activity serves to select individual actors and the social relationships among them. This method may be employed to construct what are termed *action-sets*. Mitchell (1969,39-40) argues that the action-set:

> "...is delineated in terms of the specific transaction that brings it into being...An action-set may be looked upon as an aspect of a personal network isolated in terms of a specific short-term instrumentally-defined transactional content: the personal network itself is more extensive and more durable."

In this sense, the resulting network may be viewed as a special kind of transitory transaction network, established to achieve some desired end (Mitchell 1969, Aldrich and

Whetten 1981). Good examples of this approach in the innovation field are therefore provided by diffusion studies, such as those of Coleman *et al* (1957,1966), and Rogers and Shoemaker (1971).

4.3 Abstraction and Nodal-Anchoring

Scott (1991) argues that there are two bases on which such abstraction can proceed:

> "First, there is abstraction which is *anchored* around a particular individual so as to generate *ego-centred* networks of social relations of all kinds. Second is abstraction of the overall, *global* features of networks in relation to a particular aspect of social activity: political ties, kinship obligations, friendship or work relations."

In the first approach identified by Scott (1991), the researcher focuses on the relations of a single actor in the network population, sometimes referred to as the *focal-actor*. Ego-centred networks or *focal-nets* have also been termed *personal* networks at the level of the individual (Rogers and Kincaid 1981), and *organisation-sets* at the level of the organisation (Evan 1965, Aldrich 1979, Aldrich and Whetten 1981). The term *social* network has been used more loosely in the network literature, sometimes in relation to primarily ego-centred networks of individuals (Bott 1955), while in other cases referring to socio-centred networks of individuals (Boissevain 1974). A good example of this approach in the innovation literature is provided by Auster (1990), in his study of the technology transfer behaviour of individual companies.

The concept of an ego-centred network is derived from Merton's (1957,369) concept of *role-set*, which he defines as "that complement of relationships which persons have by virtue of occupying a particular social status". As noted in section 2.7 of the previous chapter, actors occupy various social statuses or positions, termed their *status-set* (Aldrich 1979). The status-set of an individual may include, for example, employee, husband and club member (Boissevain 1974), while for an organisation, this may include the status of retailer in relation to its customers and buyer in relation to its suppliers (Aldrich 1979). Thus, for each status or position an actor occupies, a role-set or ego-centred network may be constructed (Merton 1957, Aldrich 1979). The concept of role-set is therefore akin to the concept of partial network of Barnes (1969) and Mitchell (1969). In addition, Aldrich (1979,279) also notes that:

> "Many of the dimensions used for structural analysis of networks can be applied to organisation-sets. Size, density, diversity and stability all tap different features of an organisation-set that are useful for comparing organisation-sets of different organisations or of the same organisation over time..."

This point is equally as valid for the analysis and comparison of personal networks.

The second approach identified by Scott (1991) is focused on a population of actors rather than a single actor. This is sometimes referred to as a *socio-centred* approach. Such a network is constructed by first identifying the presence of a specified type of tie defined by the researcher, such as friendship or joint-venture, between each of the actors in the population under study. The identified links are then mapped out between the actor population. A good example of this approach in the innovation field is provided by Hagedoorn and Schakenraad's (1992) study of strategic partnering in a number of the high-technology sectors, such as microelectronics and tele-communications.

In addition to the two nodal-anchoring approaches forwarded by Scott (1991), a third may be added which may be termed *action-centred*. This focus is identical to the third definitional focus described in section 4.2 above, in which an inclusion rule is based upon an actors participation in some event or activity. An action-centred approach focuses on transitory networks which may be inherently ego-centred (for example, studies based around the development of specific innovations, such as this research) or socio-centred (for example, diffusion studies, such as those of Coleman *et al* 1957, 1966, and Rogers and Shoemaker 1971, mentioned earlier). However, Aldrich and Whetten (1981,387) contend that socio-centred and ego-centred networks differ from action-centred networks (action-sets), in that they are both "constructs of an investigator who derives them as part of a strategy for analysing...relations".

FIGURE 3.4: An Example of an Ego-Centred Network (Steward *et al* 1994b,15)

FIGURE 3.5: An Example of a Socio-Centred Network (Hagedoorn and Schakenraad 1992,21)

4.4 Direct and Indirect Relationships

Actors in a network can be seen to have direct relations with a range of other actors, and indirect relations with a further group of actors with whom their direct contacts have, in turn, direct relations. Barnes (1969) has labelled the direct and indirect links to a given focal actor in terms of *stars* and *zones*. The *primary star* is the set of direct links with a given focal actor, while the *primary zone* includes both this set of direct links and any inter-connections between those actors linked directly to the focal actor. This may be extended to incorporate indirect links several times removed from the focal actor. For example, the *secondary star* includes the primary zone and any other direct links with those actors linked directly to the focal-actor.

4.5 Open and Closed Networks

Epstein (1961) suggested that the division of networks into *open* and *closed* types (Bott 1955), could be applied to different parts of a given personal network. He argued that the relatively closed parts of a personal network form an *effective* network, and the relatively open parts, form an *extended* network. Epstein (1961) used this idea to explain how the norms and values of local elites in a town percolated into the ranks of the non-elites with whom the elites themselves had no direct contact. The open and closed networks of Bott (1955) are akin to the radial and interlocking networks of Rogers and Kincaid (1981).

This dichotomy into effective and extended networks is also addressed by Katz (1966), who distinguishes between: *actual networks*, those links which are latent or activated and are currently in ego's network; *potential networks*, the possible networks of which ego can be a member; and *proximate networks*, the persons with who ego is likely to establish contact. With this in mind, Mitchell (1969,43) argues that:

> "There is an element of individual choice, therefore, in the make-up of any person's network, in the sense that the individual seeks to establish and maintain contact with a number of persons in terms of his interests in them, while he sees no point in extending casual contacts with a large number of others."

4.6 Prescribed and Emergent Networks

Organisational charts and job descriptions generally reflect the formal or *prescribed* network in a given organisation. Such prescriptions are often guided by the missions and strategies of the organisation (Chandler 1962), even though their explicitness may vary greatly between one organisation and another. In contrast, informal or *emergent* networks refer to the informal relations that emerge over and above prescribed patterns of interaction (Tichy *et al* 1979, Tichy 1981). Both prescribed and emergent networks may transcend the organisational boundary. Allen (1977) employs the term *formal organisation* to refer to formal or prescribed networks, and *informal organisation* to refer to informal or emergent networks. In addition, Crane (1972) uses the term *social* organisation to refer to informal or emergent networks.

Tichy (1981,227) argues that "metaphorically, a prescribed organizational network provides pegs from which emergent networks hang" and that "variations in a prescribed network therefore alter the emergent networks". However, research has indicated that other factors, such as proximity or expressive and affective needs (Moreno 1934, Maisonneuve 1952), also affect emergent networks.

Tichy *et al* (1979) argue that the degree to which the prescribed and emergent networks overlap, is dependent upon whether the organisation is *mechanistic* or *organic*. The mechanistic organisation uses bureaucratic principles to design, plan and prescribe roles. Thus, the influence and information channels are likely to be highly prescribed. In addition, given high task certainty, individuals will have little discretion in their choice of work-related contacts. In contrast, organic organisations are most effective when there is high task uncertainty. Since complex or highly variable tasks can not be pre-programmed, it is likely that informal relations arise to accomplish them (Burns and Stalker 1961). Thus, Tichy *et al* (1979,514) contend that:

> "This implies that the emergent network of interaction will closely follow the prescribed network in a mechanistic setting...[while] in organic organisations, emergent networks may differ considerably from prescribed networks."

Tichy (1981,225) argues that "social networks play important roles in business organizations", since "unplanned structures...emerge because organizations are so complex that plans can never anticipate all contingencies". However, Tichy (1981, 225) also warns that "such emergent networks can be dysfunctional as well as functional". The importance of social or informal networks to innovative organisations is also highlighted by Kreiner and Schultz (1993,189) who argue that:

> "In recent years, the traditional boundary activities bridging the company to its environment has been supplemented with a host of collaborative ventures...Most noticeable, probably, is...when it takes the form of strategic alliances and other formalised collaborative structures. Increasingly, we are becoming aware that much of such collaboration is also pursued along unpaved paths in the undergrowth of less formalised, personalised networks."

However, Tichy (1981,227) notes that "despite pervasive references to emergent structures in organizations...there has been very little systematic theorizing. Even fewer empirical studies of emergent structures exist".

5. Network Dynamics

Networks are not static structures. A number of researchers have highlighted the importance of studying networks over time to generate greater understanding of the dynamism of networks (Aldrich 1979, Aldrich and Whetten 1981, Cook 1982, Birley *et al* 1991, Stork 1991, McPherson *et al* 1992, Kreiner and Schultz 1993).

With reference to a number of network studies concerning network stability, Rogers and Kincaid (1981) postulate that: (1) spatially proximate links are more stable; (2) reciprocated links are more stable; (3) homophilous links are more stable than heterophilous links; (4) and links representing ascribed, rather than achieved, interpersonal relationships (such as kinship links) are more stable.

Aldrich and Whetten (1981,391) argue that "the ultimate predictor of network stability is the probability of a link failing, given that another has failed". The following two sections introduce a number of factors, highlighted by the network literature, that affect the probability of a dyadic link failing and hence the stability or instability of a network.

5.1 The Sources of Network Instability

Merton (1957) identifies five sources of instability in role-sets, that are also applicable to organisation-sets: (1) differing intensities of interaction with the focal actor among those in the set; (2) differences in the power of those involved in the set; (3) differences in the insulation of role activities from observability by members from the set, such that deviance is not easily detected; (4) differences in the observability by members of their conflicting demands upon the focal actor, resulting in members being reluctant to reduce their demands; and (5) differences in access to support from outside the set.

Aldrich (1979,280) argues that "only the focal organisation has a stake in the maintenance of the set as a set, and its troubles are compounded by each organisation pursuing its own unique interests". This is equally true in terms of a individual and his ego-centred personal network.

Aldrich (1979,321) also argues that "action-sets are fragile structures, as they bind organisations that usually have an inherent conflict of interest. Thus, stable and effective action-sets only emerge under a fairly limiting set of conditions".

5.2 The Sources of Network Stability

Aldrich (1979) and Aldrich and Whetten (1981) identify a number of sources of network stability: (1) duplication or overlap of relations of one actor with other actors, sometimes termed *redundancy*; (2) multiple relations between two actors. This is especially so for organisations when the multiplicity of ties is between a number of different boundary-spanners and external actors; (3) kinship ties. Indeed, Aldrich and Whetten (1981,393) argue that "kinship ties are probably the most stable basis of an inter-organizational relation"; and (4) environmental factors, such as non-competitive market structures, bureaucratising pressures and the manipulation of dependence relations. In addition, DeBresson and Amesse (1991,370) argue that "local networks are reinforced by personal, cultural and symbolic networks".

5.3 The Visual Representation of Networks Over Time

From a review of the network literature Steward *et al* (1993,1994a) identify three generic approaches to the visual representation of networks over time: graphic *small-multiples* (Tufte 1983), resembling a series of frames in a movie; tabular representations; and matrix depictions. Steward *et al* (1993,15) argue that the visual power of graphics and the highly narrative content of small-multiples enable "the viewer to rapidly establish morphological changes in the network".

6. Social Organisation in Science and Innovation

The concept of network has been employed to examine many configurations in science and technology since the early 1960s, such as: in the study of scientists (Crane 1972); technologists and engineers (Allen 1977); technical artifacts (Hughes 1983); and of innovating firms and their partners and collaborators (Hakansson 1989, Hagedoorn and Schakenraad 1992). Wolek and Griffith (1974) argue that much of this body of research has been encouraged by the search for ways to stimulate science and technology, and as such has received extensive support from policy-makers.

Of particular interest to this work is the body of research that has focused on the social organisation and communication patterns of scientists, engineers, and entrepreneurs. Thus, the principal focus is on the social attribute networks of individuals as opposed to the industrial networks of organisations. For an overview of the literature concerning networks of innovating organisations see DeBresson and Amesse (1991) and Freeman (1991).

6.1 The Social Organisation of Scientists and Engineers

6.1.1 Networks of Scientists

One of the central approaches to the sociology of science during the late 1950s to early 1970s, was the study of science as a social system. That is, science was treated not as a body of knowledge or as a set of methods and techniques, but as an organised social activity guided by a set of shared norms.

The earliest work on the social organisation of science focused on defining the principal norms governing scientific activity (Barber 1952, Merton 1957). These writings were later to be considered as an idealised conception of science (West 1960, Barber 1962, Merton and Barber 1963, Hagstrom 1965, Barnes and Dolby 1970, Duncan 1974). As a result of this, a number of writers have argued that scientific behaviour should be viewed as pluralistic rather than monolithic (Krohn 1961, Hill 1974, Mitroff 1974). That is, the behaviour of scientists is influenced both by their professional socialisation and their institutional setting.

From the early 1960s the emphasis began to shift towards a focus on the communication patterns of scientists and, through the adoption of a network perspective, an interest in the social structure of networks of scientists (Price 1963, Price and Beaver 1966, Crane 1969,1972, Garvey *et al* 1970, Griffith and Miller 1970, Lin *et al* 1970). In the early 1970s, with the work of Crane (1972) and Griffith and Mullins (1972), a more conscious effort was made towards linking the models of the growth of scientific knowledge, such as that of Kuhn (1962), to the social organisation of scientists.

Studies concerning the communication patterns of scientists have repeatedly shown the crucial role of informal personal networks, and the informal mechanisms through which the individual dyads of these networks are operationalised, to the science information system (Herner 1954, Menzel 1962, Lin *et al* 1970, Wolek and Griffith 1974). For example, in their study of 277 *visible* researchers in the field of geophysics, Lin *et al*

(1970) found that 73% of respondents had been acquainted with the specific work described in a sample of articles from high profile journals, on average, a year prior to the article's publication. Of these cases of prior acquaintance, Lin *et al* (1970) found that 90% had been sourced through "strictly informal" channels, with 80% of the respondents reporting that this information had proved useful in their work. The usefulness of this informally acquired information must have been significant, since Lin *et al* (1970,50) also note that 50% of the respondents "were led, by information gained from pre-publication sources, to re-interpret their own work in the area".

Research has also thrown light on the social organisation of scientists across organisational boundaries. Studies have shown, for example, the importance of two types of subgroups: *solidarity groups* and *invisible colleges* (Price and Beaver 1966, Crane 1969,1972). The solidarity group consists of a group of collaborators which, under the leadership of one or two highly productive scientists, recruits and socialises new members, and maintains a sense of commitment to the area among existing members (Crane 1972). The invisible college is the apex or elite of a specialty, formed by the highly productive scientists who communicate with each other and transmit information informally across the whole field (Price 1961,1963). In this way, the invisible college forms a communication network that links the various solidarity groups in a given speciality (Crane 1972). Indeed, Allen (1977,137) contends "it is probably safe to say that for university scientists this is a far more salient social system than is the university that employs them". In relation to the role of invisible colleges and solidarity groups within a given speciality, Price (1963,85-90) argues that:

> "...[invisible colleges] effectively solve a communication crisis by reducing a large group to a small select one of the maximum size that can be handled by interpersonal relationships...[while the creation of solidarity groups] partly solves the problem of organising the lower-level scientists so that they can be directly related to the research life of the elite."

Price (1963,85-86) goes on to argue that one of the critical characteristics of the invisible college is its informal structure, and that:

> "Possibly, if such groups were made legitimate, recognised and given newspaper-like broadsheet journals circulating to a few hundred individuals, this would spoil them, make them objects of envy or of high-handed administration and formality."

However, Price (1963,91) also warns that an invisible college is self-perpetuating and has "a built-in automatic feedback mechanism that works to increase their strength and power within science".

Crane (1972,13) argues that since social and ideational links hold various segments of knowledge together, "no research area is completely isolated from other areas". Hence, Crane (1972) suggests that the concept of *social circle* best describes the social organisation of the entire set of members in a research area. Kadushin (1966) identifies a number of characteristics of social circles: (1) their exact boundaries are difficult to define; (2) each member is usually aware of some but not all other members; (3) indirect interaction mediated through intervening parties is an important aspect; and (4) there is no formal leadership although there are usually central figures.

6.1.2 Networks of Engineers

The social organisation and communication patterns of engineers or technologists has also been an area of research interest, with much of the work being undertaken between the mid-1960s and late 1970s. However, while research has also indicated the importance of emergent or informal social and communication networks in technology (Allen 1970,1977, Frost and Whitley 1971), Marquis and Allen (1966, 1052) argue that:

> "...the communication patterns in the two areas of activity [science and technology] are not only largely independent of one another, but qualitatively different in their nature."

The variations in the social organisation of scientists and engineers can in part be explained by differences in the norms and values in science and technology. Unlike scientists who are able to organise and interact informally across organisational boundaries, Allen (1977,40) argues that engineers "are limited in forming invisible colleges by the imposition of organizational barriers". This is because the vast majority of technologists or engineers are employed by profit-orientated organisations and are thus excluded from external informal communication in two ways: firstly, they must work on problems that are of interest to their employer, and secondly, they must refrain from early disclosure of research results in order to maintain the competitive advantage of the organisation. Allen (1977,41) argues that "both of these constraints violate the rather strong scientific norms that underlie and form the basis of the invisible college".

However, Debackere *et al* (1994) view the concept of *enforced localism* in technology as increasingly constraining. Hippel (1987,296), for example, has noted that despite organisational constraints to informal communication across organisational boundaries, "on an anecdotal basis...we have found informal knowhow trading apparently quite common in some industries, and essentially absent in others". In his study of the US steel mini-mill industry, Schrader (1991) also found extensive evidence of what he termed *informal knowhow trading* between engineers in competing firms. Larson and Rogers (1984,79) highlighted the importance of friendship networks, job mobility, social foci and spatial proximity to the "free-wheeling information exchange" between engineers in competing micro-electronics companies in Silicon Valley. In addition, Kreiner and Schultz (1993) note the importance of what they term *bartering* or informal collaboration between universities and industry in the Danish biotechnology sector, while Hughes (1987) has clearly demonstrated that technologists do disseminate their knowledge via papers and patents. Nelson (1990) argues that there are industry-wide efficiency gains to be had by such sharing of technology.

Variations in the information processing systems of science and technology may also be expected to bring about differences in the communication behaviour of scientists and engineers. On this point Allen (1977,3) argues that:

> "The information-processing system of science has an inherent compatibility between input and output. Both are in verbal form...In technology, on the other hand, there is a fundamental and inherent incompatibility between input and output...The technologist must obtain his information either through the very difficult task of decoding and translating physically encoded information or by

relying upon direct personal contact and communication with other technologists."

Thus, Allen (1977,46) argues that "despite all the discussion of informal contact and invisible colleges among scientists...it is the engineer who is more dependent upon colleagues". However, because of the imposition of organisational boundaries, Allen (1977,40) argues that engineers "keep abreast of their field by close association with co-workers in their organization". Research concerning the internal communication patterns of engineers within organisations (Allen 1970,1977, Tushman and Katz 1980) highlight structures akin to the solidarity groups and invisible colleges of the social organisation of science. Allen (1977,155-157), for example, notes from his study of seventeen R&D departments that:

> "When the departmental networks of the organisation are reduced [to strong components]...two things become apparent. First, the formation of strong components is not aligned with formal organisational groupings, and second... nearly all of the gatekeepers were found together as members of the same strong component...new technology generally enters the organisation through one of the members of this component, is readily disseminated among them, and then spreads to the remainder of the organisation through contacts that they have with colleagues outside the component."

From this description it is possible to visualise such a gatekeeper network operating as an invisible college within the organisation, linking the various project or solidarity groups together. Allen (1977,161) argues that "it is difficult to imagine a system better than that of the gatekeeper network for connecting the organisation to its technological environment".

6.2 Social Organisation and Growth in Science and Technology

There exist a number of models of the growth of knowledge, from those that stress continuous cumulative growth to those that stress its absence, and those that include periods of continuous cumulative growth interspersed with periods of discontinuity. In an example of this latter model, Kuhn (1962) proposes that the growth and development of scientific knowledge in a particular field occurs as a result of the development of a paradigm or model of scientific achievement that sets guidelines for research. As a result, the attention of scientists is focused and scientific knowledge grows in a systematic and cumulative fashion. After a period of what Kuhn (1962) terms *normal* science, phenomena that the paradigm can not explain become inescapable and the field goes through a period of crisis during which a new paradigm is proposed and eventually accepted. In another version of this model, Kroeber (1957) argues that the period of growth leads to a kind of crescendo of activity ending in an exhaustion of the ideas that had stimulated the growth. Crane (1972,34) attempts to link the growth of knowledge in a research area to the social organisation of the respective scientific community, arguing that:

> "...exponential growth of a research area reflects a social interaction process in which contact between scientists contributes to the cumulative growth of knowledge. This suggests that there is an interaction between cognitive events and social events in the development of a research area that parallels the stages of the logistic curve."

The social interaction process to which Crane (1972) is referring to here, is the model of solidarity groups linked by an invisible college, discussed in section 6.1.1.

However, Price (1970) argues that neither the humanities nor technology exhibit the type of cumulative or logistic growth that occurs in the basic sciences. Crane (1972,85) contends that "this suggests that a different sequence of intellectual and social events occurs in their development". Kuhn (1962) attempts to explain this by arguing that in those fields that lack paradigms, or experience lengthy periods of confrontation between paradigms, members fail to agree about the important problems and the methods for solving them, and as a result knowledge is not cumulative. In addition, Crane (1972,95) contends that "the less precise the paradigm, the more room for disagreement, and the less likely that large numbers of researchers will accept it and choose to work on it". This general view is supported by Price (1970), who argues that the growth of literature in the humanities is entirely unstructured. Price (1970) also notes that new developments in the humanities are based on a random raiding of the entire archive of the literature, in contrast to the basic sciences which rely on a small number of recent contributions.

It is worth noting that there exist specialities in both the humanities and technology that exhibit the cumulative growth of so-called normal science, for example, sociology (Crane 1972) and micro-electronics (Larson and Rogers 1984). The cumulative growth of micro-electronics can at least be partly explained by the existence of norms akin to the scientific ethos and the extensive and vibrant invisible colleges in the Silicon Valley during the 1980s (Larson and Rogers 1984). Indeed, Debackere *et al* (1994) contend that the boundary between what has often been referred to as the *scientific community* and *technological activity* is fading. As a result of this trend, Rappa and Debackere (1992) propose that the behaviour of academic researchers and industrial researchers should be studied at a more holistic level, that is, at the level of the *technological community* or *R&D community*. Debackere *et al* (1994,22) view such a community as consisting of "scientists and engineers working towards the solution of an inter-related problem set, who are dispersed across both private and public sector organisations", through which "information and knowledge flow quite freely". However, Debackere *et al* (1994,32) also argue that such an R&D community "allows for openness and secrecy at the same time".

6.3 Entrepreneurial Networks

Johannisson and Peterson (1984,1) note the apparent paradox of entrepreneurship: that while on the one hand "the entrepreneur personifies individualism and independence", on the other "he is...very dependent on ties of trust and cooperation". Indeed, research has indicated the importance of boundary-spanning links to the innovation process of entrepreneurs (Johannisson and Peterson 1984, Leonard-Barton 1984, Birley *et al* 1991, Shaw 1993) and SMEs (Rothwell 1991, Rothwell and Dodgson 1991, Lawton-Smith *et al* 1991). With this evidence in mind, Aldrich and Zimmer (1986,9-11) argue that "comprehensive explanations of entrepreneurship must include the social context of behaviour, especially the social relationships through which people obtain information, resources and social support".

The personal networks of entrepreneurs can be seen to play a number of important roles: to generate social support for the actions of the entrepreneur; to extend the strategic competence of the entrepreneur in relation to the identification of opportunities and threats; and to supplement internal resources to resolve acute operating problems (Johannisson and Peterson 1984). Thus, the personal network should be viewed as an important, and sometimes critical, resource of the entrepreneur. Leonard-Barton (1984,113) argues that "entrepreneurs who, for geographic, cultural or social reasons, lack access to *free* information through personal networks, operate with less *capital* than do their well-connected peers". In addition, Aldrich and Zimmer (1986) contend that:

> "Within complex networks of relationships, entrepreneurship is facilitated or constrained by linkages between aspiring entrepreneurs, resources and opportunities...[and] reflects the interaction of chance, necessity, and purpose in all social action."

In relation to the individual linkages of the entrepreneurial network, Johannisson and Peterson (1984,3) argue that they "are multi-stranded involving unique syntheses of instrumental, affective and moral [bonds]", in contrast to the bureaucratic desire "to separate the strands and in particular to focus in on instrumental [bonds] only". Johannisson and Peterson (1984,4) also argue that to be effective the personal network of the entrepreneur "must become as complex and as heterogeneous as the daily activities of the venture in which he engages (Ashby 1965)". Indeed, Gibson (1991,117-118) contends that:

> "The more extensive, complex and diverse the web of relationships, the more the entrepreneur is likely to have access to opportunities, the greater the chance of solving problems expeditiously, and ultimately, the greater the chance of success for a new venture. The fewer, less dense and more homogeneous the web of relations the less likely it is for a new technology venture to succeed."

However, inherent in the maintenance of such a network is the need for the entrepreneur to continually establish and strengthen *weak-ties*, in order to prevent a few select *strong-ties* from dominating and closing the personal network to opportunities and alternatives (Johannisson and Peterson 1984, Leonard-Barton 1984, Aldrich and Zimmer 1986). It is for this reason that Birley *et al* (1991,58) contend that "networks do not emerge without considerable endeavour".

In summary, the entrepreneurship literature highlights the importance of the need for the entrepreneur to continually build, nurture and maintain an extensive and diverse personal network, in order to gather intelligence, supplement internal resources and provide moral support.

7. Summary

By drawing upon a variety of literatures, the intention of this chapter has been to synthesise and map-out the key concepts of the network approach. In doing so, this chapter is intended to provide a framework for the study of individual dyads or relations within the context of a social system or structure. This is the true methodological value of the network approach, in that it allows the simultaneous study of phenomena at both the micro (dyadic) and macro (network) level. Many of the applications of the network perspective to the study of science and technology have focused on general scientific and technological endeavour through the construction of socio-centred attribute networks. It is the intention of this research to focus on specific cases of innovation through the study of their action-centred networks.

In conclusion, Aldrich and Whetten (1981,404) argue that:

> "As more insights are gained into the substance of linkages...and the processes which generate them, the field will be able to progress beyond the current descriptive mode of research and begin making predictions about network characteristics using comparative samples."

In doing so, it is hoped that research will be capable of answering questions such as "to what is the most useful shape for innovation networks", raised by DeBresson and Amesse (1991,372).

CHAPTER FOUR: METHODOLOGY

1. Introduction

DeBresson and Amesse (1991,363) argue that "the network approach has something original, useful, and durable to bring to innovation studies". Indeed, they contend that "the concept of network may provide a bridge between disciplines" in a period in which knowledge about technology is fragmented (Clark 1987), and enable social science researchers to "overcome this artificial division between the economic unit and its environment". In addition, Tichy *et al* (1979,507) argue that "the social network perspective is an example of a theoretical framework that has developed to the point of guiding data collection as well as data analysis". However, while DeBresson and Amesse (1991,366) note that the attraction of the network approach may reside in its compatibility with a variety of disciplinary approaches, they warn us that "such a catholic appeal...may breed confusion".

The network approach offers a particularly useful tool for the systematic study of informal communication and interaction in the innovation process. On the one hand, it allows for the detailed analysis of individual dyadic links, while on the other, it provides a framework for exploring the multiple sources and pluralistic patterns of communication and collaboration typical in the development of innovative products and processes.

The focus adopted in this research has attempted to combine and draw upon the two traditions employed in innovation studies since the 1960s concerning the sources of ideas. The first of these traditions may be classified as a socio-centred attribute network approach, focused on the social organisation and communication patterns of engineers and scientists, for example, and relating to general innovative activity (Menzel 1962, Griffith and Miller 1970, Lin *et al* 1970, Allen 1977). The second, focused on innovative activity leading to specific novel products and processes (Myers and Marquis 1969, Langrish *et al* 1972, Hippel 1976,1977a,1977b), can be seen to be largely pre-occupied with the sources of ideas and the mechanisms of exchange, rather than the network of actors and links. However, studies from both of these traditions have largely ignored the origin and nature of the relationship between source and recipient actors in the innovation process.

This research then, has adopted what may be classified as an action-centred network approach, focused on the flow of ideas and information leading to specific novel products and processes. That is, the actors in the network were selected through the identification of the source and flow of relevant transactional content, rather than by specific attributes of the actors themselves. Indeed, the data-collection and analysis methodology follows the advice of Fombrun (1982,281) who argues that "the preferred strategy of organisational research is the initial focus on transactional (or exchange) networks, with a subsequent search for suitable explanatory attributes". Such an approach provides a useful framework for the analysis of the relevant source-recipient dyads, the transactional content, and the morphology of the action-centred network (action-set) involved in the development of specific innovations.

2. Innovation Sample

2.1 Single-Site versus Multiple-Site Case Analysis

Miles and Huberman (1984,1994) note that the researcher has the option of either single-site or multiple-site case analysis. Bryman (1989) suggests that the principal advantage of the latter is the greater potential for generalisability of results. In essence, the multiple-site approach avoids the possible idiosyncrasies of detailed single-site case analyses. This view is supported by Miles and Huberman (1984,151), who contend that:

> "Having multiple sites increases the scope of the study and, thereby, the degrees of freedom. By comparing sites or cases, one can establish the range of generality of a finding or explanation, and, at the same time, pin down the conditions under which that finding will occur. So there is much potential for both the greater explanatory power and greater generalisability than a single case can deliver."

Innovation studies adopting a socio-centred network approach tend to be either single-site (*e.g.* Menzel 1962) or focused on a single discipline (*e.g.* Lin *et al* 1970). This is hardly surprising because of the effort required in undertaking the necessary data collection. However, many of the studies of the sources of innovation may be classified as multiple-site case analyses (*e.g.* Myers and Marquis 1969, Langrish *et al* 1972). In these cases, data collection is generally limited to the actors and activity that led to specific instances of product or process innovation.

Following in the tradition of such classic studies as *Wealth From Knowledge* (Langrish *et al* 1972), this research has adopted a multiple-site case analysis approach. The principal motivation behind this choice was the hope that more generalisable results would be obtained.

2.2 Innovation Sampling Techniques

Having decided upon a multiple-site case analysis approach, the next critical step was to determine the manner in which an appropriate sample of innovations could be selected. Miles and Huberman (1994,29-30) argue that:

> "Multiple-case sampling...has to be thought through carefully. An explicit *sampling frame* is needed. It will be guided by the research questions and conceptual framework...random sampling will not help."

To aid in this process, Miles and Huberman (1994) provide a broad typology of sampling strategies available to the *qualitative* researcher; this is detailed in Table 4.1 overpage. The typology may be applied to either within-case (single-site) or across-case (multiple-site) sampling decisions. Further, sampling strategies are not mutually exclusive, but may be combined to focus the sample.

TABLE 4.1: Typology of Sampling Techniques in Qualitative Enquiry (Adapted from Miles and Huberman 1994)	
Type of Sampling	**Purpose/Description**
Maximum Variation	To document diverse variations and common patterns
Homogeneous	To focus, reduce and simplify
Critical Case	To permit logical generalisation
Theory Based	To find examples of a theoretical construct
Dis/Confirming	To elaborate initial analysis and seek exceptions
Snowball/Chain	To build sample dynamically
Extreme/Deviant	To learn from highly unusual manifestations
Typical Case	To highlight what is normal or average
Intensity	To locate information-rich cases of certain case types
Political Case	To avoid/attract attention to study
Random Purposeful	To add credibility when purposeful sample too large
Stratified Purposeful	To illustrate subgroups and facilitate comparison
Criterion	To locate cases of given criterion
Opportunistic	To follow new leads and advantage from unexpected
Convenience	To save money, time and/or effort
Comprehensive	To examine every case in given population
Quota	To examine instances of identified subgroups
Reputational	To build sample on recommendation of experts
Comparable	To select cases to promote replication over time

A wide variety of sampling techniques have been employed by earlier innovation studies to select innovation samples: (1) award-winning innovations - *criterion* (Utterback 1971, Langrish *et al* 1972); (2) innovations selected from industry trade journals (Peck 1962, Greenhalgh 1971, Shaw 1985); (3) innovations selected by recourse to industry experts - *reputational* (Hippel 1976, Voss 1985, VanderWerf 1990); (4) innovations representing complete or partial new product development portfolios of selected companies -

comprehensive (Peplow 1960, Mueller 1962, Spital 1979); (5) innovations selected by the respondents themselves (Sowrey 1989); (6) radical innovations - *extreme* - identified from various sources within a particular time-frame (Hamberg 1963, Jewkes *et al* 1969) and within a particular industrial sector (Enos 1962).

2.3 Innovation Sampling Technique Adopted in the Study

It was decided that the innovation sample would be selected with reference to recent winners of two high-profile UK innovation award schemes: The Queen's Award for Technological Achievement and the British Design Award. Both awards emphasise commercial achievement or potential as well as novelty, and are cross-sector and nation-wide schemes generating a combined annual sample of around 50 innovations. This approach may be classified as drawing upon three sampling strategies (each described in Table 4.1): *criterion,* as focused on winners of specific awards representing instances of successful innovation; *reputational*, as these award-winners were selected by a panel of industry experts; and *quota*, since the award panels selected the innovations to represent a breadth of industrial categories (explicitly in the case of the Design Award).

This is a very similar approach to the *Wealth From Knowledge* study, which investigated the 1966-69 Queen's Award winners for innovation. With respect to this selection technique, Langrish *et al* (1972,4,13) argue that:

> "Rather than select our own sample, we used one that was selected independently of us...Whatever biases may have gone into the selection of these award winners, they were at least not put in by us so that we could examine the [innovation] histories without feeling that our conclusions might have been determined at the outset by preconceptions which we brought to the initial step of picking the cases...However, because of the emphasis in the Queen's Award scheme on the use of new technology, the sample is possibly representative of the kind of innovations which make important contributions to national wealth."

The Queen's Award for Export and Technology, dating back to 1965, are considered by some to be the highest corporate honour awarded to British businesses. Applicants for either of these awards must satisfy stringent criteria. With respect to the Queen's Award for Technological Achievement, awarded to around 30-40 companies annually, winning innovations are scrutinised by specialist committees and must exhibit:

> "A significant advance, leading to increased efficiency, in the application of technology to a production or development process in British industry or the production for sale of goods which incorporate new and advanced technological qualities. Innovation by itself, however, is not enough...applicants must also provide evidence of a product's commercial success" (Queen's Award Office 1992).

The British Design Awards are received by around 15-20 companies each year as a "mark of achievement awarded by peers of the design industry to products that are exemplars of good design" (The Design Council 1989). Innovations are entered under one of seven product categories: engineering, components, motor industry, medical equipment, computer software, contract goods, and consumer goods. Winning products are assessed using the following criteria:

> "International design innovation in the concept of the product. Benefits in manufacturing, particularly in the effective use of materials and resources. Outstanding appearance, ergonomic features...Good functional performance and reliability...Good commercial performance..." (The Design Council 1989).

With reference to the above selection criteria, it can be seen that Queen's Award winning innovations tend to represent more major developments with a longer commercial track-record than Design Award winners.

Although the combination of the two award schemes provides a broad cross-section of innovations for study, it is probable that some organisations are more likely to apply for these awards than others. Langrish *et al* (1972,63) point out, for example, that in the Queen's Award scheme:

> "Many of the awards are applied for by the sales organisation of the firms concerned and it might be that award-winning firms have sales organisations which are more on the look-out for new publicity angles than firms who do not apply for awards."

3. Issues Relating to Existing Network Research

There are a number of issues that have been identified in the network literature that relate to areas of weakness in existing network research. These issues were high-lighted early on in the research project in order that they would be addressed in the data-collection and data-analysis stages of the study.

3.1 An Underemphasis on Data-Gathering

Rogers (1987,17) argues that "without good data, network analysis is worthless", but notes that "network scholars have stressed making advances in computer network analysis programs at the expense of learning how to improve the quality of their network data". This view of an under-emphasis on data-gathering and an over-emphasis on data-analysis by network analysts is supported by Alba (1982), among others.

3.2 Shortchanging Network Message Content and Time

Alba (1982) argues that network analysts have focused mainly on the *form* of networks, while largely ignoring the *content* of the information that flows through network links. Rogers (1987,19) suggests that "perhaps a major reason for ignoring network content is due to our overwhelming dependence in network data-gathering upon sociometric, who-to-whom questions".

In addition, Rogers (1987,19) argues that "past network research has mainly been cross-sectional in nature, thus ignoring time as a variable". However, a few network scholars have effectively brought time into their studies, including Klovdahl's (1985) investigation of the diffusion of AIDS among the homosexual community, and the study of Hagedoorn and Schakenraad (1992) concerning the trends in strategic alliances and joint ventures between leading firms in a number of information technology sectors.

3.3 Theory-Less Orientated Research

Rogers (1987,14) argues that "while we can easily point to numerous important network data-analysis contributions, it is much more difficult to identify really significant theoretical advances". Indeed, this view is supported by Burt (1980,134) who contends that "the lack of network theory seems to me to be the most serious impediment to the realization of the potential value of network models in empirical research". Granovetter (1979) has called this the *theory-gap* in network studies.

One such important network theory is the *strength-of-weak-ties* (Granovetter (1973), which is employed in this study and discussed in Chapters 2 and 3. In this instance, Rogers (1987,14-15) recognises both the attractiveness "of its seemingly paradoxical nature" and the fact that network scholars altered their methods of measuring networks as a consequence.

3.4 Network Sampling and Generalisability

Due to the interdependent nature of network actors, no fully adequate procedure for *within-case* network sampling has been determined (Rogers 1987). Indeed, Knoke and Kuklinski (1982,30) argue that:

> "Conventional statistical analyses of social data are premised on the random sampling of units of observation...Network data, consisting of relations among interdependent actors, clearly violates the random sampling assumption and make problematic the application of conventional statistical procedures."

Another problem in network sampling arises from the difficulty in specifying network boundaries. Indeed, Barnes (1979,416) argues that "networks are interesting but difficult to study since real-world networks lack convenient natural boundaries". However, the network researcher must also be wary of natural boundaries, since as Alba (1982,43) argues, "natural boundaries may at times prove artificial, insofar as individuals within the boundaries may be linked through others outside of them".

3.5 Incongruity and the Unit of Analysis of Actors

A review of the network literature reveals that the unit of analysis of actors of most network studies remains consistent, *i.e.* at the level of the individual or the organisation. Thus, Frost and Whitley (1971) and Allen (1977) focus on technologists as their unit of analysis, while Hagedoorn and Schakenraad (1992) focus on organisations. Where the unit of analysis of actors is constant, as in the above network studies, then the link between actors is *meaningful*: for example, links between technologists may represent formal work relationships, while links between organisations may represent joint ventures.

However, this study in attempting to investigate the multiple sources of information and pluralistic patterns of collaboration typical in the development of innovative products and processes, incorporates more than one unit of analysis of actors: individuals and organisations. The problem arises when a link is identified as existing between an *individual* and an *organisation*. This incongruency occurs since while it is individuals within organisations rather than organisations themselves that interact, there are many instances in which an individual in one organisation is linked to a *faceless* individual in another, by virtue of their organisational roles.

This problem may be resolved with recourse to the network literature concerning *block-modelling* (Boorman and White 1976, White *et al* 1976, Light and Mullins 1979). Block-modelling is essentially a technique for compounding or aggregating social relationships between actors into *blocks* which are *structurally equivalent*, that is, groups of actors which tend to exhibit the same pattern of relationships. Thus, in block-modelling, the concept of structural equivalence is akin to the concept of social role (Boorman and White 1976). Indeed, Light and Mullins (1979,87) argue that "a block empirically defines a social role". In this *bottom-up* approach, data is held concerning the relationships both within and between each block.

It would appear useful in this research to borrow two of these ideas from the block-modelling literature: firstly, that of a block defining a role; and secondly, that of a block representing an aggregate of actors, considered here as a *black-box*. In this way, a network could thus be envisaged as incorporating a series of blocks representing a range of aggregations of actors, from an individual to an entire organisation. From this perspective, the incongruency may be resolved.

4. Setting the Boundary of Analysis

Establishing the boundaries of the network under investigation, is one of the fundamental issues that need to be addressed when conducting research employing the network perspective. Yet despite this, few published studies have been explicit in specifying the researchers *rules of inclusion*. Laumann *et al* (1983,18) argue that "the problem of boundary definition should be given conscious attention" and that "care must be given to specifying the rules of inclusion" in relation to both "the selection of actors or nodes...and to the choice of types of social relationships to be studied". In addition, Mitchell (1969,40) argues that:

> "Clearly some limit must be put on the number of links to be taken as definitive for any specific network, otherwise it would become co-extensive with the total network. This difficulty is resolved by fixing the *boundary* of the network in relation to the social situation being analyzed...There can be no general rule."

This view is supported by Fombrun (1982,288) who argues that "if there is no agreed on boundary to an inter-organisational network, the choice of the boundary should reflect the purposes of the researcher and the research hypotheses of the study". However, Crane (1972,14) contends that "the amorphous character of research areas complicates the problems of defining the membership of the social circles". Auster (1990) argues that the approach through which boundaries are drawn up is a critical step in the research process, since it creates the sample of linkages that are examined. Laumann *et al* (1983) also note that carelessness, in what they term *system specification*, can distort the overall configuration of the network. With this in mind, Fombrun (1982,288) warns that the "conclusions drawn from the study must be carefully scrutinized for the possibility of alternative explanations grounded in the effects of the untapped networks".

4.1 The Nominalist versus the Realist Approach

Laumann *et al* (1983) highlight two methods for establishing the research boundaries in network analysis. The first of these methods is termed the *nominalist* approach, where the boundaries are defined by the researcher according to certain selection criteria. The second method is termed the *realist* approach, where the boundaries are constructed by those within the network itself. It must be noted however, that the realist approach inherently incorporates nominalist qualities, since those actors included in the sample reflect the selection criteria of the researcher and his expectations of the system boundaries (Auster 1990).

There are elements of both a nominalist and realist approach in this research. On the one hand, respondents were asked to identify the relevant actors in the innovation process, on the other, the *relevance* of a given actor was embodied within the interview questions. In this sense, the respondent selected a sample of actors within the constraints set by the interviewer.

4.2 Abstraction: Definitional Focus and Nodal-Anchoring

Parsons (1951) argues that a social system may be differentiated in any number of ways depending on the questions the analyst is interested in answering. However, it is also true that certain bases of social differentiation are likely, in any given empirical case, to be of special salience and significance (Blau 1975). That is, the rules of inclusion adopted in a research project are inextricably linked to the research question.

Since this research is based on the investigation of the development process of a series of discrete innovations, it was felt that the most appropriate definitional focus for the inclusion of actors (see Chapter 3, Section 4.2) was one that selected actors by their participation in a specified event or activity. Thus, the emphasis was laid on the construction and mapping-out of action-sets, as opposed to attribute or transaction networks. In relation to nodal-anchoring (see Chapter 3, Section 4.3), this approach is clearly action-centred. However, since each development project was undertaken by one, or in some cases two or three, identifiable actors, the approach may be viewed as ego-centred within a broader action-centred focus.

This research project then, has adopted what may be classified as an action-centred network approach, focused on the source and flow of ideas and information leading to specific novel products and processes. As noted earlier, the methodology adopted in this study has attempted to combine and draw upon the two traditions employed in innovation studies since the 1960s, concerning the sources of ideas.

With respect to the adoption of this action-set/action-centred approach, Aldrich and Whetten (1981,386) argue that "focusing on resource flows or boundary-role interaction avoids the problem of mixing transitory or ephemeral relations with enduring or consequential ones". While Laumann *et al* (1983,24) note that "both the composition (in terms of the attributes of actors) and the relational pattern of a network are empirically at issue, while participation in the event...is predetermined".

4.3 Incorporating Direct and Indirect Relationships

Aldrich and Whetten (1981,400) note that "a problem related to the linkage-identification issue is how far investigators should go in recording and analysing indirect, as opposed to direct, ties...". A number of existing studies (*e.g.* Levine 1972, Allen 1974) have only dealt with direct ties between actors in their samples, even though many indirect ties were also present. However, as Milgram's (1967) work on the small-world phenomenon implies, if one continues to add steps between network nodes, eventually an entire society is encompassed by the sample. It seems sensible to argue that it is not so much that the researcher needs to tread a middle ground between these two extremes of linkage recording, but that the sample needs to reflect the requirements of the research question at hand. In addition, the resource limitations of the researcher will constrain the boundary of investigation.

Since the study was to focus on around thirty to forty innovations, resource constraints were certainly seen as an important factor in limiting the investigation primarily to direct links, prior to data collection. However, because of the interest in the role of liaisons, bridges and link-pins in the innovation process, indirect links were pursued if they existed in relation to channels providing transaction content of high *exchange value* to the innovation project under study.

5. Data Collection

5.1 Tight versus Loose Research Designs

The conventional image of qualitative field research is one that keeps pre-structured research designs to a minimum. However, Wolcott (1982,157) contends that although there is merit in open-mindedness and willingness to enter the *field* looking for both questions and answers, "it is impossible to embark upon research without some idea of what one is looking for and foolish not to make that quest explicit". Further, Miles and Huberman (1994) argue that the degree of pre-structuring depends on a number of factors, including the experience of the researcher, the time available, how much is already known about the phenomena under study, the instruments available, and the analysis that will be made.

For the inexperienced researcher, Miles and Huberman (1994,17) advocate *tighter*, more structured qualitative research designs, since they provide "clarity and focus" while containing "diffuseness and overload". In addition, Miles and Huberman (1994,18) argue that tighter research designs are more appropriate for multiple-site studies, since they "yield more economical, comparable, and potentially generalisable findings".

5.2 Qualitative Data Collection Techniques

Earlier studies of the sources of innovation have tended toward the adoption of quantitative techniques of data collection, such as structured interviews and questionnaires, to identify the key actors, links and inputs in to the innovation process. It became evident from an early stage in this research project that the desire to learn more about the nature, origin and operationalisation of the source-recipient links themselves, would require a more qualitative approach to data collection. This view was based on the contention of Bryman (1989,141) that:

> "The proximity of the qualitative researcher to organizational phenomena contrasts sharply with the distance between researcher and subject that much quantitative research involves."

Indeed, Boissevain (1974,46) argues that in researching networks "subjective evaluation must be added, for it works as a necessary correction to an over-reliance on the quantitative indices of content and structure". While Mitchell (1969,31) contends that:

> "Sociometrists have used questionnaires successfully in collecting information for constructing sociograms...But the detailed information needed for the construction of a sociogram is limited...It seems, therefore, that questionnaires should play a supportive rather than a major role in the study of more general sociological situations, where contents may vary and other characteristics of the network are likely to be significant."

There exist three main techniques of data collection associated with qualitative research: participant observation, unstructured and semi-structured interviewing, and the examination of documents (Bryman 1989). The choice of interviewing as the means of data collection was quickly established through the ruling out of the other two techniques. As a retrospective study of successful innovation observation was not an option, while the nature of the data sought concerning relationships between individuals and organisations was unlikely to be recorded in documentation.

In the event, a semi-structured interviewing approach was adopted. This allowed the interviews to be guided by a pre-existing schedule, centred on fairly well-formed research questions, while providing flexibility to depart from that schedule where interesting themes emerged during the discussions. In addition, it was also noted that given time is one of the most common reservations to organisations allowing access to researchers (Bryman 1989), semi-structured interviews would probably be more efficient in eliciting information than unstructured interviews.

5.3 The Stages of Data Collection and the Approach Adopted

The field-work was undertaken in three stages: the pilot study in the spring of 1992, involving four companies; the first phase of the main study during the early summer of 1992, incorporating the 1991 award-winners and involving eighteen companies; and the second phase of the main study conducted later that same summer, incorporating the 1992 award-winners and involving a further twenty companies.

5.3.1 Access to the Award-Winning Organisations

The Queen's Award Office and Design Award Office were contacted in December 1991 and May 1992 for information concerning the names and addresses of the award-winning organisations in 1991 and 1992, respectively. Both were extremely cooperative: the Queen's Award Office providing copies of the official press release documents, that detailed the award-winners, their addresses, contact names, and brief descriptions of the innovations; the Design Award Office providing copies of the official award presentation packs, detailing the award-winners, their addresses and a page summary of each innovation. This provided an original sample of 59 award-winners from 1991, and 49 from 1992. Accounting for joint award-winners, the number of award-winning innovations was actually 52 in 1991 and 45 in 1992.

Letters were sent to all but four of these award-winners: briefly explaining the purpose of the research; requesting information concerning the award-winning innovation and the organisation itself; and enquiring about the possibility of access to undertake interviews with the key people in the development. The initial response (around 60%) to this request was extremely positive, with only four negative replies from a total of sixty three. Such a good response had not been anticipated, since experienced researchers such as Bryman (1989,161) had warned that:

> "In much the same way that survey research can engender uncomfortably low response rates, qualitative researchers often report considerable difficulty in getting access to organisations."

This response rate may be accounted for by the fact that people like to talk about their successes and achievements. In addition, in an attempt to circumvent such problems of access, recourse was made to the advice of experienced organisational researchers. Buchanan *et al* (1988,56), for example, advise the use of "non-threatening language when explaining the nature and purpose of your study" and the researcher to "deal positively with respondents' reservations with respect to time and confidentiality".

TABLE 4.2: Breakdown of 1991/92 Award-Winners and Final Sample

	Queen's Award		Design Award		Total
	1991	1992	1991	1992	
No. of Winners	40/33	38/34	19	11	106/95
No. of Letters Sent	38	36	17	11	102
No. of Replies	25	21	10	7	63
No. Unwilling	1	2	1	0	4
No. Unavailable	9	5	2	1	17
No. Available	15/13	14/13	7	6	42/39
Pilot Sample	3/3	0	1	0	4
Final Sample	12/10	14/13	6	6	38/35

In the event, the final sample incorporated a total of thirty five innovations, representing 37% of the award-winning innovations, and a total of thirty eight organisations, representing 36% of the award-winners. This does not include the pilot sample of four innovations, which were not included in the main study. Much of the *fall-out* between the initial response and the interview process arose through the unavailability of relevant individuals in the time-frame of the field-work.

In terms of both the nature of the innovations and the innovators themselves, the sample investigated in this research is relatively broad in relation to earlier studies. With respect to organisational size, the sample of innovators incorporates: 12 (34%) small organisations (less than 50 employees); 6 (17%) medium-sized organisations (50 to 500 employees); and 17 (49%) large organisations (greater than 500 employees). In this classification of organisational size, subsidiaries and divisions of larger companies were pigeon-holed according to the size of their parent. Where an innovation was jointly-developed, the size of the larger partner was used for classification.

In addition, the sample of innovative products and processes can be seen to be drawn from a wide range of industrial sectors. These may be grouped under eight broad headings: scientific, medical and educational equipment (5); industrial and agricultural chemical products and processes (3); engineering products (5); engineering components (3); software products (5); consumer goods (4); electronic, communications and computer products and components (7); and pharmaceutical products and processes (3). The figures in brackets indicate the number of innovations in each group.

5.3.2 The Pilot Study

Prior to the main study, a pilot study involving interviews within four award-winning organisations was undertaken. The requirement for a pilot study was stimulated by three factors. The first, was the need to gain general experience of the interview process. The second, involved the need to experiment with the level of pre-interview knowledge, concerning the innovation and innovating organisation, necessary for the smooth running of the interview. This concern was based on the contention of Crane (1972,2) that:

> "Few sociological problems are so complex as that of understanding the social institutions that produce ideas...[since] in dealing with these types of phenomena,

> the sociologist is faced with the problem not only of understanding the social relationships between individuals but also understanding the ideas themselves, which can be highly technical and abstruse."

The pilot interviews highlighted the problems of confusion and wasted time that arose through insufficient knowledge of the innovation in particular, but to a certain extent the innovating organisation as well. Subsequently, in the main study, information concerning the innovation and innovating organisation was sought, primarily from the organisation itself, and thoroughly digested prior to the respective interview.

Finally, the need to experiment with the approach to eliciting both the strong and the weak-ties during the innovation process, was recognised as important. This recognition was drawn from Rogers (1987) and Scott (1991), who note that experience in social science research has highlighted the difficulty that some respondents have in answering what are termed *unlimited choice* questions, such as 'Name ten informal relations at work'. Indeed, some interviewees find such questions time-consuming and tedious. In addition, Crane (1972,46) found that:

> "The degree of perceived difficulty seemed to depend on whether the respondent thought that he was being asked to list every possible influence or only those that had been especially important."

A form of *roster choice*, dynamically updated during the interview process, was found to work well.

5.3.3 Data Sought in the Interview Process

For each of the innovations under investigation, the interview process first sought to identify the range of inputs into the innovation process. The role (impetus, concept, feature or solution), origin and importance (*exchange value*) of these inputs was then determined. For those inputs that were found to be sourced externally, further information was then sought concerning a number of dimensions of the source-recipient relationship, including: the nature of the dyadic link (exchange of friendship, power, information or goods); the degree of formalisation; the degree of reciprocity or *symmetry*; the extent of *multiplexity* (ie. single or multiple links); and the strength or intensity of the relationship.

The task of each interview was thus to gather as much information as possible concerning the three components of *relevant* dyadic relationships: the source actors, their relationship with the innovating organisation, and the nature and flow of transaction content.

5.4 Issues of Respondent Accuracy

5.4.1 Retrospective Data

Research by Bernard *et al* (1982) concerning informant accuracy in the reporting of past communication found that: (1) asking respondents about the significance or importance of their interactions with others produces no better results than simply asking them who they talked to; (2) in general, the more recent the time *window* in which respondents reported communication, the more accurate they tended to be; and (3) over all, respondents recall less than half of their communications. In conclusion, Bernard *et al* (1982) go as far as contending that what people say about their communications bears no useful resemblance to their behaviour. In explaining this dissonance, Bernard *et al* (1984) note that research has indicated the effects of memory *decay* or *drift* (Sudman and Bradburn 1973) and systematic distortion due to cultural training (Shweder and D'Andrade 1980) on informant accuracy.

Despite these findings, Bernard *et al* (1984) contend that the acceptable degree of accuracy of informant responses concerning past events in a given study, is related to the explicitness of both the formal theory employed and the purpose of the research. In addition, Bernard *et al* (1984,496) also argue that on the whole the validity and accuracy of informant responses may be taken in their *naive senses,* "because most anthropological theory is too unexplicit to permit more specific or subtle determinations". Crane (1972,17) outlines a more practical argument, in relation to her study of the social organisation of scientists:

"In order to assess the nature of the social relationships in these areas and the manner in which they had changed over time, it was essential to obtain information from individuals who had published in these fields at different times. This meant that some respondents were replying about events that had taken place many years ago...it was considered preferable to have such information in spite of possible unreliabilities inherent in retrospective replies."

With respect to the nature of the sample of innovations and the information sought concerning their development, this latter view was taken by the researcher.

5.4.2 Respondent Bias

Crane (1972,45) also noted that in collecting sociometric data from respondents, one must be wary that "they may tend to include persons of higher status than themselves and omit persons who are of the same or lower status". However, Crane (1972) was able to obtain at least partial validation through citation analysis of the literature in the research areas under investigation. Such validation is not so easy in the study of technological developments, since the technologist is less motivated to report the details of his innovations in the literature because of confidentiality and issues of commercial exploitation (Crane 1972, Allen 1977).

5.4.3 Respondent Omissions

One key methodological problem arising from the network approach outlined, is ensuring that the individual respondents within each of the innovating firms provide the full and relevant information about linkages and so enable the action-set to be fully mapped-out by the researcher. This is of particular importance since bridges are defined in network theory as weak-ties (Granovetter 1973). Thus the research problem is to avoid "only tracing out strong links" (Collins 1982,47). One must therefore be wary about traditional sociometric techniques that "tend to discourage the naming of those weakly tied to the respondent, by sharply limiting the numbers of choices allowed" (Granovetter 1973,353). For "those ties which are furthest from the forefront of a respondents mind could for some innovating networks be the most important...a lack of consciousness of a source of knowledge is not the same as a lack of importance" (Collins 1982,47-60).

A useful approach that may be adopted is the *roster choice* method (Roistacher 1979, Rogers 1987), in which respondents are asked, for example, to select individuals from a list of work colleagues with whom they have informal relations. Indeed, this was the method adopted in the interview process, with the questions structured to identify the full range of ideas sources and check the responses of the interviewees. However, Roistacher (1979,484) warns that with large groups of actors this method may "require extensive preparation, administration, and coding time".

5.4.4 Informants and Inaccessible Respondents

Except in extraordinary circumstances, the questioning of a respondent yields more accurate information than the questioning of a informant concerning that respondent (Zelditch 1961). However, Singer (1972) notes a number of reasons why informants might be substituted for respondents: (1) economy, in terms of the time and cost of data collection; (2) where it is impossible to gain access to respondents; and (3) where there is reason to distrust the validity of the information provided by the respondent.

In this project, a combination of resource constraints inherent in multiple-site studies, limiting the interviews to the focal actor (the award-winner), and access and time constraints typical of much organisational research, limiting the interviews to only one or two of the respective project team-members, meant that informants frequently spoke for both themselves and for others involved in the innovation process. However, this was felt to be at least partly overcome by only including those organisations in the study sample where access to one or more of the key actors in the development of the respective award-winning innovations was possible.

In addition, it was noted that a study by Singer (1972,611) of the responses of informants and patients suffering from Parkinson's disease concerning a number of questions relating to daily functioning and social participation, found that:

> "...when questions are relatively objective, when informants have a high degree of observability with respect to respondents, when the population is fairly homogeneous, and when the setting of the interview provides no clear-cut motivation to distort responses in one direction or another, the information obtained from informants is likely to match that given by respondents reasonably well, and differences between them are likely to be small and random."

6. Data Analysis

6.1 Case-Study versus Network Analysis Approaches

DeBresson and Amesse (1991,371) argue that "in the beginning of any new field, case studies are necessarily descriptive, searching for the relevant issues and the hypothetical causes". With regard to existing innovation network research, they note that "part of this preliminary work is still going on. But measurement and formalisation of network analysis is already occurring". However, DeBresson and Amesse (1991,371) also argue that "formalisation and measurement may be premature" since "any formalisation exercise has an aesthetic seduction...the more abstruse the mathematics, the more magical the seduction". Thus, they believe that some causal hypotheses and theories should emerge before a concerted effort is made toward the measurement of innovation networks. This research has in fact attempted to take a middle-path between these two analytical poles: on the one hand drawing upon the narrative text of the case-material through quotations and *vignettes*, while on the other attempting to obtain a quantitative feel for the morphology of the action-sets.

6.2 The Elements of Qualitative Data Analysis

Miles and Huberman (1994) view qualitative data analysis as consisting of three concurrent and interactive flows of activity: data reduction, data display, and conclusion drawing and verification.

6.2.1 Data Reduction

Miles and Huberman (1994,10) define *data reduction* as the process of "selecting, focusing, simplifying, abstracting, and transforming the data that appear in written-up field notes or transcriptions". This process may occur throughout the life of the qualitatively orientated project. Indeed, in this study data reduction was driven by the research questions and conceptual framework adopted by the researcher even before the data was actually collected.

In the instance of this investigation, brief *contact summary sheets* (Miles and Huberman 1994) were written shortly after each interview in order to record the main themes and personal reflections relating to the case material. In addition, rough action-sets were drawn to accompany the text. Each interview was tape recorded and transcribed at a later data. The process of transcription yielding around five hundred A4 sheets of text. Due to the large volume of transcribed text relating to the innovations under investigation, a systematic process of data reduction was employed.

The first stage of data reduction undertaken involved the process of *coding*, to allow for the retrieving and organisation of data (Miles and Huberman 1994). Words, phrases, sentences and chunks of text were tagged with *codes* to assign meaning. The codes in this instance were focused very clearly around the well-formed research questions and hence related to actors as sources of inputs to the innovation process, the inputs themselves, and the nature of the links between innovators and external actors.

Alongside the process of coding, two further techniques of data reduction were employed: *memoing* and *vignettes*. Glaser (1978,83-83) defines a memo as "the theorising write-up of ideas about codes and their relationships as they strike the analyst while coding". While Miles and Huberman (1994,81) define vignettes as "a focused description of a series of events taken to be representative...[having] a narrative, storylike structure", which are "helpful in formulating core issues...[and] can be embedded usefully in a [write-up]".

Subsequent stages of data reduction involved the categorisation of data concerning actors, dyads and transaction content, and the use of matrix data displays to present this categorised information. This process was undertaken initially on a *within-case* basis and latterly on a *cross-case* basis. A number of important classifications were employed in order to allow for the analysis of the case-material. Transaction content was classified, for example, with respect to: the exchange value of the flow, which was categorised as *critical* (fundamental to the innovation, which could not have proceeded without the input), *important* (major input to one or more core elements of the innovation); *useful* (constructive input into one or more elements of the innovation), or *minor* (minor or no input into the innovation process); and the nature of the flow, which was categorised as cognitive, material or service (see section 2.3.1 of Chapter 2). In addition, dyads were classified with respect to: the nature of the relationship, that is, instrumental, affective or moral (see section 2.2.1 of Chapter 2); the formalisation of the link, that is, formal or informal (see section 2.2.6 of Chapter 2); or whether the link had been established prior to, or during, the project under investigation.

Data analysis involved an iterative process of data reduction and data display, providing a sort of audit trail from the transcribed material to the tables presented in the subsequent chapters. Taking Table 6.1 in Chapter 6, for example, Table A.7 then Table A.5 in the Appendices provide the trial backwards to the case-material.

6.2.2 Data Display

The process of *data display* involves the organisation, compression and assembly of information to permit *accessibility* to the data and aid conclusion drawing (Miles and Huberman 1994). As such it is not separate from analysis but *part* of analysis, since the designing of any data display is an analytic activity. There exists a variety of types of data display that may be adopted, including text, matrices, graphs, charts and networks. Miles and Huberman (1994,11) argue that "looking at displays helps us to understand what is happening...[and thus] better displays are a major avenue to valid qualitative analysis".

The adoption of matrices and networks to organise, compress, assemble and display data has proved invaluable to this research project. Matrices were adopted to display *intermediate* data concerning *within-case* data, in an iterative process of data reduction, as noted above (see appendices). Matrices were also employed to display *cross-case* data, as an aid to the drawing of conclusions (see Chapters 6, 7 and 8). Network displays were employed to graphically represent the action-sets of each of the innovation projects studied, based on *within-case* data (see Chapter 8). In designing and constructing these action-set network displays, recourse was made to ongoing research in the department concerning the graphic representation of innovation networks (Conway and Overton 1994, Steward *et al* 1993,1994a,1994b). In addition, illustrative quotations were also employed as a means of data display, in order to "give a sense of what the observed world is really like" (Strauss and Corbin 1990,22).

6.2.3 Conclusion Drawing and Verification

Although *final* conclusions will tend not to be drawn to the latter stages of the research process, Miles and Huberman (1994,11) argue that "from the start of data collection, the qualitative analyst is beginning to decide what things mean - is noting regularities, patterns, explanations, possible configurations, casual flows, and propositions". However, Miles and Huberman (1994,11) also contend that "the competent researcher holds these [early] conclusions lightly, maintaining openness and scepticism". As the data analysis proceeds, the researcher seeks to verify these early conclusions in order that they become increasingly explicit and grounded in the data. This is indeed the manner in which the process of conclusion drawing and verification proceeded in this research project, beginning prior to the stage of data collection.

CHAPTER FIVE: INTRODUCING THE INNOVATIONS

1. Introduction

The purpose of this chapter is to provide a brief introduction to each of the innovations investigated in this study. The thirty five innovations have been classified according to one of eight broad industrial classifications, and are addressed alphabetically within each of these categories.

2. Chemical Products and Processes

2.1 The E70A LCD Mixture

The E70A series of *multiplexing* liquid crystals represents the second generation in LCD technology, superseding the *direct-drive* liquid crystal displays invented in the early 1970s. This innovation was awarded the Queen's Award for Technological Achievement in 1992, and was developed by Merck Limited, the world's leading supplier of liquid crystals.

In direct-drive LCDs, wires are attached to each segment of the display and an electrical current is applied to the required segments in order to alter their state and provide the desired character. However, the complexity of the characters capable of being displayed using this type of display is very limited, since the greater the number of segments the greater the number of wires required. To overcome this limitation development work began in laboratories around the world to create a multiplexing-drive liquid crystal display, where you have a series of rows and columns (like a matrix) rather than a set of segments, and characters are formed by passing electrical signals along these row and columns. The E70A was the first multiplexing LCD mixture to enter the market-place, and has remained the world standard since its launch over a decade ago.

2.2 Pyrethroid Insecticides

This case refers to the development of two pyrethroid insecticides: Tefluthrin, which is the only pyrethroid effective against two major soil pests in US corn - rootworm and cutworm; and Lambdacyhalothrin, which is effective against a wide range of agricultural and other pests, such as mosquitoes, cockroaches and aphids. These innovations, which jointly won the Queen's Award for Technological Achievement in 1992, were undertaken by the Insecticide Project Team of the Research and Development Department of ICI Agrochemicals.

These new environmentally-friendly agricultural insecticides are more active than earlier forms and provide high potency from low application rates against a broad spectrum of pests. In addition, they provide favourable mammalian toxicity, are active against pests resistant to other insecticides, and are readily degraded in the environment.

2.3 Puraspec

This process innovation encompasses a number of fixed bed absorbents and catalysts, and associated technology, for the purification of liquid and gaseous hydrocarbons and carbon dioxide in industrial processes. Developed by ICI Katalco, this innovation won the Queen's Award for Technological Achievement in 1991.

Puraspec is displacing conventional purification systems such as molecular sieves and iron sponges: its main advantages being the low cost of materials, the low temperatures of operation, the ease of operation, and environmental friendliness. The technology was originally developed for the removal of sulphur but has since been extended to many other elements, including halogens, oxides of nitrogen, organ-metallic compounds and mercury.

3. Consumer Goods

3.1 Backlite

Backlite is the first system to enable the heating elements of a standard heated rear windscreen of a car to be used as a radio antenna. The device was developed and commercialised by BSH Industries Limited, a small start-up company based in Swinton, despite failed attempts by a number of large companies such as Lucas Industries and Pilkington Glass plc. Launched in the mid-1980s, sales through licence had reached approximately one million units per annum by the year it received the Queen's Award for Technological Achievement in 1991.

The innovative system is capable of meeting the requirements of FM/VHF reception at all wavelengths as well as AM on long, medium and short waves. The performance has been achieved by developing isolating and matching circuitry which matches and tunes the heating elements to enable them to operate efficiently as an antenna.

3.2 Canned Draught Guinness

This innovation allows for the reproduction of the Draught Guinness head in canned Guinness. Developed by Guinness Brewing Worldwide, the multi-national brewing and spirits company, the innovation won the Queen's Award for Technological Achievement in 1991. The technique has since been copied by many UK brewers, who have employed an array of widgets.

Starting from first principles, the chemical process that causes the head to develop was first established and then simulated using a number of widgets and techniques. In the final product the Draught Guinness head is achieved by inserting a small plastic chamber with a small hole in the can. The can is filled with carbonated stout followed by liquid nitrogen, and then sealed. The pressure of the nitrogen leads to its dissolution into the stout and forces the liquid into the plastic chamber. When the can is opened the pressure inside the chamber forces both the stout and gas through the hole in the plastic insert, and this creates the necessary conditions for the formation of the traditional Guinness head.

3.3 The Condor Rucksack

The Condor rucksack is considered by expert users to provide a major increment in rucksack design. The innovation was developed by Karrimor International, a well-established medium-sized company whose name has long been synonymous with rucksacks and mountaineering equipment. The rucksack won the British Design Award in 1991 and has enabled Karrimor to maintain its firm grip on the rucksack market.

The rucksack uses stronger and lighter components, and incorporates an innovative back system which is easily adjustable to the users size and profile. A blending of industrial design, fashion design and advances in ergonomics has had a major impact on the comfort and aesthetics of the product, as well as upon the manufacturing process, dramatically reducing components, materials, and time of manufacture.

3.4 The Yeoman Marine Navigator

The Yeoman Marine Navigator provides for the automatic plotting of positional data, obtained from navigation equipment, on to conventional navigation charts. This replaces the traditional process of manually plotting positional data. Developed by Yeoman Marine Limited, a small company specialising in marine navigation equipment, the innovation was awarded the British Design Award in 1991.

This innovative electronic plotter has been designed for use in leisure craft, of which there are some four million world-wide. The impetus for the development arose from the company chairman, who like a number of his employees, is an experienced yachtsman. The Yeoman offers sophisticated technology at a low price, and combines smart functional industrial design with high levels of accuracy. These features have steered Yeoman Marine Limited in to a commanding position in the leisure craft market.

4. Electronic, Communications and Computer Products and Components

4.1 The ARM RISC Microprocessor

The ARM RISC microprocessor is a low cost 32-bit microcomputer processor, utilising reduced instruction set architecture (RISC). This innovative product was developed by a small team of highly creative engineers within the Acorn Computer Group plc, then an independent medium-sized company. The product won the Queen's Award for Technological Achievement in 1992.

This innovative microprocessor is typically one quarter of the size of other RISC processors, which allows it to be combined with other components to build a computer on a micro-chip that requires very little power to operate. As a result of this, the ARM RISC microprocessor is ideally suited for use in portable computers.

4.2 The VideoLogic DVA-4000

The VideoLogic DVA-4000 provides for the combination of video and graphics signals on the display screen of a personal computer, alongside synchronised audio signals. The initial development work was undertaken by VideoLogic Limited in the mid-1980s, which at the time was a small start-up company employing a handful of highly skilled engineers and video production staff. The innovation was awarded the Queen's Award for Technological Achievement in 1992, and has enabled the company to play a major role in the European multi-media industry.

By utilising digital techniques the DVA-4000 has overcome the problems experienced with low resolution analogue systems which it replaces. Principal among these problems was the difficulty in synchronising the graphics signals from the computer and the signals generated by the various video standards, such as, cable broadcasts, camcorders, and VCRs. Initially developed for IBM PC compatibles, the innovation was the first to enable computer controlled real-time editing of these video formats.

4.3 Flexilink

Flexilink is a connection system for fibre-optic cables, which also allows the cables to be terminated and protected when the connector is removed. The innovation, which was developed by an engineer within Pilkington Communication Systems Limited, was awarded the Queen's Award for Technological Achievement in 1992. The innovator is part of the Pilkington Glass group of companies.

The Flexilink system simplifies traditional optical cable connections, reduces the size of the racking required for the cables, reduces the risk of damaging the optical cables, and is easier to install and maintain than previous systems and techniques. The product range provides an array of interfaces to allow different types of computers, voice and video systems to benefit from communications employing fibre optic technology: allowing this to be undertaken quickly, easily and cost effectively.

4.4 The Nicam 728 Broadcasting System

Developed by a project team within the Engineering Directorate of the British Broadcasting Corporation, the Nicam 728 broadcasting system allows for the transmission of high quality digital sound for television. This innovation was awarded the Queen's Award for Technological Achievement in 1992.

This innovative broadcasting system facilitates the transmission of two high quality digital sound signals within the existing UHF television channel, in addition to the normal monophonic analogue sound signal. The two digital audio signals, which offer quality comparable with that of the compact disc, can be used to enhance programmes with stereophonic sound, or alternatively, allow the provision of a dual-language service. Optimisation of the new carrier system through which the signal is conveyed provides reliable stereo reception, whilst ensuring no interference to the existing vision and monophonic sound signals.

4.5 The On-Line Tape Certification System

This innovation allows for the automatic on-line certification of digital magnetic tapes at 1600 and 6250 bpi simultaneously. Developed by Double R Controls Limited, a small control equipment company based near Manchester, this certification system won the Queen's Award for Technological Achievement in 1992.

The on-line tape certification system employs specially coated ceramic reader heads and air bearings which have been developed to float the tape over these heads. In addition, reflective markers are applied automatically at the beginning and end of each magnetic tape, to allow computerised optical identification. The whole operation previously employed manual intervention and required two hours in order to certify fifty tapes. The new certification system undertakes the same operation entirely automatically and in just ten minutes.

4.6 Scimitar H

The Scimitar H is a lightweight high frequency radio designed for military use. It was developed by the Military Communications Division of GEC-Marconi Communication Systems Limited, part of the GEC-Marconi group, and received the Queen's Award for Technological Achievement in 1991.

The innovation incorporates electronic counter measures to ensure that transmitted signals are not jammed, intercepted or used by the enemy for identifying the location of the operator. This was achieved through the adoption of frequency-hopping techniques, facilitated through the incorporation of microprocessors and synthesizers. In addition to being a man-pack, the radio can easily be configured with higher output power for use in vehicle installation as a base station. It is also contained in a high impact-resistant case. The high performance and versatility, together with the reduction in weight, were achieved through the careful design and selection of components: sourced and developed both internally, within the GEC-Marconi group, and externally.

4.7 Studio 9000

The Studio 9000 is a computerised pagination system for use in the graphics art industry. Developed by a project team within Crosfield Electronics Limited, the company was awarded the Queen's Award for Technological Achievement in 1992.

Although the Studio 9000 incorporates state-of-the-art advances in both computer hardware and software, the system has been developed in such a way that knowledge of technology or computers is not required. Operation of the pagination system is through icons on the computer screen, representing different tools, which were designed to be intuitively easy to understand, remember and work with.

5. Engineering Components

5.1 Linear Actuator

The linear actuator is a unique integrated mechanical device designed for use on boats to move the rudder in response to commands from an autopilot. This development was undertaken by Hydraulic Projects Limited, a small company based in Devon that makes an extensive range of values and pumps for a variety of applications. The innovation gained the British Design Award in 1991.

The major design innovation of the product is its containment of all the hydraulic circuit components within a single sealed unit: valve block, actuator cylinder, pump, motor assembly, and oil reservoir. This design avoids the common problem of an ingress of air and dirt during operation, thereby minimising the risk of failure and allowing the actuator to be fitted anywhere, even underwater for the first time. This innovation represents a totally new design approach to an established technology, and offers the possibility of promising valuable applications outside of the marine world, such as providing greater mobility for the disabled.

5.2 Shielded Magnet

The shielded magnet forms the core component of the Magnetic Resonance Imaging (MRI) body-scanner developed by one of the innovator's sister companies. This advancement in super-conducting magnet technology was undertaken by Elscint Cryomagnetics Limited, representing one of only a few relatively small firms competing successfully with the giant multi-nationals in this research intensive field. It is part of a world-wide group of companies, whose general business is medical-imaging and whose headquarters are based in Israel. This innovation was awarded the British Design Award in 1991.

There are basically three cross-linked parameters to control in the development of super-conducting magnets for MRI scanners: the emission of stray magnetic fields, which cause serious interference to electronic equipment; the homogeneity of the magnetic field, which affects the clarity of the image; and the loss of liquid helium used to cool the magnets down from super-conducting temperatures, which represents an expensive running cost. The principal benefit of this innovation is its ability to shield stray magnetic fields, whilst at least matching existing performance in the latter two parameters. The high levels of technological innovation and quality embodied in the magnet have enabled the group to capture a niche at the top end of the MRI body-scanner market.

5.3 Stripper-Head

Attached to the front of combine-harvesters, the Stripper-Head is considered by some as the most revolutionary break-through in agricultural machinery for 70 years, allowing for the harvesting of crops at up to twice the speed possible with standard cutter bars. The innovation has won universal acclaim, winning a number of prestigious awards in recent years, including the British Design Award in 1991 and the Queen's Award for Technological Achievement in 1992. Continually breaking world records for harvesting speeds, the Stripper-Head has put Shelbourne Reynolds Engineering Limited, a small Suffolk company, on the international farming map.

The innovation is the result of a simple but ingenious design: eight rows of keyhole shaped teeth which strip the grain from the top of the crop, leaving the straw standing, rather than cutting the crop near its base as with existing crop cutters. This approach reduces the straw intake into the combine harvester by up to 80%, leaving the machine free from the traditional chores of sifting, sorting, shaking, beating and transporting, and yields a substantial increase in crop through-put while enabling huge savings on machinery and fuel.

6. Engineering Products

6.1 Fastrac

The Fastrac is the world's first genuine high-speed agricultural vehicle, combining the productivity of a hard-working tractor with the speed and versatility of an on/off road transporter. Developed by JCB Landpower Limited, a subsidiary of JCB Excavators, the innovation was awarded the British Design Award in 1992.

The innovation is claimed to be the first initiative in tractor design since the 1940s, incorporating features such as air operated disc brakes on all four wheels and a full suspension system not normally found on tractors. The impetus for the innovation arose from a study of tractor use undertaken by JCB in 1986, which discovered that only 30% of usage involved draft work while 70% involved haulage work and travelling between jobs. Since tractors are not designed to haul, they demonstrated a lack of speed, adaptability and comfort.

6.2 Hydro-Probe

The Hydro-Probe sensor is used to measure moisture in a variety of process industries, the largest of which is concrete batching for the pre-cast, ready-mix and construction industries. Hydronix Limited won the British Design Award for the innovation in 1992.

This small company was founded in 1982 specifically to develop and commercialise the use of microwave technology in accurate moisture measurement.

The product is totally innovative in its design, and provides the most accurate and cost-effective method for on-line measurement of moisture in sands and aggregates. The major innovation of the product is the unique manner in which the microwave absorption principle has been adapted to a single head, thus offering great flexibility of use: earlier sensors had employed two sensors (one transmitter and one receiver) which were less accurate and had to be located precisely in relation to each other. The Hydro-Probe is located at the mouth of a silo, where it continually measures the moisture content in the materials that flow. This enables the batch computer to compensate for the water in the material in the weighing process or determine the water to be added in the concrete mixing process, for example. The innovation embodies state-of-the-art microwave knowledge and comprises two main elements: the sensor itself and the control equipment that provides the interface between the sensor and the user.

6.3 Polifold

Polifold is an incremental innovation in roofing for transport vehicles. The innovation, which was awarded the British Design Award in 1992, was developed by Glass Transport Systems Limited, a small company based in Hertfordshire.

Polifold is a PVC sheet folding roof for transport vehicles, which uses polypropylene leaf springs to produce an automatic concertina effect to maximise the roof opening and hence facilitate loading by overhead crane. The roof system was originally developed for glass transportation vehicles, where the maximisation of the roof opening is required by virtue of the indivisibility of glass and its weight that necessitates loading by crane. The Polifold roof is water-tight, gives 90% roof opening, and is easier to operate by one person, maintain and repair than previously existing roof systems on the market.

6.4 Pullman Series of Relocatable Buildings

The Pullman series represents an incremental innovation in relocatable buildings: designed to be the first pan-European product through meeting a wide range of climatic and regulatory requirements. Developed by Portakabin Limited, a large UK company whose name has become synonymous with relocatable buildings, the product was awarded the Queen's Award for Technological Achievement in 1992.

The innovation incorporates a number of advances in relocatable buildings, including the development of: an internal skin that acts as a vapour barrier; a one-piece composite steel roof panel to avoid joints where failure could occur; a aluminium foil faced thermal blanket to provide a thermally efficient floor; and a leg-system that allows a single person to deliver and unload the building despite weighing in excess of ten tonnes. The Pullman series has allowed the innovator to maintain its position at the forefront of relocatable building design, in an increasingly competitive market.

6.5 Water Mains Refurbishment System

This innovation in drinking-water mains refurbishment comprises of two separate developments: an epoxy resin for coating the inside of water mains pipes and a lining machine for applying the resin. The system won the Queen's Award for Technological Achievement in 1992, and was developed by Mercol Descaling Limited, a well-established medium-sized company which specialises in water mains refurbishment.

Accelerated tests by the DOE have indicated that the life-span of the epoxy resin to be in excess of one hundred years. The epoxy resin is also non-toxic, provides minimal resistance to water flow and has a short curing time. The innovative lining machine allows the refurbishment of the water mains to be undertaken *in situ*, thus providing a cost saving of 75% compared to the relaying of water mains pipes.

7. Pharmaceutical Products and Processes

7.1 Carboplatin

Carboplatin is a platinum-based anti-cancer drug. This pharmaceutical innovation won the Queen's Award for Technological Achievement in 1991. There were essentially three parties involved in the development and bringing to market of this anti-cancer drug: the Bio-Medical Department of the Johnson Matthey Technology Centre in the UK, who undertook the chemical developments and manufacturing; the Institute of Cancer Research, supported financially by the Cancer Research Campaign, who undertook the toxicology tests; and the multi-national pharmaceutical giant, Bristol-Myers Squibb, who supervised the drug through its clinical trials, registration, and commercialisation stages.

Carboplatin is active in a variety of cancers and has been used successfully in both drug combination regimes and as a single agent. In addition, it has efficacy equivalent to cisplatin, the first platinum anti-cancer drug, in terms of response and survival but produces much less toxicity so that patients may be treated on an out-patient basis and thus enhancing their quality of life.

7.2 Diflucan

Diflucan is a well-tolerated agent for the treatment and prophylaxis of superficial and systemic fungal infections, especially in immune-compromised, AIDS and cancer patients. This anti-fungal drug was awarded the Queen's Award for Technological Achievement in 1991, and was developed by the Central Research Division of the multi-national pharmaceutical company, Pfizer Limited.

This drug is the only anti-fungal medicine that is available in both oral and intravenous forms. Its excellent distribution throughout the body ensures that it is effective in all major sites of fungal infection including the lungs, kidneys, and brain where it is of particular value in the treatment of fungal meningitis in AIDS patients.

7.3 Peboc Pharmaceutical Intermediate Manufacturing Process

This process innovation allows for the manufacture of a major pharmaceutical intermediate utilised in the production of a leading anti-biotic. This environmentally friendly process meets all current and anticipated environmental regulations, while remaining competitive in terms of costs and efficiency. The innovation was developed by Peboc Limited and won the Queen's Award for Technological Achievement in 1992.

8. Scientific, Medical and Educational Equipment

8.1 First-Sense

This innovative system for use within primary schools, allows for the measurement and logging of light, sound, pressure, humidity, temperature and rotation data, through the use of hand-held sensors. The innovation was developed by Philip Harris Limited, a large and well-established Midlands company with an annual turnover in excess of £50m and an international reputation as a leading manufacturer and supplier of science and technology teaching equipment. First-Sense was awarded the British Design Award in 1992

The First-Sense product range is comprised of three main elements: the range of hand-held sensors themselves; the interfacing unit (that links the sensors to the computer); and the software, that operates on a variety of computers in order to present the data registered by the sensors and stored initially on the interfacing unit.

8.2 The MRC-500 Confocal Microscope

The MRC-500 represents the first viable laser scanning confocal imaging system. The development was initiated and prototyped by a cell biologist within the Laboratory of Medical Biology of the Medical Research Council, who required improvements in the quality of cell imaging for his research. The proto-type was then designed for manufacture and commercialised by Bio-Rad Limited, an American multi-national that specialises in instrumentation for a number of application areas. In 1991, these two organisations were awarded the Queen's Award for Technological Achievement in recognition of the numerous technological advances embodied in the innovation.

Although not the first confocal microscope, the MRC-500 was the first system to provide the necessary sensitivity for cell-biologists to successfully employ fluorescent microscopy techniques to look inside cells and obtain quality images. The performance of this innovation has revolutionised biomedical microscopy.

8.3 Symphony

Symphony was the first, and remains the only, WC-disposable colostomy bag in the market-place. This medical consumer product won the Queen's Award for Technological Achievement in 1991. The development was undertaken by Simcare, part of the Medical Division of the Smiths Industries conglomerate, which as a group had an annual turnover of £655 million in the year of the award.

This innovative colostomy bag is formed of two layers: an outer water soluble layer, which dissolves in a WC; and an inner insoluble layer, which contains the faecal material. The product has significantly improved the quality of life for those users of this type of device. The principal area of development in this innovation concerns the film material which was required to embody four properties: strength, softness and quietness, flushability, and provision of an odour barrier.

8.4 The Town and Country III

The Town and Country III is an incremental innovation in electric-tricycles for the disabled and elderly. Winner of a British Design Award in 1992, the product was developed by Booster Electric Vehicles Limited (a father-son partnership), considered to be the world leader in electric-tricycle design.

The Town and Country III incorporates a number of innovative features which have reinforced the company's reputation in the market-place: down-hill speed control, emergency-braking, rear-wheel drive, puncture-proof tyres, maintenance-free batteries, lights and indicators. Industrial design has also been employed to improve the ease of use, the aesthetics, and the manufacturability of the product.

8.5 The Xenos Pain Management System

Xenos is an electronic pain relief device based on the proven drug-free method Transcutaneous Electrical Nerve Simulation (TENS), and is employed in conditions such as spinal injury, arthritis, and post-operative pain. Launched in 1989, the Xenos rapidly established itself as the UK market leader and won the British Design Award in 1991. Though much of the development work was undertaken externally, the innovation was envisaged, realised and commercialised internally by Neen Pain Management Systems, a small Norfolk company of around ten employees.

Although an incremental innovation, the Xenos offers many new improvements over existing TENS devices, such as sensitive touch control for users with limited dexterity and an automatic memory for retaining settings for future use. Many of these unique features are made possible by the employment of a state-of-the-art Application Specific Integrated Circuit (ASIC) microchip, which lies at the heart of the product. TENS works by activating a mechanism by applying a low frequency current to the pain area, whereby pain impulses are intercepted and attenuated within the spine on route to the brain.

9. Software Products

9.1 Amethyst

Amethyst is an expert system for the automatic diagnosis of rotating machinery faults through the analysis of their vibration patterns. This innovative software product was developed by Intelligent Applications Limited, a small company based near Edinburgh that specialises in the application of expert system technology. The package was awarded the Queen's Award for Technological Achievement in 1991.

The innovation is used in vibration based condition monitoring and achieves in a matter of minutes what previously took four to eight hours as a manual process undertaken by highly skilled engineers. The vibrations of a given piece of machinery are monitored using a hand-held vibration data-collector, the output of which is then analyzed by the software package run on an IBM PC compatible. The package will indicate fault conditions where they are located enabling lower skilled staff to be employed in the monitoring task and eliminating the unnecessary stripping down of machinery, and therefore leads to greater overall plant efficiency.

9.2 Elektra

Elektra is a software package for the analysis of electro-magnetic frequencies generated by high technology devices. The innovation was awarded the Queen's Award for Technological Achievement in 1992, and was developed by a small software/consultancy company based in Oxford. The company includes a number of highly regarded electro-magnetic scientists who were previously employed by the prestigious Rutherford Appleton Laboratory.

This highly innovative and technical software is an important aid in the design of high technology electrical equipment, and is in use in many areas requiring the analysis of electromagnetic frequencies to very high tolerances, including: MRI body-scanners, medical diagnostic equipment, super-conductivity, and electrical machines, such as motors, generators and transformers. Elektra is enhanced by the Opera package, a parallel software development that provides a three-dimensional graphics front-end.

9.3 Isoview 3

The primary function of this computer network management software package is to monitor and control the various components of a local area network (LAN): which is becoming a more and more important task as companies increasingly rely on their computer communication networks. The development work was undertaken in-house by 3Com Limited, a leading international manufacturer of hardware and software networking products. This software package won the British Design Award in 1992.

Isoview 3 collects and processes pertinent information using a fully integrated relational database, and employs report tools to format this information for report generation and planning purposes. In addition, the software package incorporates two types of network security: security from network failure and security from malicious intent. Isoview is designed for ease of use, employing an intuitive icon based user-interface, thereby freeing valuable highly skilled staff for more complex tasks.

9.4 MotorMonitor

This innovative software package provides for the on-line monitoring of large industrial induction motors, many of which are used in critical duties in oil production, petrochemicals, steel manufacture and mining. In these industries, any down-time of machinery for fault diagnosis is very expensive, but the sudden failure of these machines can have drastic repercussions. MotorMonitor was thus developed to diagnose the potential failure of an induction motor on-line, so that it could be fixed at the most appropriate time. This innovation which won the Queen's Award for Technological Achievement in 1992, was developed by the Electrical Projects Group of In-spec Manpower and Inspection Services Limited: a medium-sized company based in Aberdeen, which supplies a variety of services and products to the oil and petrochemical industry.

The innovation employs expert system technology and is based on fundamental research undertaken at the Robert Gordon Institute of Technology in the early 1980s. This research found that metal fractures within a motor altered the electrical current inside the machine, which was reflected back in the supply cables. It was also found that different machines and faults altered the electrical current in different ways. By monitoring the current in the supply cable, faults can thus be diagnosed whilst the machine is in operation.

9.5 Synon/2

Synon/2 is a software package that helps programmers to write new programmes. The software development was undertaken by Synon Limited, a small start-up software company based in London. The product has seen exponential sales growth since its launch in the late 1980s, and was awarded the Queen's Award for Technological Achievement in 1991.

The unique feature of this innovation is its data modelling facility which enables applications to be designed correctly from the out-set. The application generator than aids the process of programme writing by automatically generating standard chunks of programme code and inserting these into the application. The package has been designed specifically for the architecture of the IBM AS/400 relational database.

CHAPTER SIX: THE ROLE AND EXCHANGE VALUE OF EXTERNAL INPUTS IN SUCCESSFUL INNOVATION

1. Introduction

The intention in this chapter is to present the results of the qualitative analysis of the case-material in relation to the identification of the role, nature, locus and exchange value of the external inputs into the innovation process. Thus, the emphasis here is upon the transaction content and the external actors from which it was sourced. The nature of the relationships between the innovators and these external actors, and the mechanisms employed to operationalise these links, are addressed in Chapter 7.

In analysing the case material, an attempt was made to categorise the importance of external sources to each of the innovations studied. This was undertaken by evaluating the *exchange value* (critical, important, useful or minor) to the innovator of external inputs to the project as a whole, and specifically to the idea-generation (features), problem-solving (solutions) and field-testing stages of each innovation. The evaluation was based on a combination of the explicit opinions of the interviewees and the judgement of the researcher with respect to other transcript interview data.

This chapter is essentially divided into three main sections: the first presents the results concerning the role and exchange value of external inputs utilised in the innovation process; the second evaluates the role and importance of various generic groups of actors as the sources of these inputs; and finally, an evaluation is made concerning the extent to which these results vary according to variations in the nature of the innovation or innovator, such as organisational size.

2. The Role and Exchange Value of External Inputs

The analysis of the thirty-five innovations investigated in this research revealed that only seven (20%) were considered to have not benefited, or to have benefited to only a minor extent, from external inputs: canned Draught Guinness, the DVA-4000, Flexilink, Nicam 728, the Peboc pharmaceutical manufacturing process, Puraspec, and Studio 9000. At the other extreme, input from external sources was considered to have been critical to the development of seven (20%) of the other innovations: Amethyst, Hydro-Probe, MotorMonitor, the MRC-500 microscope, the combine-harvester Stripper-Head, Xenos, Yeoman. In addition, the analysis revealed that in a further twelve (34%) cases, external sources had provided important input, with useful input derived in the remaining nine (26%) innovation projects. Typical of the innovations which received useful input from external sources is Elektra. With reference to the development of this software package, it was recalled that:

> "The basic concept and ideas are all from Vector Fields. The gloss on it is from the users, who have allowed us to tidy it up." (Simkin: Vector Fields 1992)

The results of the qualitative analysis of the case material were therefore seen to support the evidence of earlier research, that illustrates the importance of external sources to the innovation process. The findings of these earlier studies are summarised in Table 1.1 of the introductory chapter.

TABLE 6.1: The Exchange Value of External Inputs to the Innovation Process

Exchange Value	No. of Projects	% of Projects
Critical	7	20
Important	12	34
Useful	9	26
Minor	7	20
Total	35	100

However, the exchange value of external inputs was seen to vary between the different stages of the innovation process. The analysis of the case-material found, for example, that in the sample as a whole external inputs were of greater importance during problem-solving (solution inputs) and field-testing, than during idea-generation (inputs concerning the features, functionality and specifications of the innovation). In both of the first two functions, external sources were found to contribute important or critical inputs in fourteen (40%) of the cases, but in only eight (23%) instances with respect to idea-generation.

Earlier studies have tended to indicate the greater importance of external sources to idea-generation rather than problem-solving (see section 1 of Chapter 1). However, this contradictory result ties in with the expectation that the post-war proliferation of knowledge would tend to lead to the increased specialisation of organisations (see section 3.3 of Chapter 2), and hence to the need to source ideas, information and technology, externally.

The following sub-sections take a closer look at the role of external sources in the development of the innovations, by analysing the exchange value of the external inputs in stimulating the projects, and in aiding the idea-generation, problem-solving and field-testing processes.

2.1 The Sources of Project Stimuli

An analysis of the original stimuli for each of the innovation projects investigated revealed that twenty-four (69%) may be classified as primarily *need-stimulated* and the remaining eleven (31%) as primarily *means-stimulated* (see Table A.6 in the Appendices for a summary). This balance between need and means-stimulated innovation corresponds very closely to the results of earlier research, which are summarised in Table 1.3 in Chapter 1.

TABLE 6.2: The Stimuli of the Innovations Investigated		
Project Stimulus	**No. of Projects**	**% of Projects**
Need	24	69
Means	11	31
Total	35	100

However, of the twenty-four need-stimulated projects only nine (26%) may be considered as resulting from *market-pull*, that is, an explicit market-need (the E70A LCD mixture, Flexilink, Isoview 3, the linear actuator, the on-line tape certification system, Polifold, Symphony, the Town and Country III, and the water-mains refurbishment system). This is perhaps not too surprising given the innovative nature of the sample and the limited time-horizon in which all but a few lead-users perceive their future needs. Indeed, six of these nine market-pull innovations may be considered as relatively minor increments to existing products. This result tends to reflect the views expressed in a number of the interviews and articulated below in relation to the development of Isoview 3:

> "A lot of the feedback you get from customers tends to be on what's currently available. And actually trying to get them to look into the future...is actually very difficult." (Jallard: 3Com 1992)

A further eight (23%) of the need-stimulated projects resulted from a perceived rather than an explicit market-need, following market or trend analysis undertaken internally (Backlite, canned Draught Guinness, Diflucan, Fastrac, the Pullman series, Synon/2, Xenos, and Yeoman). Thus, a total of seventeen (49%) of the projects studied resulted primarily from market-orientated stimuli.

The remaining seven (20%) need-stimulated projects resulted from internal rather than market needs: four (11%) arising from internal technical needs, including a process (the Peboc pharmaceutical intermediate manufacturing process), a component (the ARM RISC microprocessor), and two product innovations (the MRC-500 and the Nicam 728 broadcasting system); and three (9%) from internal business needs (the Condor rucksack, Scimitar H, and the shielded magnet), to combat competitive pressures or to create new high-volume *cash-cow* products.

TABLE 6.3: The Stimuli of the Need-Stimulated Innovations

Project Stimulus	No. of Projects	% of Projects
Explicit Market-Need	9	26
Perceived Market-Need	8	23
Internal Technical-Need	4	11
Internal Business-Need	3	9
Total	24	69

TABLE 6.4: The Stimuli of the Means-Stimulated Innovations

Project Stimulus	No. of Projects	% of Projects
Science-Push	2	6
Technology-Push (Internal)	4	11
Technology-Push (External)	2	6
Technology Application	3	9
Total	11	31

Of the eleven means-stimulated innovation projects, two (6%) may be classified as resulting from science-push and nine (26%) from technology-push. In both of the cases of science-push (Carboplatin and the pyrethroid insecticides), the original science that stimulated the projects was not undertaken by the innovator, whereas for the technology-push project cases: four (11%) were stimulated by technology developed in-house (Hydro-Probe, Elektra, Puraspec, and Studio 9000); two (6%) directly by specific enabling technology developed externally (MotorMonitor and Stripper-Head); and three (9%) by an internal recognition of the potential of existing technology in the market-place for new applications (Amethyst, the DVA-4000, and First-Sense). Thus, seven of the means-stimulated projects were initiated in response to internal stimuli, and only four by external stimuli.

In summary, of the thirty-five projects investigated a total of thirteen (37%) may be classified as being primarily stimulated by external sources, with the other twenty-two (63%) projects being triggered by primarily internal stimuli.

2.2 The Sources of Concept Definition

In relation to the initial conception of the innovations studied, the balance between internal and external sources was seen to be evenly balanced. Analysis found that internal sources accounted for the origination of the innovation concept in eighteen (52%) of the thirty-five cases, with five (14%) originating directly from specific external sources (the Condor rucksack, Fastrac, Isoview 3, the linear actuator, and Stripper-Head). Of particular interest here, with respect to these external sources, is the adoption of user-panels by JCB and Karrimor in the formulation of the product concept and features in the development of Fastrac and the Condor rucksack, respectively. The creation and use of these user-panels will be reviewed more fully in the following chapter.

In the remaining twelve (34%) cases, the innovation concept already existed more generally outside of the innovating organisation prior to the commencement of the particular project: embodied within earlier generations of products (First-Sense, Polifold, the Town and Country III, and Xenos); un-met market-demands (Symphony); or academic work and prototypes (the ARM RISC microprocessor, the MRC-500, and the pyrethroid insecticides).

2.3 The Sources of Inputs into the Idea-Generation Process

In terms of defining the features, functionality and specifications of the various innovations studied, the analysis found that external sources only contributed the critical inputs in one case (Amethyst). However, external sources were seen to provide important inputs in terms of idea generation in seven (20%) other cases (the Condor rucksack, Fastrac, Isoview 3, MotorMonitor, Stripper-Head, the Town and Country III, and the water-mains refurbishment system), and useful input in relation to a further seventeen (48%) innovations.

The external input with respect to the features and functionality of the developments studied, was seen to arise primarily from feedback relating to earlier generations or versions of the innovations, or as a result of field-trials or beta-tests of the innovation itself. In addition, government regulations and industry standards were seen to influence the technical specification of the innovation in a number of cases. For example, government regulations provided an important input into the technical specifications of the Pullman series, which was developed by Portakabin to be the first pan-European re-locatable building. A further example is provided by reference to Isoview 3, where international standards concerning data-communication set down the basis of the technical specification for this product.

TABLE 6.5: The Exchange Value of External Inputs to the Idea-Generation Process

Exchange Value	No. of Projects	% of Projects
Critical	1	3
Important	7	20
Useful	17	48
Minor	10	29
Total	35	100

The vast majority of the external inputs into the idea-generation process were seen to be in the form of ideas, information and general feedback, and therefore may be classified as largely cognitive transaction content passing from source to recipient. In two of the cases, as noted earlier, user-panels were employed to elicit the ideas for the features and functionality of the innovations, and in this sense the transaction content may be classified as both cognitive and service. Although the flow of power between user and innovator was not focused upon in this research, it is highly likely that in some instances cognitive transaction content would have been accompanied by instrumental transaction content, where the user was attempting to influence the design of the innovation.

2.4 The Sources of Inputs into the Problem-Solving Process

As noted earlier, external sources were found to contribute important or critical inputs into the problem-solving process in fourteen (40%) of the innovations. In addition, useful input was sourced externally in a further twelve (34%) cases. Of the six (17%) projects where external sources were seen to provide critical solution inputs, four (11%) of the cases represent innovations where the enabling technology was developed outside of the innovating organisation as part of the innovation process: the research into electrical signals from faulty motors in the development of MotorMonitor; the image-processor technology for the MRC-500; the plastic teeth design for the Stripper-Head; and the digitising technology for the Yeoman. In the remaining two cases, the bulk of the development work was undertaken externally, with the role of the technological entrepreneurs limited to largely setting the broad specifications for the components and coordinating the *action-set* of external sources employed.

TABLE 6.6: The Exchange Value of External Inputs to the Problem-Solving Process

Exchange Value	No. of Projects	% of Projects
Critical	6	17
Important	8	23
Useful	12	34
Minor	9	26
Total	35	100

The external input into the problem-solving process was seen to arise largely from innovators approaching suppliers for the provision of innovative components, and research establishments and consultants in relation to the sourcing of technical information and ideas. In addition, solution inputs of a broader and more tacit nature were also sourced externally by tapping into technical (scientific or trade) networks of scientists and engineers.

The transaction content passing between external source and innovator during the problem-solving process, was found to range from largely material in some cases, to largely cognitive in others. In terms of those cases where external sources provided critical or important solution inputs, the transaction content was primarily components developed for the innovator and hence largely material. With respect to those cases where external sources provided useful or minor solution inputs, the transaction content was primarily in the form of tacit information and ideas, and hence largely cognitive in nature.

2.5 The Sources of Inputs into the Field-Testing Process

The analysis also revealed the high exchange value of external sources in the pre-commercial field-testing of the innovations studied, providing important or critical input in fourteen (40%) of the cases. In addition, external sources were found to have played a useful role in a further nine (26%) of the innovations.

TABLE 6.7: The Exchange Value of External Inputs to the Field-Testing Process

Exchange Value	No. of Projects	% of Projects
Critical	3	9
Important	11	31
Useful	9	26
Minor	12	34
Total	35	1

The three (9%) projects identified as involving critical external input in this respect included Amethyst, Stripper-Head and the water-mains refurbishment system. During the development of Amethyst there was daily interaction between the distributor (IRD in the US), who undertook the alpha and beta-tests in conjunction with their own customers, and the developers (Intelligent Applications) based in Scotland. During this period of intense interaction mediated by modem and fax-machine, IRD would report programme bugs and issues of functionality on a daily basis, and Intelligent Applications would respond rapidly by making the necessary changes and sending the new version of the software. In this way, the innovation was seen to evolve throughout the field-testing. A similar process of what may be termed *interactive* development through "multiple and continuous interaction" was related with respect to the Stripper-Head, as follows:

> "...so we were out there [on working farms] and if we didn't like something we would take it up to the farm shop, put a gas-torch to it, or get a piece of metal welded on, or come back to the office and draw something up, get it made, take it back out and put it on [the combine-harvester] and then run another test." (McCredie: Shelbourne Reynolds 1992)

In the case of the water-mains refurbishment system, the Water Research Centre at Swindon was commissioned to undertake accelerated aging tests to ensure the integrity of the epoxy pipe-lining material that had been developed internally. Without such toxicology tests, government regulation would have prevented the commercialisation of this particular innovation.

The high incidence of external sources utilised in field-trials and beta-testing was accounted for by many of the interviewees in terms of the limitations of testing an innovative product in an artificial or laboratory environment in-house. In relation to the Stripper-Head, for example, it was noted that:

> "You can only do so much with a small plot [100ft]...at the end of the day what counts is when you put the machine going up and down [a crop field] continually all day...You've got to start there [with a small plot], as that's where you get your initial ideas from, but you can't take a machine into a commercial situation from that..." (McCredie: Shelbourne Reynolds 1992)

While with respect to the testing of prototypes of the MRC-500 it was pointed out that:

> "It's very important to have naive users on a machine, because you tend when working on something yourself to get used to its quirks." (Amos: MRC 1992)

The interaction between the innovator and various external sources during the field-trials and beta-testing of the innovation, was seen to involve a two-way flow of transaction content, including: material transaction content from the innovator to the user in the form of innovation prototypes; service transaction content from the user to the innovator in relation to the undertaking of the field-tests; and cognitive transaction content between both parties. In a number of the cases investigated, including those introduced above, the two-way flow of transaction content was found to be intense during this test period.

3. <u>The Locus of External Inputs</u>

3.1 <u>Users</u>

As noted earlier, users were seen to play only a minor role in stimulating new innovative projects and in providing inputs to aid concept definition during the early stages of the innovation process. In attempting to explain this, one interviewee forwarded the following observation which is indicative of the view expressed by a number of others during the field-work:

> "Very seldom can you actually go up with a specification to a customer and say 'What do you think of this spec?'...That won't give you the feedback you need...Give them [a prototype] to play with...but then it's too late to do very much about it [the core specification] on that product generation." (Conley: Marconi 1992)

However, the analysis did identify users as *the* major external source of inputs into the process of defining the features, functionality and specifications of the innovations studied. Indeed, two of the cases, the development of the MRC-500 microscope by microbiologists at the MRC and the Nicam 728 broadcasting system by the BBC, clearly illustrate Hippel's (1976,1977a) concept of user-dominated innovation. From the study, users were seen to provide important inputs into the idea generation process in six (17%) of the innovations: in the development of the Condor rucksack and Fastrac (both through user-panels, discussed later), and in the re-innovation of earlier models of Amethyst, Isoview 3, MotorMonitor, and the Town and Country III. Indeed, it was noted that in subsequent versions of the Amethyst software package:

> "The substantial number of changes have come from the users...We try and be really careful about putting our own ideas in unless a user agrees with it." (Milne: Intelligent Applications 1992)

In addition, users were also seen to represent *the* major external source for the pre-commercialisation field-testing of the innovations, playing a critical role in two (6%) cases (Amethyst and Stripper-Head) and an important role in a further nine (26%) cases (Backlite, the Condor rucksack, Elektra, Fastrac, Hydro-Probe, MotorMonitor, Symphony, Synon/2, and Yeoman). Some of these development projects involved quite substantial periods of field-testing: four years of continual field-testing and refinement in the case of the combine-harvester Stripper-Head; and around two years for the Fastrac, during which prototypes were left on farms for a couple of months at a time prior to seeking feedback from the farmers. This adds support to Habermeier's (1990) hypothesis that product characteristics and user requirements can often only be discovered if the innovation is actually used, sometimes for long periods of time.

It is also worth noting that in most of these cases field-testing was undertaken by what Hippel (1986) has termed *lead-users*. Thus, in the case of the MotorMonitor machinery fault diagnosis software, Scottish Power and British Coal were instrumental in testing the package. Field-tests were seen not only as an important test-bed for the technical performance of the innovations, but also for the suitability of the embodied features and functionality.

However, it is also true to say that a fair amount of what may be considered as post-commercialisation *field-testing* was highlighted by the research. That is, a number of the small and small-to-medium sized companies either consciously or unwittingly commercialised rather *rough and ready* versions of their innovations, which were subsequently tested by users in a commercial situation. This led directly to new versions of the products that incorporated debugging and/or much improved functionality. This point was expressed quite openly in relation to the development of the Hydro-Probe:

> "I suppose at the back of your mind you're realising that you're doing development, to a certain extent, maybe, on your customers." (Laffan: Hydronix 1992)

This form of *field-testing* may occur for a number of reasons, for example, it had occurred consciously in relation to the development of Xenos, largely because of the lack of financial resources:

> "[larger competitors] can afford to produce a thousand pre-production prototypes and put them out to all sorts of people...And they'll have all the [feedback] that comes in. We are not able to do that. So we have to take our best bet...and do a certain amount of development afterwards once it gets out into the field." (Sherlock: Neen Pain 1992)

However, this situation had arisen unwittingly with respect to MotorMonitor through the uniqueness of the software package and the company's ignorance of the application area:

> "Initially a lot of the [product] ideas came out of here. Then once it was applied [in the field] we found situations no-one in here had ever considered. People were using it on machines we had never even heard of. So we learned a lot that way!" (Leith: Inspec 1992)

Although the principal identified role of users concerns their input into the features and field-testing of the innovations, users were also seen to provide information and equipment to aid in the problem-solving process (the on-line tape certification system and MotorMonitor), as well as adapting and modifying the innovation to local needs (Backlite and the MRC-500). The latter case is well illustrated by the re-innovation process of the original MRC-500 microscope:

> "There's also been a terrific input from users there [post-commercialisation], because we have hundreds of users worldwide and a lot of them are very smart. They're quite capable of creating software and optical improvements." (White: MRC 1992)

In summary, users were found to be *the* major external source of inputs in defining the features of the innovation and in the subsequent field-testing of the prototypes. In these roles, users were found to play an important or critical role in six (17%) cases in relation to defining the innovation features, and in eleven (31%) cases with respect to field-testing. The two-way flow of transaction content during idea-generation was almost entirely cognitive, with little evidence of user developed prototypes as found by a number of earlier studies (see section 1 Chapter 1). However, in terms of field-testing there existed a two-way flow of cognitive transaction content, accompanied by both material and service transaction content.

3.2 Suppliers

The analysis highlighted the supplier as *the* major external source of solution inputs into the innovation process, playing a critical role in four (11%) of the innovations. In these four cases (Hydro-Probe, the MRC-500, Xenos, and Yeoman), the supplier was seen to have developed one or more of the critical components of the innovation in response to specific requests from the innovator. In the development of the Hydro-Probe and Xenos, for example, the respective technological entrepreneurs essentially played the role of project coordinator rather than developer, orchestrating a series of developments by innovative suppliers. Whilst in the development of the MRC-500 and Yeoman, suppliers were commissioned to develop the enabling technologies for both of these innovations: image processor technology and large-scale digitising technology, respectively.

Suppliers were also found to have provided important inputs through their development of one or more of the core components in a further eight (23%) of the innovations studied, including: the water-proof fabric for the Condor rucksack; the software for First-Sense; the ceramic reader-head for the on-line tape certification system; the electronic relays and detachable key-pad for the Scimitar H; the plastic teeth for the Stripper-Head; the film materials for Symphony; the speed control system for the Town and Country III; and the electronics for the water-mains refurbishment system.

Perhaps with the exception of Hydro-Probe and Xenos, the above examples aptly illustrate the complementary, rather than substitutive, nature of external sources of technology to indigenous innovative activity, as noted in section 1 of Chapter 1.

Thus, suppliers were seen to have developed, in response to specific requests from the innovator, important or critical components in a total of twelve (34%) of the innovations investigated. In addition, suppliers developed components of a more peripheral nature in two other innovation projects and provided various information, concerning material specifications in a number of other cases. Thus, in addition to the material transaction content resulting from the provision of innovative components by suppliers, the analysis also revealed the often intense two-way flow of cognitive transaction content between supplier and innovator.

3.3 Research Establishments

In contrast to earlier research, in particular that of Langrish *et al* (1972), the analysis of the case-material found that universities and research institutes played some role in well over 50% (twenty) of the projects. Admittedly, in many of these instances the input was considered peripheral rather than core to the innovation process (ie. useful but not important or critical). However, research establishments were considered to have provided not only the critical input into the problem-solving process of two (6%) of the innovations, but also the stimuli for these projects. To this must be added the origination and prototype development of the MRC-500 by the Medical Research Council.

The first of these two innovations refers to the MotorMonitor software package. In this case, the original and subsequent research into the patterns of electrical signals emitted by faulty motors was undertaken by Robert Gordon University. The second case refers to the Stripper-Head for use on combine harvesters. Here the development of the plastic teeth design, to strip the top off agricultural crops rather than cut the crop at the base as with traditional combine harvesters, was undertaken by the Silsoe Research Institute (under the remit of the Agricultural and Food Research Council). In both of these projects this external input was fundamental to the development of the innovations.

The role of research bodies in the innovation process was seen to be largely in relation to problem-solving. Fundamental and applied research projects undertaken by external research institutes on behalf of innovators were seen to provide useful solution inputs in the case of five (14%) innovations (Carboplatin, Diflucan, the E70A LCD mixture, the Peboc process, and the pyrethroid insecticides), and what has been termed *gap-filling* science in one further case (Hydro-Probe).

In addition, research establishments were found to have been commissioned for consultancy work in seven (20%) of the innovations (the ARM RISC microprocessor, Backlite, the Condor rucksack, Diflucan, the Pullman series, the pyrethroid insecticides, and Xenos). The nature of this consultancy work was largely in the form of evaluating the integrity of existing designs, such as in the case of the Pullman Portakabin with respect to insulation, or in terms of optimising the solution, as with the electronic content of Backlite and the ergonomics of the Condor rucksack. The solution input into all of these instances was considered to have been of a secondary or peripheral nature (ie. useful).

The analysis also revealed that research establishments provided useful, if somewhat more intangible and tacit, inputs into the problem-solving process of a further twelve (34%) innovation projects. This cognitive input was obtained by informal approaches to universities, and the tapping into, or membership of, broad research networks. The latter of these two mechanisms was seen to be the most frequently operationalised.

In addition to their input into the problem-solving process, research establishments were also seen to play a part, if some what more limited, in relation to idea-generation and field-testing. In the case of the water-mains refurbishment system, for example, the Water Research Centre undertook a critical role in relation to field-testing the epoxy resin, as noted earlier. Other examples include the utilisation of test equipment at the Silsoe Research Institute by Shelbourne Reynolds, in the testing of early prototypes of the Stripper-Head.

However, many of the interviewees whose organisations utilised research establishments as a resource, whether in the context of the innovation sample or more generally, noted that they more frequently employed universities in exploratory research rather than in product development. This occurred because of the variance between commercial and research organisations with respect to time-scale expectations and ways of working. The following comments were typical:

> "We have huge number of links with academia, both in academic [basic] and applied research...The further away from the goal-posts the research is, the more likely it is to be done in collaboration with a university." (Bushell: ICI Agrochemicals 1992)

> "We've had CASE [Phd] awards with universities, which were OK...which were cheap, but we didn't actually get anything from them. I think we quickly learnt that the direction that a postgraduate student takes forms no relation to what we are interested in. It was too easy for them to get deflected onto something of interest...The Teaching Company Scheme...is much more related to our work...and we can use them for speculative things...[that] involve a lot of research...The Teaching Company Scheme is allowing us to find out about what are the fields which could be important." (Simkin: Vector Fields 1992)

In addition, the Stripper-Head case-study reveals the tensions that can exist between research establishments and commercial organisations. In this project, the Managing Director of Shelbourne Reynolds (the innovator) became so frustrated with the commercial naivety of the Silsoe Research Institute (the inventor), that he eventually commercialised the invention without the aid of the SRI.

One further mechanism for cognitive transaction content from research establishments to cross the boundary of the organisation is via scientific and technical journals.

However, while the analysis of the case-material found that many of the companies had access to technical libraries, scientific and technical journals were explicitly mentioned as playing a role in providing information and ideas in only eight (23%) cases (Amethyst, the ARM RISC microprocessor, Carboplatin, Diflucan, the Peboc process, the pyrethroid insecticides, Scimitar H, and Synon/2). For example, with reference to the role played by scientific journals in the development of Diflucan, it was stated that:

> "We clearly had ideas, chemical ideas, biological ideas, based on what was going on in the literature, but what you do is you take those and extend them, define them, and build on that...I'm certain that it helped us to develop it." (Troke: Pfizer 1992)

While in the case of Synon/2, it was felt that academic journals had been "very valuable" in post-rationalising the ideas of the development team:

> "We worked out our fundamental ideas more or less intuitively from the patterns that we'd seen from writing all systems for the City...In theoretical academic papers we found the rationale for what we had arrived at...It was very valuable finding the theoretical underpinning." (Knowles: Synon 1992)

This result probably under-represents the role of technical literature in the innovation process. It is possible that this external source is perhaps one of the greatest *sufferers* of memory decay or drift in retrospective data (see section 5.4.1 of Chapter 4).

In summary, the analysis of the cases found that while research establishments seldom played an important or critical role in the innovation process, they frequently provided useful cognitive input into problem-solving. Where the input was commissioned, the transaction content may be classified as both service and cognitive. In addition, a great deal of intangible and tacit cognitive transaction content was found to flow between research establishments and innovators via *active* (person-to-person) rather than *passive* (literature) mechanisms.

3.4 Consultants and Industrial Designers

The analysis also reveals that consultants, other than those commissioned from research establishments, were employed in a total of sixteen (46%) projects. The nature of this consultancy work can be neatly dichotomised into technical consultancy and industrial design consultancy.

Technical consultants were utilised in nine (26%) of the projects (canned Draught Guinness, Diflucan, Elektra, the on-line tape certification system, the Pullman series, the pyrethroid insecticides, the shielded magnet, Stripper-Head, and the water-mains refurbishment system). This consultancy work was seen to cover a variety of functions, but on the whole was used on an adhoc basis to provide information or advice for specific problems that needed addressing in the problem-solving process, or for the evaluation of the performance of components or prototypes. In discussing the manner in which the expertise of technical consultants is capitalised upon in the development of the shielded magnet, it was recalled that:

> "If we wanted a specific piece of work done then we commissioned it." (Bird: Elscint 1992)

A toxicologist was employed by Mercol Descaling to evaluate the epoxy resin it had developed for the lining of its water-mains refurbishment system. Whereas in the case of the development of canned Draught Guinness, consultants were employed not only to test the internally developed solution but to attempt to brain-storm potentially better solutions. In all these projects, external technical consultancy was considered complementary to existing internal resources, providing useful rather than important inputs into problem-solving and laboratory testing.

With respect to product design, industrial design consultants were employed in six (17%) projects (Fastrac, First-Sense, Hydro-Probe, the Town and Country III, Xenos, and Yeoman), and a Fashion Designer in one further case (the Condor rucksack). These consultants were invariably commissioned to undertake a specific piece of work on a formal basis, rather than on the often more adhoc basis of technical consultancy work. In each of these cases, the design consultancy work focused on both aesthetics and the sensitising of the product to the end-user. So, for example, in designing First-Sense the consultant took account of the fact that young girls were not particularly switched on by science by experimenting with product colour. While in the Fastrac project, JCB commissioned the Ergonomics Division of the Agricultural Development Advisory Service (ADAS) to design the layout of the cab.

Although in relation to the technical solutions and functionality embodied within an innovation the aesthetics and ergonomics may not be considered as a core input, the industrial design may provide the vital differentiator in terms of commercial success. This point was articulated in relation to a number of the innovations mentioned above, for example, with reference to Xenos:

> "It's important that a product not only should work and look good, but actually feel good. At the beginning it [Xenos] looked as though it was going to come out far too light, and if it was we were going to weight it!" (Sherlock: Neen Pain 1992)

With respect to both the technical and design consultancy inputs, the transaction content was found to be a combination of cognitive (two-way), service, and material, in the form of reports, design drawings and mock-prototypes (flowing from consultant to innovator).

3.5 Distributors

Although only rarely identified by innovation studies as a source of innovation (Hippel 1988, Yoon and Lilien 1988), this study found two (6%) instances in which distributors played a critical role in the innovation process. The first of these cases involves the development of Amethyst. In this case, the distributor played a critical role in both providing the features and functionality, and in coordinating the beta-testing of the software package with its own customers. For example, it was noted with respect to the role of the supplier in the development of Amethyst, that:

"When we built it [Amethyst], they [IRD the distributors] told us what to do. So although we built the expert system, we took their market knowledge and their knowledge of what was needed, and used that to build a successful product ...They decided on the colour scheme. They decided on all the functionality. They knew what their users would need. That's a classic case of where we are a technology-provider." (Milne: Intelligent Applications 1992)

However, it was also pointed out that in relation to the roles of the distributor and end-user that:

"It's hard to know [the end-users role], because they [user comments and feedback] were all consolidated before they got to us [by IRD the distributor]. So I think there were some pretty major inputs, but we can never really separate them out." (Milne: Intelligent Applications 1992)

The second example in which the distributor played a critical role in the innovation process is provided by the development of MotorMonitor by Inspec. In this case the roles outlined above were reversed, such that Inspec provided the technical knowledge behind the package whilst the US distributor (Entek) provided the programming capability that was not available in-house.

Analysis of the case-material reveals only two (6%) further instances in which the interviewees believed that the distributor played more than a minor role: in the development of Stripper-Head and the Town and Country III. With respect to the Town and Country III, a number of the features and specifications (including the introduction of lights, indicators and maintenance-free batteries) were driven by the firm's Dutch distributer, which services a sophisticated user-base.

Thus, distributors were found to play a varied role in the development of a small number of innovations. In both the Amethyst and MotorMonitor projects there existed an intense two-way flow of cognitive transaction content centred around an interactive development process. In the case of Amethyst this was accompanied by a flow of service transaction content from the distributor to the innovator, and material transaction content (in the form of software) in the case of MotorMonitor. Whereas in the cases of Stripper-Head and the

Town and Country III the transaction content was entirely cognitive, with the distributors acting primarily as a conduit for the needs and demands of overseas markets.

3.6 The Professions

Professionals, such as doctors and educationalists, were seen to play an important role in the development of two (6%) products (Carboplatin and Diflucan), and a useful role in a further three (9%): First-Sense, Symphony, and Xenos.

As ethical drugs, Carboplatin (an anti-cancer treatment) developed by Johnson Matthey and the Institute of Cancer Research, and Diflucan (an anti-fungal agent) developed by Pfizer, were required to go through lengthy *in vivo* clinical trials prior to their commercialisation. This process necessitates the full cooperation of a number of clinicians who are prepared to test the new drug on their patients. In both of these developments clinicians were seen to work closely with the innovating organisations throughout the clinical trials. Indeed, in the case of Carboplatin there existed strong links between the Royal Marsden Hospital and the Institute of Cancer Research, which were both based on the same site at Sutton:

> "We've ready access to experienced clinicians. We haven't got to persuade them to do our clinical trials...It's very different from the traditional pharmaceutical operating link, where the pharmaceutical company goes away and develops its compound fully, makes an application to the authorities to have their compound approved-testing, and then goes out and seeks to interest clinicians in testing that particular product." (Barnard: Johnson Matthey 1992)

The clinicians were also instrumental in encouraging the market-launch of Carboplatin, which was in fact commercialised by Bristol-Myers Squibb:

> "It was actually more pushed from the clinicians who had used it than from us, because it had a very short patent life and its attractiveness wasn't that great... However, from the point of view of the patient and the doctor it was a lot easier to use and a lot safer, and therefore there was a pressure on us to clinically develop it quickly rather than the other way round...Johnson Matthey had actually given some of the drug to some clinicians to try, because they were aware that Bristol

> Myers wasn't all that keen on commercialising it...and they [the clinicians] went through the back-door to put pressure on us." (Barrett: Bristol-Myers Squibb 1992)

Thus, in the two cases of drug development, clinicians were seen to play an important role in clinical-trials, resulting in an intense two-way flow of cognitive transaction content between innovator and doctor. This was accompanied by the flow of drugs to the clinicians (material transaction content) and the undertaking of the trials on behalf of the innovators by the doctors (service transaction content).

However, in the development of First-Sense, Symphony and Xenos the strength of such relationships and the flow of transaction content between innovator and professional was found to be less intense. The role played by stoma-nurses in the development of Symphony, and doctors and physiotherapists in the Xenos project, for example, was largely one of providing information and the names of patients willing to test new medical products:

> "We've built up a lot of contacts with doctors who run the pain-clinics...A lot of good friends. We don't have a sales-force, unlike all of our competitors. Our *sales-force* is the doctors and the physios themselves, because they recommend it to one another and the word gets about...With professional people, once you've built up your reputation and a relationship with them, they are very loyal...They're happy to then pass on their patient into your care, and this is effectively what's happening." (Sherlock: Neen Pain 1992)

With respect to First-Sense, primary school teachers played a useful role in supplementing the knowledge of the Philip Harris R&D team, whose own experience lay mainly in developing science products for the secondary school market. In addition, these teachers undertook a number of field-trials with their classes using prototypes of the First-Sense product. Thus, in these three cases the two-way flow of transaction content between innovator and professional was found to be largely cognitive.

3.7 Competitors

Competitors were rarely mentioned explicitly in relation to providing inputs into the innovation process, either with respect to interacting with competitors or in analysing their products. In fact, only five (14%) of the interviewees indicated that cognitive input concerning the features, functionality and specifications of competitors' products had in some way influenced their innovations (Diflucan, Isoview 3, the shielded magnet, the Town and Country III, and Xenos). The most notable of these cases is provided by the development process of the shielded magnet:

> "Another important aspect of our work, and perhaps the driving force, is the patent situation. Our competitors, as do we, have numerous patents based around the idea of magnets...It becomes not only a creative exercise for a new product, but determining which [competitor's] specifications you're going to meet or exceed and also as to how you can steer round your competitors patents in order to get something which is unique to ourselves." (Bird: Elscint 1992)

With the sample of largely highly innovative and first-to-market products and processes used in this research, the minor input from competitors is probably not surprising. However, the pride of the engineers and scientists working on these projects may have led to an under-representation of the role of the competitor. Interestingly, of those innovation mentioned above, all but Diflucan are examples of relatively minor incremental developments of existing innovations entering highly competitive markets.

4. Variations by Innovation and Innovator Classification

In terms of both the nature of the innovations and the innovators themselves, the sample investigated in this research is relatively broad in relation to earlier studies (see Tables A.2 and A.4 in the Appendices). As a result of this, the opportunity was taken to explore the possibility that variations in the results may exist in relation to the organisational size of the innovator or the industrial classification of the innovation.

TABLE 6.8: The Exchange Value of External Inputs to the Innovation Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	4	33
	Medium	2	33
	Large	1	6
Important	Small	3	25
	Medium	3	50
	Large	6	33
Useful	Small	4	33
	Medium	1	17
	Large	4	24
Minor	Small	1	9
	Medium	0	0
	Large	6	35
Total	Small	12	100
	Medium	6	100
	Large	17	100

An analysis of the exchange value of external inputs in relation to organisational size, found that small and medium-sized innovators relied more heavily on external sources in the innovation process in general, than large innovators. External sources were seen to provide critical or important inputs in the development of 58% (seven) of the innovations developed by small firms and 83% (five) of those developed by medium-sized organisations. In comparison, only 39% (seven) of those innovations developed by large organisations sourced critical or important inputs externally. Although the numbers are small, they are suggestive of the greater inclination of small and medium-sized organisations to source inputs externally (see Table 6.8 above for greater detail).

An analysis of the exchange value of external inputs to the features, solutions, and field-testing of the innovations in relation to organisational size was also undertaken. With reference to the origin of the inputs into the idea-generation and problem-solving processes, there appears to be a less marked difference between small and large organisations than that highlighted above, both relying less on external sources. However, medium-sized companies were still seen to depend heavily on external sources in both of these phases of the innovation process. Refer to Tables 6.9 and 6.10 below, for a more detailed breakdown of the data.

The analysis of the data suggests that the variation in external sourcing between small and large organisations identified at the overall project level, is largely accounted for in terms of the inputs into the field-testing of the innovations. It was found that in relation to field-testing and beta-testing, external sources were seen to provide critical or important inputs in 50% (six) of the innovations developed by small companies, 66% (four) of those by medium-sized companies, but only 24% (four) of those developed by large organisations.

TABLE 6.9: The Exchange Value of External Inputs to the Idea-Generation Process in Relation to Organisational Size

Exchange Value	Company Size	No. of Projects	% of Projects
Critical	Small	1	8
	Medium	0	0
	Large	0	0
Important	Small	1	8
	Medium	4	66
	Large	2	12
Useful	Small	7	59
	Medium	1	17
	Large	9	53
Minor	Small	3	25
	Medium	1	17
	Large	6	35

TABLE 6.10: The Exchange Value of External Inputs to the Problem-Solving Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	3	25
	Medium	2	33
	Large	1	6
Important	Small	1	8
	Medium	3	50
	Large	4	24
Useful	Small	5	42
	Medium	1	17
	Large	6	35
Minor	Small	3	25
	Medium	0	0
	Large	6	35

TABLE 6.11: The Exchange Value of External Inputs to the Field-Testing Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	1	8
	Medium	2	33
	Large	0	0
Important	Small	5	42
	Medium	2	33
	Large	4	24
Useful	Small	3	25
	Medium	1	17
	Large	5	29
Minor	Small	3	25
	Medium	1	17
	Large	8	47

Although the sample is small, the data suggests that small and medium-sized organisations are more inclined to utilise external inputs in the innovation process. This relation is strongest for medium-sized innovators with respect to field-testing.

In analysing the origin of inputs into the innovation process in relation to the eight innovation groupings (detailed in Table A.4 in the Appendices) only a few correlations appeared to stand-out. There was a tendency, for example, for those innovations in the industrial and agricultural chemical products and processes group, as well as those in the electronic, communications and computer products and components group, to be developed largely in-house. It is worth noting that seven of the ten innovators in these two groups are large organisations. In contrast, the pharmaceuticals group tended to be characterised by large companies with a strong inclination to utilise external inputs, particularly from research establishments, clinicians, and scientific journals.

5. Summary of Findings

The analysis of the thirty-five innovations investigated in this research revealed that only seven (20%) were considered to have been developed almost entirely in-house. At the other extreme, input from external sources was considered to have been critical in seven (20%) other developments. Indeed, external inputs were considered to have been either important or critical to the innovation process in 54% (nineteen) of the sample. Thus, the aggregate results of the qualitative analysis of the case material support the evidence of earlier research, that demonstrates the importance of external sources to the innovation process (see Table 1.1 in Chapter 1). The results also support the findings of earlier studies that suggest external sources are an important complementary source of inputs into the innovation process, rather than a substitute for indigenous innovative activity (see section 1 of Chapter 1).

In addition, the analysis of the case-material found that in the sample as a whole external inputs were of higher exchange value during the problem-solving process (solution inputs) and field-testing than during the idea-generation process (inputs into the features and functionality of the innovation). In both of the first two functions, external sources were found to contribute important or critical inputs in fourteen (40%) of the cases, but in only eight (23%) with respect to idea-generation. Earlier studies have tended to indicate the greater importance of external sources to idea-generation rather than problem-solving (see section 1 of Chapter 1). However, this contradictory result ties in with the expectation that the post-war proliferation of knowledge would tend to lead to the increased specialisation of organisations (see section 3.3 of Chapter 2), and hence to the need to source inputs externally.

In relation to the locus of the external inputs into the innovation process, the analysis found that the user was *the* major external source of inputs into the idea-generation and field-testing phases of the innovation projects, with suppliers as *the* major external source of inputs into the problem-solving process. In addition, research establishments were seen to be utilised in twenty (57%) of the projects, though often in more peripheral roles. This finding is contrary to earlier findings, such as those of Langrish *et al* (1972). Technical and design consultants were also employed in 46% of the developments, the former largely in relation to problem-solving, the latter with respect to aesthetics and ergonomics. Distributors and professionals (such as doctors and educationalists) were seen to play a more limited role, as were competitors, as a source of external inputs.

An analysis of the inputs arising from external sources during the innovation process, found that the transaction content was primarily cognitive in relation to idea-generation, but a combination of cognitive, service and material transaction content in the problem-solving and field-testing stages.

Finally, although the sample is small, the data suggests that small and medium-sized firms are more inclined to utilise external inputs in the innovation process. This relation was found to be strongest for medium-sized innovators with respect to field-testing. Variations in the exchange value and origin of external inputs with respect to the product groupings were less clear-cut, but once again the sample is small.

CHAPTER SEVEN: THE ROLE, NATURE AND EXCHANGE VALUE OF INFORMAL BOUNDARY-SPANNING DYADS IN SUCCESSFUL INNOVATION

1. Introduction

Having identified the locus, role, nature and exchange value of the external inputs into the innovation process, this chapter focuses on analysing the nature of the dyadic relationships through which such transaction content flows between source and innovator. As noted in sections 4 and 5 of Chapter 1, earlier studies have frequently ignored the links through which external inputs are channelled and have rarely attempted to research them in a systematic manner beyond mapping out the overall network. It is thus the intention here, to present the findings of a more systematic analysis of the boundary-spanning dyads employed in the innovation process.

Of particular interest in this chapter is the role, nature and exchange value of informal boundary-spanning relationships between individuals in the innovation process. After all, as was noted in one of the interviews:

> "Companies don't keep in touch, people in companies do." (Urquhart: Acorn Computer 1992)

Thus, for example, affective (friendship) and moral ties are considered alongside more instrumental relationships. In addition, the nature of the ties between source and recipient at the level of the individual, rather than the organisation, are explored in an attempt to explain the motives behind informal exchange behaviour. In presenting the results of the qualitative analysis of the case-material, this and the subsequent chapter explore the relevance of associating such emotive terms as *friendship*, *alumni* and *community*, for example, with the innovation process.

This chapter is essentially divided into four main sections: the first presents the results concerning the role and exchange value of external inputs derived informally; the second explores the nature of the relationships between the innovators and the sources of external inputs; the third attempts to explain the incidence of informal inputs with reference to economic and social exchange theory; and finally, an evaluation is made concerning the extent to which these results may vary according to variations in contingent factors, such as the organisational size of the innovator.

2. The Role and Exchange Value of Informal Boundary-Spanning Dyads

This section focuses upon determining the role, nature and exchange value of those external inputs derived informally during the innovation process. In order to achieve this, the interviewees were questioned about the nature of the boundary-spanning dyadic relationships that existed with the various external sources that were identified as contributors to the innovations under investigation. Particular emphasis was placed on the role of the individual in the exchange process and the manner in which the dyadic link was operationalised, that is, the nature of the exchange mechanisms. Thus, the data employed here is a subset of the data used in the previous chapter, resulting from the extraction of those inputs considered by the interviewee to have been sourced informally.

The degree of formalisation is used here to refer to the extent to which a boundary-spanning transaction or relationship is given official recognition and administratively sanctioned (see section 2.2.6 of Chapter 2). Thus, in the context of this chapter, of particular interest are those unsanctioned boundary-spanning transactions that occurred between individuals during the innovation process.

The re-analysis of the data collated for the previous chapter revealed that external inputs sourced informally played a critical or important role in eight (23%) of the innovations (Backlite, Fastrac, Hydro-Probe, MotorMonitor, the MRC-500, Scimitar- H, Stripper-Head, and Yeoman). This compares to nineteen (54%) projects considered to have employed critical or important inputs from external sources overall. In addition, informal external sources provided useful inputs in a further sixteen (46%) of the projects. Only around a third (eleven) of the projects were considered to have not benefited, or to have benefited to only a minor extent, from external inputs sourced informally: this compares to a fifth (seven) of the projects from external inputs generally.

TABLE 7.1: The Exchange Value of Informal Boundary-Spanning Dyads to the Innovation Process

Exchange Value	No. of Projects	% of Projects
Critical	2	6
Important	6	17
Useful	16	46
Minor	11	31
Total	35	100

These results illustrate the exchange value to the innovation process of external inputs derived informally. The findings thus support those of a more limited set of earlier studies (see section 5.1 of Chapter 2). However, as with the exchange value of external sources in general, the exchange value of external inputs derived informally was found to vary between the various stages of the innovation projects. For example, the analysis of the case-material found that in the sample as a whole, informally derived external inputs were of slightly greater importance during idea-generation than during problem-solving. This result lends some support to a study by Myers and Marquis (1969), which found that personal boundary-spanning contacts accounted for 30% of the major inputs into idea-generation, but only 17% of the major solution inputs. These results are not as conclusive.

This finding is contrary to that revealed for external inputs in general, where external solution inputs were found to be of greater exchange value than inputs into the idea-generation process. The results therefore highlight the fact that a far higher proportion of the external inputs into idea-generation are informally derived compared to those in relation to problem-solving.

The following sub-sections take a closer look at the role of informal boundary-spanning activity by analysing the exchange value of informally derived external inputs in stimulating the innovation project, defining the innovation concept, and aiding the idea-generation, problem-solving and field-testing processes.

2.1 The Formalisation of Project Stimuli

The results concerning the origin of the stimuli for each of the projects, presented in the previous chapter, indicate that nine (26%) were stimulated by an explicit market-need (the E70A LCD mixture, Flexilink, Isoview 3, the linear actuator, the on-line tape certification system, Polifold, Symphony, the Town and Country III, and the water-mains refurbishment system), and four (11%) directly by a specific science or technology project undertaken externally (Carboplatin, MotorMonitor, the pyrethroid insecticides, and Stripper-Head,). Thus, a total of thirteen (37%) projects were found to result from identifiable external stimuli. The other twenty two (63%) projects were stimulated by various internal processes: internal needs, perceived external needs, in-house technology, or the recognition of the potential application of existing external technology.

In assessing the formalisation of the external stimuli of these thirteen projects, it was found that only two of the need-stimulated innovations (the linear actuator, and the on-line tape certification system), and one of the means-stimulated innovations (Carboplatin) arose from a formal approach by an external actor. Both of the need-stimulated projects were initiated following formal customer approaches, and the means-stimulated project following a formal approach from a research establishment. In the case of Carboplatin, it was recalled that:

> "The original discovery was made by Professor Rosenberg of Michigan State University. He found that in a particular experiment he got some rather strange activity associated with platinum, and was able to correlate that later on with anti-tumour activity...He then...approached Johnson Matthey as the key company interested in platinum marketing...[who] funded his group...to see whether it would have some potential." (Barnard: Johnson Matthey 1992)

The other ten projects were triggered by external stimuli of a more casual and informal nature, often arising from disparate sources. This process is typified by the examples of Flexilink and Polifold. In the latter case, Glass Transport Systems was spurred into action following mounting customer complaints concerning existing market solutions, which it installed but did not manufacture. The process through which the former was stimulated was related as follows:

> "Even though I am a design engineer in the office, I get involved with clients...I therefore got to see the need and hear the comments first-hand." (Hughes: Pilkington Communication Systems 1992)

Thus, the results suggest that informal mechanisms were the most prominent with regards to those innovation projects initiated in response to external stimuli.

2.2 The Formalisation of Concept Definition Inputs

In the previous chapter it was noted that the innovation concept was defined by external sources in only five (14%) cases. In all but one of these, the process of concept definition was found to have resulted from formal mechanisms. In the development of the linear actuator and the on-line tape certification system, for example, the concept was defined upfront in the formal approach of a specific customer. However, in relation to the Condor rucksack and Fastrac, the concept was defined by user-panels established on a formal basis by the respective innovators, JCB and Karrimor. With reference to the origin and role of the user-panel in the development of Fastrac, it was recalled that:

> "From some of the people [farmers and agricultural contractors] we spoke to, we formed a user-panel. Essentially five people, that sat down and worked out the broad specification of what this machine should be able to perform, rather than what it might look like...They were paid a consultancy fee...We wanted them to feel as though they had some commitment towards us, in terms of giving us the benefit of their knowledge...that they were being rewarded for their expertise." (Tatt: JCB Landpower 1992)

In the case of the Condor rucksack, the user-panel that was employed to define the product concept is run on a continuing basis in the form of a *Think-Tank* team. This team consists of around five to six internationally renowned individuals, carefully selected for their all round knowledge of mountain activities, training and outdoor education. Although the Karrimor Think-Tank team were paid a retainer and provided with sponsorship on expeditions, the members were

"...close personal friends, in most cases, of the MD." (Pickard: Karrimor 1992)

Thus, in this respect the results suggest that in the few instances in which external actors originated the innovation concept, formal mechanisms of definition were the most prominent.

2.3 The Formalisation of Idea-Generation Inputs

In analysing the degree of formality of the exchange process for the transaction content employed in idea-generation, informally derived external inputs were not found to be critical in any of the projects and important in only four (11%): Fastrac, Isoview 3, MotorMonitor, and Stripper-Head. This compares to eight (23%) cases for external inputs in general. However, useful inputs derived informally were seen to have arisen in sixteen (46%) of the projects. Informal mechanisms of exchange were considered unimportant or minor in fifteen (43%) cases, compared to ten (29%) for external inputs in total.

TABLE 7.2: The Exchange Value of Informal Boundary-Spanning Dyads to the Idea-Generation Process

Exchange Value	No. of Projects	% of Projects
Critical	0	0
Important	4	11
Useful	16	46
Minor	15	43
Total	35	100

The largely informally derived external input into the idea-generation process of these projects appears to be linked to the *tacit* and *incomplete* nature of many of the *messages*. In addition, a good proportion of this external input was obtained on an ad hoc basis from a large number of actors with whom the innovator had only a transitory relationship. In the development of the Condor rucksack, for example, Karrimor was reported to have:

> "...absorbed product ideas from many, many sources and we audited them quite critically." (Pickard: Karrimor 1992)

This clearly supports the contention of Allen *et al* (1983,201) that "bits and pieces of what eventually becomes a new idea arrive from a variety of sources", and that the creative contribution of the innovator is the integration of these disparate messages (see section 3.2 of Chapter 2). In the development of Amethyst by Intelligent Applications (as mentioned in the previous chapter), this integration role was undertaken externally by their distributor.

Individuals within the innovating organisations were also found, however, to employ to good affect a smaller set of long-term relationships in which friendship played an important part. Such relationships were found to be instrumental in providing greater scope for the two-way flow of cognitive transaction content over-time, thus allowing ideas to take form in a more interactive manner. In the development of MotorMonitor, for example, it was noted that:

> "There were definitely key users who contributed a lot more feed-back than others...They're quite demanding...[but] it is sociable as well. If we're down there we'll sort of drop in and see them whether they need to see us or not, and visa versa with them...With our colleagues at Scottish Power [one of the lead-users], we have put a paper in a conference together." (Leith: Inspec 1992)

The results therefore suggest that while a great deal of useful input was informally sourced from a diverse set of transitory relationships, the input of greatest exchange value in idea-generation was often obtained from a smaller sub-set of long-term multiplex links, coupling affective and cognitive transaction content.

2.4 The Formalisation of Problem-Solving Inputs

The analysis of the data in relation to the degree of formality of the exchange process for the transaction content employed in the problem-solving, found that informally derived external inputs were critical in only two (6%) cases (MotorMonitor and Yeoman), and important in a further two (the MRC-500 and Scimitar H). This compares to fourteen (40%) cases for external inputs in general. However, useful inputs derived informally were seen to have arisen in thirteen (37%) of the projects. Thus, informal mechanisms of exchange were considered as unimportant or minor in half of the cases, compared to one quarter for external inputs in total.

TABLE 7.3: The Exchange Value of Informal Boundary-Spanning Dyads to the Problem-Solving Process

Exchange Value	No. of Projects	% of Projects
Critical	2	6
Important	2	6
Useful	13	37
Minor	18	51
Total	35	100

Although many of the useful inputs into the problem-solving process of these innovations were cognitive and tacit in nature, the important and critical inputs were seen to be largely material, for example, through the development of components and materials by suppliers. This material transaction content was frequently found to result from a formal approach by the innovator to a supplier, to carry out the necessary development and then supply the product. In the Xenos project, for example, Neen Pain formally commissioned Cambridge Consultants to undertake the critical electronic component development.

The development of the MRC-500 is perhaps atypical, but provides an interesting example of where important solution inputs were provided informally by individuals from outside of the innovating organisation. In this case the control software was coded by an ex-Phd student of the inventor, while much of the optical and mechanical design was undertaken by the husband of another MRC cell-biologist in the same laboratory as the inventor.

The analysis found that much of the useful input into the problem-solving process was both tacit and incomplete. This largely cognitive transaction content was more frequently derived through informal mechanisms than the material transaction content discussed above. A common mechanism for the informal exchange of this solution input was found to be person-to-person contact at international scientific conferences (Carboplatin, Diflucan, Elektra, the pyrethroid insecticides, the shielded magnet). However, this exchange process was often found to be tempered by the commercial interests of the employers of these scientists and engineers. In the development of the shielded magnet:

> "The ideas that we got came back mainly from conferences...we attend international conferences...at least once a year...each in our own specialty...We would talk to...basic research scientists working in the field, including competitors...It's very informal. Well, it's formal and informal, because if you talk to a competitor there are only certain questions you are allowed to ask obviously. So you phrase your conversation in a structured way so as not to compromise your associate, but it's surprising how open people can be if asked the questions in a witty way!" (Bird: Elscint 1992)

The results here thus indicate that the important and critical inputs in to the problem-solving process are largely sourced via formal mechanisms, while the useful inputs are typically sourced informally.

2.5 <u>The Formalisation of Field-Testing Inputs</u>

In contrast to the results concerning the formality of the exchange process in problem-solving, the analysis found that over half of the important and critical inputs in the field-testing of the innovations were derived informally. Thus, informally derived external inputs were seen to be important in eight (23%) of the projects (Backlite, Elektra, Fastrac, Hydro-Probe, MotorMonitor, Stripper-Head, Symphony and Yeoman), although critical in none. This compares to fourteen (40%) cases for external inputs in general. Useful inputs were also found to be derived informally in a further seven (20%) projects. Therefore, informal mechanisms of exchange were considered as unimportant or minor in twenty (57%) innovations, compared to twelve (34%) for external inputs in total.

TABLE 7.4: The Exchange Value of Informal Boundary-Spanning Dyads to the Field-Testing the Innovations

Exchange Value	No. of Projects	% of Projects
Critical	0	0
Important	8	23
Useful	7	20
Minor	20	57
Total	35	100

Typical of the informal nature of external input into the field-testing process is the case of Elektra:

> "We have strong connections with...ten firms that we use...They're lead-users, where we know the people who are using the software in the companies and have a high level of expertise...They're friends...We tried to establish [formal] beta-test sites where we get feed-back and it just didn't work, so we just work with individuals that we're friendly with." (Simkin: Vector Fields 1992)

Also of interest is the field-testing of the Yeoman:

> "The second prototype we took to sea extensively. It was still a top-secret project then...We selected friends we trusted and we used to take it out in their boats and get their comments, their feed-back...This was the first attempt to crack the user-interface." (Parfitt: Yeoman Marine 1992)

In the field-testing of the Elektra software package the utilisation of relationships reinforced by friendship allowed Vector Fields to obtain better feed-back. For Yeoman Marine, and also Neen Pain in the development of Xenos, the employment of friends in field-testing was primarily one of retaining the secrecy of the project.

Thus, the results not only illustrate the exchange value of informal boundary-spanning inputs into the field-testing process of innovative products, but also the importance of friendship between particular individuals in the innovating organisation and those outside, frequently within so-called user-organisations.

2.6 External Product Champions

In addition to the major role users have been shown to play in both the idea-generation process and field-testing, the analysis also highlighted the incidence of informal product championing by individuals outside of the innovating organisation. Interviewees in six (17%) of the cases explicitly referred to external individuals who had played a role analogous to the so-called *product champion* (Amethyst, Backlite, Hydro-Probe, MotorMonitor, Synon/2, and the water-mains refurbishment system). For example, in the testing of early prototypes of the Synon/2 software package:

> "The DP Manager there [City Bank], who knew us, believed in our ideas, was prepared really to risk quite a lot." (Knowles: Synon 1992)

While the Hydronix interviewee recounted in detail the important role played by an individual within English China Clays both in the field-testing of the Hydro-Probe and in developing their basic understanding of the technology:

> "We didn't understand the relationship of the output signals of the sensor. My colleague didn't even realise the relationship is different for different materials ...We fairly early on met somebody from English China Clays, on the technical side, and they were very interested in the product...He had one of the first ones we made...He had a little laboratory down there and he actually built a silo so he could test our product out with a variety of different materials...He did some curves for us [voltage/moisture] on different materials...The sort of work we couldn't have done. He did it for his own interest...So that was a totally informal relationship...When you get a big company with an enthusiastic technical employee, they can do wonders for a small company...He championed the product!" (Laffan: Hydronix 1992)

Furthermore, Intelligent Applications consciously scan the market for potential external product champions prior to initiating development projects:

> "In all these product developments there's always been a couple of key [external] individuals that make it all work...In every case their is a [external] product-champion. And we've found these guys initially through this market-survey sweep process, where it emerges who's really keen and who isn't." (Milne: Intelligent Applications 1992)

A number of the interviewees also commented explicitly on the informal role played more generally by lead-users and the professions in the adoption and diffusion of the innovations (Carboplatin, Elektra, MotorMonitor, MRC-500, Nicam 728, Synon/2, Xenos, and Yeoman). The role of doctors in the diffusion of Carboplatin and Xenos, for example, was mentioned in section 3.6 of the previous chapter. In relation to the role of lead-users in the adoption of the Synon/2 software package, it was noted that:

> "Certainly in the early sales in the States and Europe, you saw...people in companies who were interested in things state-of-the-art...I would say they were literally adopting for the sake of adopting, to make their lives more interesting, but without them, certainly, I don't think we would have got very far." (Knowles: Synon 1992)

Thus, the analysis reveals that in six (17%) of the cases the interviewee identified an individual outside of the innovating organisation as a product champion. Of interest here is the fact that four of these six companies were very small (less than ten employees) and the other two medium-sized (around one hundred employees). In addition, the adoption and diffusion of eight (23%) of the innovations was promoted informally by lead-users and professions. These individuals appear to have been motivated both by the capabilities of the innovations and their inherent innovativeness.

2.7 Behind Every Formal Link

The case material provides many references, both explicit and implicit, of the importance of informal boundary-spanning relationships between individuals in supporting formally established links between organisations. That is, there exists much evidence to corroborate with the contention of Freeman (1991,503) that:

> "Behind every formal network, giving it the breath of life, are usually various informal networks...Personal relationships of trust and confidence...are important both at the formal and informal level."

Moreover, the Acorn interviewee argued that there exists:

> "a grey area between formality and informality..." (Urquhart: Acorn 1992)

This *breath of life* is well illustrated by referring explicitly to the interview material from just some of these cases. For example, in his discussion of the role of the *LCD Consortium* (a group of companies and research establishments brought together by the MOD to work on LCD technology) in the development of the E70A LCD mixture, it was recalled that:

> "The LCD Consortium was formal, but there was a tremendous informal back up to it. People would meet frequently. They'd talk on the phone frequently. We'd all been in it together since the beginning and it wasn't so much a customer-supplier relationship as a personal friend relationship. Quite a lot of the liquid crystal business is still like that." (Coates: Merck 1992)

The importance of friendship in collaborating with external partners was also noted by others:

> "We have very close relationships with the groups that we collaborate with...It is the friendships...It is important. It develops a level of understanding which you wouldn't get otherwise." (Simkin: Vector Fields 1992)

Whilst in response to a question concerning the formality of the external links employed during the development of the Scimitar H, it was argued that:

> "If you think you can actually write it down [the nature of the relationship] on one piece of paper [ie. contractual]...it doesn't work. It works on a person to person basis. If it gels it can be a very, very productive relationship." (Conley: Marconi Communication Systems 1992)

Indeed, where individuals do not *gel*, the personal relationships can be counter-productive to the formal link at the level of the organisation. The development of the Stripper-Head provides a good illustration of this point. In this case, the frustration of Shelbourne Reynolds with the commercial naivety of the Silsoe Research Institute was compounded by a personality clash between senior figures in these two organisations.

Since the combining of formal and informal relationships is therefore an important element of successful collaboration, the origin of this dualism or multiplexity is of interest. Boissevain (1974,30) argues that "there is a tendency for single-stranded [ie. uniplex] relations to become many-stranded [ie. multiplex] if they persist over time" (see section 2.2.5 of Chapter 2). This begs the question of whether informal relationships precede formal relationships, or *vice versa*. The analysis of the case-material reveals that both of these processes are in evidence. For example, in relation to the formation of friendships which developed within the framework of a formal collaboration with a lead-user during beta-tests, it was noted that:

> "We made some very good friendships among some of the developers [at City Bank during the beta-test]...Of course, if you're working on something new with someone it's a good environment to make friends." (Knowles: Synon 1992)

Conversely, the importance of previously existing friendships was stressed in the decision to involve Philips in the Elektra project:

> "The group at Rutherford got heavily involved with...Philips, STC, GEC...to form a big [EEC] project [in the early 1980s]...Friendships were formed in that original project, which carried forward. You learnt who it was good to work with, who you could rely on." (Simkin: Vector Fields 1992)

In summary, the analysis of the case-material revealed the importance of informal friendship-based boundary-spanning relationships in *breathing life* into formal collaborations. This supports the contention of Cunningham and Homse (1984, 17) that "social bonds between organisations are an important element of many successful [formal] relations". In this sense, by removing the formally derived external inputs to analyze the exchange value of informally derived inputs, one is in fact under-estimating the importance of informal boundary-spanning relationships in the innovation process. Indeed, a number of the formal organisation-level relationships identified in the case-studies were initiated by previously existing informal friendship-based boundary-spanning relationships between individuals.

3. The Nature of Boundary-Spanning Dyads

3.1 Users

The results of the analysis of the locus of external inputs into the innovation process presented in the previous chapter, indicated that users were *the* major external source in idea-generation and field-testing. This input is derived via a plurality of mechanisms, including: informal and transitory contact at exhibitions, informal customer-site visits, formal user-groups, formal and informal user-panels, formal and informal beta-tests, and informal person-to-person contact driven by friendship.

A good proportion of the messages entering the idea-generation process were found to be sourced informally from transitory relationships with users. The principal mechanisms mentioned by the interviewees in this respect include: exhibitions (First-Sense, Symphony, and the Town and Country III); customer-site visits (the E70A LCD mixture, Flexilink, the on-line tape certification system, Puraspec, Scimitar H, and Stripper-Head); person-to-person contact over the phone or on-site (Elektra, Hydro-Probe, Isoview 3, MotorMonitor, Polifold, and the Town and Country III); and questionnaires (the Pullman series). This was largely a one-way flow of cognitive transaction content from the user to the innovator, often in the form of tacit and incomplete information concerning product feed-back and user needs.

Although the exchange value of much of this input into the idea-generation process was classified as only useful or minor, the Booster interviewee, for example, argued that it served to avoid the commercial pitfalls of so-called *engineer-solutions.* Typical examples of informal user input channelled through these mechanisms include the positioning of the rechargeable plug and adoption of puncture proof tyres in the development of the Town and Country III. With respect to the inputs to the Yeoman:

> "They were largely in-house ideas with some feed-back from other yachtsmen and friends and journalists. And good feed-back too. Although there weren't that many changes to the original idea, so we had it pretty well right the first time. The changes were subtle." (Parfitt: Yeoman Marine 1992)

Interestingly, in all but three of the above cases (the E70A LCD mixture, the Pullman series, and Puraspec) this boundary-spanning activity involved engineers working on the project itself. It was argued that this prevented distortion in user input in the development of the Town and Country III, allowed the instant filtering of the feed-back and ideas, and sensitised the engineers to the user. A good illustration of this direct contact between engineers and users was provided by the Symphony case:

> "The R&D people will get involved in the clinical trials, and in the clinical trials you've got to meet the patients, and talk to the patients. You may not be doing market research about your product, but what you are doing is to get to know your customer in the general conversation. You can start by bouncing a few ideas around and seeing whether they perceive what ever it is, to be a real problem or not." (Cross: Simcare 1992)

In addition, in relation to the field-trails of the Scimitar H, it was commented that:

> "It's interesting, on the trials abroad, it was the design engineers who were sent...so that feed-back was immediate. It was a very useful education for us." (Conley: Marconi Communication Systems 1992)

This process was enhanced in the development of First-Sense by essentially *internalising* a user within the R&D team:

"Our R&D staff, I encourage them to be out in the market-place, to talk with teachers, visit schools...One of them was a teacher anyway...fresh from education. So she's on the ball. She knows what's going on. So she's able to put the teachers point of view straight into the R&D evaluation programme...She understands fully...the objective of the equipment [in the classroom] and understands the syllabus." (Foley: Philip Harris 1992)

However, in three (9%) of the developments (the Condor rucksack, Elektra, and Xenos) input from all but lead-users was considered with varying degrees of contempt. Two of these three innovations were developed for consumers rather than industrial users. Thus, with respect to user input during the development of Xenos, for example, it was pointed out that:

"We didn't do too much with customers, partly through security and partly because we had enough knowledge amongst ourselves...[However] we were using about half a dozen different people to assess to benefits and the bugs...from friendships built-up over the years." (Sherlock: Neen Pain 1992)

Whilst in the development of the Elektra software package, it was noted that:

"Some of our users wouldn't know that there was an error [in the software]...and perhaps optimise at the wrong dimensions as a result, and not really realise!" (Simkin: Vector Fields 1992)

The creation of user-groups was viewed by a number of the interviewees as a more effective mechanism for the sourcing of user input into the innovation process. In this forum it was felt that user feed-back, ideas and needs could be explored in a more systematic manner, and articulated in a more *complete* form. The role and importance of formal user-panels has already been discussed in relation to concept definition and idea-generation in the development of the Condor rucksack and Fastrac. In addition, Karrimor utilised a formal *Test Team*, established and run along the same lines as their Think Tank, to systematically test the Condor rucksack and report back. As one of the approaches adopted by JCB to gain feed-back from prototypes of Fastrac, the company established informal user evaluator-panels. These were described as follows:

> "We then had these five or six prototype machines, which I took out and initially left on farms for a couple of months. What we did then was we would set an evening aside and we would invite the [JCB] design people...We would sit down in various rooms, hotels, pubs...I had a flip-chart and I just went through the vehicle - 'What do you think of the engine? What do you think of the gear-box?...Get an overall impression. Then each delegate, and these would range from tractor-drivers to the farmers themselves, they would be allowed three votes, and we asked them 'If you had a wish-list, which three items would you change?'" (Tatt: JCB Landpower 1992)

Two other companies, Inspec and Vector Fields, reported the useful role played by semi-formal user-groups formed on a more general basis, while a third, Booster, plugged into already existing groups such as local branches of the Polio and MS societies. The Vector Fields user-group meetings, for example, were described thus:

> "It's essentially one or two days. Some sort of social event in the evening, to start it off and to encourage people to come, and also you get people talking outside of the formal atmosphere of the lecture room. Then a series of lectures by Vector Fields people who are involved...A report on the existing products, the sort of problems that people have had. A report on the next releases which are coming out, and developments which are coming for the future. That takes roughly half a day and the rest of the time is users talking about the product, reporting problems with the software." (Simkin: Vector Fields 1992)

Thus, user-group meetings provided a suitable forum for the two-way flow of both cognitive and affective transaction content, and the establishment of longer-term friendship-based relationships between individual users and engineers, alongside already existing formal organisational links.

The analysis reveals that in eight (23%) of the fourteen (40%) projects where the exchange value of user input in field-testing was considered to be important or critical, the resource was derived informally (Backlite, Elektra, Fastrac, Hydro-Probe, Motor-Monitor, Stripper-Head, Symphony, and Yeoman). In the first four of these cases, the analysis also revealed the importance of friendship based relationships as an effective mechanism of exchange and as a key element in the selection of users for field-testing. This is well illustrated by the comments made in relation to the Yeoman:

"Hugh and I sailed on a friends yacht...to San Tropez and tested it [the first prototype]...Although we'd worked a lot on the software in the office, it's not until you take a product like that to sea that you really find what you've got...And we were able to change the software dynamically on board the vessel as I had it all on a lap-top computer...The second prototype we took to sea extensively. It was still a top-secret project then...We selected friends we trusted and we used to take it out in their boats and get their comments, their feed-back...This was the first attempt to crack the user-interface between man and machine." (Parfitt: Yeoman Marine 1992)

Further examples of the importance of friendship between individual engineers and users has already been provided earlier in this chapter, including MotorMonitor (2.3), Elektra (2.4), and Synon/2 (2.6).

In summary, informal input from users was found to be particularly evident in idea-generation and the field-testing of the innovations, with the exchange value being greater in the latter. The analysis revealed a plurality of informal mechanisms through which this informal input was channelled and highlighted the importance of friendship between engineers and users in the exchange process.

3.2 Suppliers

In contrast to the informal nature of much of the input from users, supplier input into the innovation process was found to be largely formal. In the previous chapter it was reported that the exchange value of supplier input into the problem-solving process was considered to have been critical in four (11%) of the innovations, and important in a further eight (23%). However, analysis of the nature of the exchange mechanism and the relationship between the innovator and the supplier, indicated that the exchange value of input sourced informally was considered to be critical in only one of the projects (Yeoman) and important in one other (Scimitar H). With reference to the role of suppliers in the development of the Scimitar H and the nature of the supplier relationships, it was noted that:

> "There was a lot of work with suppliers on the LCD that went into the pack. There was some work with people doing the membrane key-pad, because that was a bit new and special...Yes, we did use suppliers expertise. The most significant area of that was within the antenna tuning unit, because its design is very specialised and important to provide the frequency-hopping activity. We had a very close liaison with a particular manufacturer of relays...Most of these things were done fairly informally throughout...I certainly remember friendly relations with the supplier...As a young engineer you had a certain respect for the supplier. After all, the supplier is the expert in his field, so you have to respect him...If it was something very specialised it would be face-to-face contact, engineer to engineer, but for more general components it would... engineer to salesman." (Conley: Marconi Communication Systems 1992)

The informal role of the supplier was also recalled in the Yeoman project, with respect to the development of the digitising technology:

> "We managed to persuade a couple of manufacturers to have a go at it." (Parfitt: Yeoman Marine 1992)

However, the importance of friendship and informality was stressed by a number of the interviewees with respect to the nature of the formal relationships that existed between the innovator and their suppliers in the projects studied. For example, in relation to the development of the MRC-500:

> "Initially, we had two prime contractors...They were very close links that we had and we were able to specify something that we needed...They [the contractors engineers] got excited about the project...There had to be a lot of good-will, because inevitably things go wrong and basically it doesn't do any good sort of sticking your heals in and saying 'Well, it wasn't my fault'...So preparing...to get on with something before formal contracts were drawn up...was important..." (White: Medical Research Council 1992)

Thus, while the analysis found much of the important and critical supplier input into the problem-solving process was derived via formal mechanisms, the innovative nature of the components required of the suppliers necessitated good-will and informality. In addition, the frequent boundary-spanning interaction at the engineer-level allowed friendships to evolve.

3.3 Research Establishments

As detailed in the previous chapter, input from research establishments was found to fall into roughly three areas: fundamental or applied research projects, consultancy work, and the *tapping* of researchers and research networks.

The analysis found that research establishments were involved in undertaking fundamental or applied research in five (14%) of the projects. In all of these cases funding was provided to the research organisation, and specific objectives and modes of reporting to the sponsor were laid out. However, despite the formality of the relationship at the organisational-level, such funding was often found to originate from previously existing informal relationships between individuals within the respective organisations. In discussing the academic research undertaken in relation to the Carboplatin project, for example, it was commented that:

> "Each person I suppose, from a university background, tends to pick up one or two people [academics] that they talk to more freely, as a spring-board to understanding what's happening in university life or whatever, what the problems are...You can also bounce ideas back off them to see how they respond...you've got that, which is a very personal link with a few people...We also have a very broad network of contacts with the universities. It's a very free two-way exchange of ideas, with proposals either coming to us, or us taking research suggestions out." (Barnard: Johnson Matthey 1992)

This point is reinforced by comments made concerning the development of Diflucan:

> "I think it is the individuals who make the link, especially earlier on [in the project]. Our scientists are all encouraged to maintain close contacts with people: close contacts with people in other countries, close contact with people in government research departments. And those contacts are on an informal basis. So you meet them at conferences...and so as one goes to meetings, one presents research and discusses it with those experts you get to know. Some of those people who strike up a very good working relationship and maybe then even choose to use them as your consultant or to do some research. Some people you know are more peripheral...but we're all interested in science...So there are lots of informal contacts." (Troke: Pfizer 1992)

Certainly, the nature of academic links with innovators appear to provide good illustrations of the "grey area between formality and informality". Referring to the links utilised in the development of the Peboc process, for example, it was noted that:

> "We have a lot of contact with Bangor [University]. It's one of the reasons the company is [based] here, because there's a chemistry department there...Because we have research things going on there, we have a formal context, but we also have informal things going on as well. It's important...We tend to discuss with them [informally] the problems that we're having and they'll come along with some ideas." (Higgins: Peboc 1992)

The analysis of the formalisation of the external inputs also found that the much of the consultancy work was undertaken on a formal basis. However, in contrast to the dualism of formality and informality apparent in the examples of research funding links, four of the seven instances of consultancy were characterised by primarily formal relationships (Backlite, the Condor rucksack, the Pullman series, and Xenos). These four represent very minor incremental innovations in relation to the other three projects (the ARM RISC microprocessor, Diflucan, and the pyrethroid insecticides), in which consultancy was commissioned. In the case of the ARM RISC microprocessor, for example, the informal manner in which a professor at Cambridge University was asked to review the chip design, was recalled as follows:

> "So since a lot of people at Acorn came from the computer lab...links with the various members of the teaching staff work very well...It was informal [the chip design review]. It was 'How would you like to have a look at this?', rather than 'Here's some money will you act as a consultant?'. Very informal. Friendship orientated." (Urquhart: Acorn Computer 1992)

However, perhaps the most widespread mechanism for obtaining input from research establishments was through informal approaches to universities, or the informal tapping into, or membership of, broad research networks. These mechanisms were evident in a third of the cases investigated. A number of good examples are provided in the case-material of such informal interaction. For example, in the development of the pyrethroid insecticides, it was noted that:

> "We have huge numbers of links with academia, both in academic [basic] and applied research...When we got to the manufacturing process, huge numbers of people both inside ICI and in academia had their brains tapped...largely informally...to come up with ideas...to see which was going to be the best manufacturing route." (Bushell: ICI Agrochemical 1992)

This informal interaction was also noted in relation to the development of Elektra:

> "We have a good understanding with university groups who have research in the areas that are important, or could be important, to Vector Fields...Friendship is very important in this respect." (Simkin: Vector Fields 1992)

The most common manner in which these networks were operationalised was through informal face-to-face contact at technical conferences. Thus, for example, in the development of Carboplatin:

> "Conferences were also very, very important, particularly specialist conferences. In the platinum [cancer drug] area, there was a conference in San Diego recently...which was an outstandingly successful meeting because it brought together, from across the world, experts...It was less the formal communications, probably more the informal chatting that was important. Bouncing ideas, sharing views, and talking about experiments that should be done...There's a world-wide network of informal contacts...collaborators, friends." (Harrap: Institute of Cancer Research 1992)

Indeed, Johnson Matthey actively organised such conferences in order to facilitate informal interaction:

> "But in terms of getting everybody together and trying to pull in the doctors and the chemists and so on...a mini sort of conference, but a very informal little conference, to try and pull-in people for a day, so that they all got to talk to each other, find out who else was interested in this particular problem. To see the other side of it." (Barnard: Johnson Matthey 1992)

In summary, the analysis reveals that while on the surface many of the links appear to be formalised, in that research projects are formally funded and consultancy work commissioned, it is the underlying informal links between individuals that are often the most important. This is because in addition to the frequent informal two-way flow of cognitive transaction content, it is through these informal relationships that many of the formal links are initiated. This dualism only occurs where the innovator employs researchers and scientists itself, since it is these individuals who have the ability to plug into, or become embedded in, the research network most effectively.

3.4 Consultants and Industrial Designers

It was noted in the previous chapter that external consultants were utilised in nine (26%) projects concerning technical matters and a further seven (20%) projects in relation to industrial product design. In all but one of these cases (Hydro-Probe), the consultants were commissioned on a formal basis, although there did exist some flexibility in the arrangements in the development of the shielded magnet:

> "If we want a specific piece of work done then we'll commission it...If we wanted some advice, then we would ring them up, and they'll maybe or maybe not charge us depending on how they're feeling on that day or how long the conversation goes on for!" (Bird: Elscint 1992)

The analysis also revealed that these formal inputs, particularly in relation to product design, were largely undertaken at *arms-length.* That is, these relationships tended not to be characterised by the dualism highlighted in relation to research establishments. A typical example of the nature of these links was provided by the First-Sense project:

> "We commissioned a company called Kinneir Dufort, a company of design consultants, who were recommended to us by the Design Council. Not personally recommended. We were given a list of companies. And it's been a successful relationship...[but] formal, very formal." (Foley: Philip Harris 1992)

This arms-length approach is also well illustrated by the example provided by the Xenos project, concerning the product and circuit design:

> "I ended up going to Cambridge Consultants in 1987. I laid down a specification of what I wanted...the minimum size, and that sort of thing. They came back with

these concept drawings and none of them were really ideal...I set them a challenge...Having worked on some [more] drawings...they came up with a mock-up." (Sherlock: Neen Pain 1992)

Thus, it was found that it was most common for consultants to undertake work on a formal and arms-length basis.

3.5 Distributors

In both of the cases (Amethyst and MotorMonitor) in which the distributor was found to play a critical role in the innovation process, the relationship was formal. However, the intensity of the interaction during the development of these innovations and the consequent need for good communication, meant that personal ties were also forged. The nature of these relationships is well illustrated by the Amethyst case:

> "The programmer guys have never met, but they have worked extremely well for several years now...They'd talk on the phone and tell jokes, and have a good time, and try and build that repartee up...but it is quite remarkable that you could build such a successful product, without the programming teams meeting...But the link was not that far, it was just a modem and fax machine away!..."He [the IRD new product manager] was a very friendly and very easy going guy. Real friendly. And we got on really well...Certainly it was critical that we had a really good flow of information. They could specify what they wanted and we could respond... Certainly without the good communications, we would never have got the product right in the first place." (Milne: Intelligent Applications 1992)

The other two instances (Stripper-Head and the Town and Country III) in which distributors were explicitly cited as playing a role in the innovation process, the flow of cognitive transaction content was found to be informal but tempered by the more formal nature of customer-supplier relationships.

3.6 The Professions

Of the five cases (Carboplatin, Diflucan, First-Sense, Symphony, and Xenos) in which input was shown to be sourced from the professions, further analysis found that these relationships and the flow of transaction content was primarily informal. For example, the informal links with educationalists were highlighted in the case of First-Sense:

> "Extremely informal. We've got twelve representatives in the field, all gone through education in some form or other. Most of them have been with us for a fair time, I would think the average is ten years...So they tend to know all the teachers...through to inspectors, head-teachers, heads of departments, even Her Majesty's Inspectorate...One major exhibition each year is the annual Association of Science Education exhibition...the atmosphere is terrific... Inevitably you talk about education...in a friendly and informal way." (Foley: Philip Harris 1992)

However, while the vast majority of these relationships are informal and often reinforced by friendship, a small number of professionals are sometimes paid for their services. For example, it was noted in the case of Xenos that:

> "We've built up a lot of contacts with doctors who run the pain-clinics...A lot of good friends...With professional people, once you've built up your reputation and a relationship with them, they are very loyal...We have a couple we actually pay as consultants and it means that it puts it all on a more formal footing." (Sherlock: Neen Pain 1992)

While it was commented in relation to the nature of the links with clinicians in the field-trails of the Carboplatin anti-cancer drug that:

> "We have a UK advisory panel of doctors, which advises us on what we're doing and what we shouldn't be doing. And again, that's a formal thing where we pay them, but they're very happy to help, not because we pay them, I think they'd probably do it for nothing because of our relationships, but obviously we've got to give them something for their time. That works very well. So we know what's going on, what they want." (Barrett: Bristol-Myers Squibb 1992)

In other cases, there existed an overlap in the boundary of the innovating organisation and the profession. This was particularly well illustrated by the Johnson Matthey, once again with respect to the development of Carboplatin:

> "The Royal Marsden [Hospital] operates from two sites...The Institute of Cancer Research is sited on their Sutton site, and there are various clinicians who are both

> members of the hospital staff and the Institute of Cancer Research staff. So that provides a good link for bringing compounds and new developments into the hospital...So we've ready access to experienced clinicians. You haven't got to persuade him to do your clinical trial." (Barnard: Johnson Matthey 1992)

Thus, while many of the relationships that exist between individuals within the innovating organisations were found to be informal and reinforced by friendship, a small number were found to be formalised.

3.7 Competitors

Although rarely cited explicitly as a source of input into the innovation process, a number of the interviewees commented on the nature of the relationship between individuals in competing organisations at the level of the engineer. Perhaps the most notable example of informal relations between engineers in competitive organisations was provided by the Scimitar H case:

> "Probably the majority of the R&D links are forged at the engineer-level, directly between engineers in different companies. We do within the Engineering Department actually go to conferences. We're not in complete isolation. And we involve ourselves in symposia and things like that, especially with the IEE...Certainly in this project there was a high level of direct involvement with these." (Conley: Marconi Communication Systems 1992)

In addition, with reference to the development of the anti-fungal agent Diflucan by Pfizer, it was commented that:

> "We have direct links with other pharmaceutical companies at many different levels...We have links at the discussion of research level, because as scientists we do discuss research, we don't discuss exactly what we're doing of course, but in terms of discussing research we're all scientists and interested...There's a basic code about...We'll go and see if we can find out what everybody is doing...That's part of the game." (Troke: Pfizer 1992)

Thus, while a number of the interviewees highlighted the informal *trading* that occurred between competitors at the engineer level, the sensitivity of such interaction was also recognised. In relation to the benefits of such informal trading with competitors, it was contended that:

> "One has to recognise the fact that much of that information may well be commercially sensitive...This is increasingly so. And there's a careful balance to be drawn between doing that [informal trading] and not being so secretive about what you're doing that it's counter-productive." (Gleave: The British Broadcasting Corporation 1992)

4. Explaining Informal Boundary-Spanning Inputs into the Innovation Process

4.1 Economic Exchange as an Explanation

In attempting to explain the incidence of informal exchange activity in boundary-spanning relationships, economic exchange theorists argue that organisations and individuals act rationally, and therefore that such behaviour results from the desire of actors to maximise *economic rent*. That is, informal exchange behaviour in the innovation process can be best explained in terms of *informal trading* or *bartering* (see section 5.4.1 of Chapter 2).

There is certainly evidence in the case-material of informal exchange behaviour primarily motivated by the maximisation of economic rent, and consequently characterised by trading or bartering between individuals in different organisations. In discussing the flow of cognitive transaction content between his R&D team and competitors and suppliers in the development of the shielded magnet, for example, in the development of the shielded magnet, it was recalled that:

> "The ideas that we got [externally] came back mainly from conferences that we attended...So we would talk to them [competitors and suppliers] there and get maybe a little bit of information, and there would be a little bit from us, and so on." (Bird: Elscint 1992)

Such informal boundary-spanning trading was also recollected in relation to the development of the Nicam 728 broadcasting system. In addition, the institutional-isation of this informal exchange behaviour was also noted:

> "Part of the brief of the engineer is...to contribute to that arena...but at the same time to draw from that wider environment what information they need. It's a two-way process the whole time." (Gleave: The British Broadcasting Corporation 1992)

However, while the above examples tend to support the trading explanation through implication, more explicit evidence was also provided by the research. In considering the informal nature of the important contribution of suppliers in the development of the Scimitar H, it was contended that:

> "Most of these things were done fairly informally throughout, because it's general touting for business. Suppliers expect to put some development effort upfront in the hope that you might get an order." (Conley: Marconi Communication Systems 1992)

Thus, these and a number of other examples from the case-material were found to emphasis the material outcomes of the boundary-spanning exchange behaviour, and as such support the hypothesis of the economic exchange theorists.

Yet further instances of informal exchange activity throw doubt on the universality of this proposition. With reference to Vector Field's relationship with its lead-users in the beta-testing of the Elektra software package, it was noted that:

> "They normally have a desire to use it [pre-release software] because it's going to let them achieve something which they can't with do with the released software...They're friends, but one of the reasons they're involved is because they're getting something out of it. They're getting extra functionality, that they may have suggested they'd like to have...We tried to establish [formal] beta-test sites where we get feed-back and it just didn't work, so we just work with individuals that we're friendly with." (Simkin: Vector Fields 1992)

In this instance, friendship was seen to play a part in the exchange activity within the dyadic relationships. Thus, there also exists evidence that suggests that informal exchange behaviour may be more complex than simply looking to the material outcomes of the exchange activity.

In summary, it is clear from the analysis of the data that while economic exchange theory helps explain some of the identified instances of informal exchange between individuals, particularly with those within supplier and competitor organisations, much of the exchange behaviour remains problematical.

4.2 Social Exchange as an Explanation

In contrast to economic exchange theory, social exchange theory acknowledges the social complexity of exchange behaviour. Of particular interest in this analysis, is the contention of social exchange theorists that exchange behaviour is invariably influenced by the membership of a given dyad and the social structure in which that dyad is embedded (see section 5.4.2 of Chapter 2). These two elements of social exchange theory will be evaluated in turn, with respect to the case-material.

The extensive informal exchange activity and the exchange value of the resulting transaction content to Inspec in the development of MotorMonitor, can largely be explained with reference to the membership of the dyads:

> "It's worked very well. The Condition Management team [at the Robert Gordon Institute of Technology] is quite small and we all know each other...I was there doing my degree and PhD. Donald [the project instigator at Inspec] did his degree there." (Leith: Inspec 1992)

In the case of the development of the on-line tape certification system, it was recalled how equipment vital to the testing of the innovation was procured:

> "David, who had come to work for me, used to work for CEGB, and he knew somebody called Greg. And Greg had gone up in CEGB. He phoned Greg and said 'Look, we need to borrow a piece of equipment' and Greg said 'Right. OK!'" (Rothwell: Double R Controls 1992)

The case of the development of the ARM RISC microprocessor provides further evidence of the importance of dyad membership, but also implies the crucial role played by social structure and group solidarity. In recounting the nature of the informal exchange activity during the development of the microchip, it was noted that:

> "Herman [thecompany founder] did a PhD. at the computer labs at Cambridge University. ...Some of the ideas, some of the people they got were from Cambridge: both Roger and Steve [key developers of ARM]. It's because it's the centre of some very rich talent, some very bright minds...Since a lot of people at Acorn came from the labs...links with members of staff work very well...It was informal [the design review]...Very informal. Friendship orientated." (Urquhart: Acorn Computer 1992)

The importance of social structure, or what has been termed *citizenship* or *dual-exchange* (Ekeh 1974), is also demonstrated in the development of Carboplatin:

> "There's a world-wide network of informal contacts...collaborators, friends...You make many very good friends in science." (Harrap: Institute of Cancer Research 1992)

In attempting to explain this symbiotic relationship between many of the individuals in the field in which the drug was developed, it was noted that:

> "It's a very friendly atmosphere and I think it's like no other area of medicine I've been involved in before. Everybody is trying to make something happen. It's a common goal, which is the cure of cancer, and everybody who is involved believes passionately in doing that. So of course you have to work closely together." (Barrett: Bristol-Myers Squibb 1992)

It is evident from the analysis of the case-material that in many of the identified instances of informal exchange, the exchange behaviour was invariably influenced by the membership of the given dyad. It was frequently found, for example, that friendship between source and recipient was a key element in the observed exchange behaviour. In addition, the social structure in which the dyads were embedded was also seen to play a role, to varying degrees, in the exchange value of transaction content flowing between individuals.

4.3 Other Possible Explanations

The case-material reveals a number of instances of exchange activity in which neither social or economic exchange theory provide a completely satisfactory explanation. There are three (8%) cases of particular interest in this respect, in which important input was sourced externally: in the field-testing and championing of the Hydro-Probe by a technical employee of English China Clays (discussed in section 2.5 of this chapter); in the adaptation, field-testing and championing of the Backlite by a Ford employee; and finally, in the development of the control software for the MRC-500 by an ex-Phd student of the inventor and instigator of the innovation project. The nature of the input into the Backlite project and the motivation of the Ford employee, was recalled as follows:

> "And then we got to know this chap from Ford...who was fed-up to the back-teeth with the work he was doing on run-of-the-mill telescopic aerials...Being interested technically [in Backlite], he managed to persuade his bosses to cover-up for him...So when he was working on this to see if he could adapt it onto the car [Ford Orion], his time was pushed onto something else...he did it...and eventually Ford decided to put it on the Orion." (Waller: BSH Industries 1992)

While with reference to the nature of the input into the MRC-500 project and motivation of the ex-Phd student, was described thus:

> "John [the inventor] had a research student who'd just done his Phd...he was just looking around for what to do...He knew what was going on and got quite interested. There was a lot of programming to do and the programming was really quite difficult. He was so interested in it that he decided to have a go...So as a favour to his [ex]supervisor he did the software for this new microscope and it is quite wonderful." (Amos: Medical Research Council 1992)

The responses of the interviewees in each of these cases would appear to indicate that a principle motivator for the involvement of these individuals was the intrinsic personal satisfaction gained through under-taking the task itself. However, in both the Backlite and MRC-500 projects the membership of the respective dyads did have some bearing on the occurrence of the input.

5. Variations by Innovation and Innovator Classification

An analysis of the exchange value of informally derived external inputs in relation to organisational size, found that small and medium-sized innovators relied more heavily on informal boundary-spanning dyads in the overall innovation process than large innovators. Informal boundary-spanning channels were seen to provide critical or important inputs in 25% (3) of the small firm projects and 34% (2) of the medium-sized firm projects. This compares to 18% (3) of the developments undertaken by large firms (see Table 7.5 below for greater detail). However, this pattern appears to be less marked in relation to informal inputs into the idea-generation process, but more marked with respect to informal inputs into the field-testing process of the innovations studied (see Tables 7.6, 7.7 and 7.8 below for greater detail).

TABLE 7.5: The Exchange Value of Informal Boundary-Spanning Dyads to the Innovation Process in Relation to Organisational Size

Exchange Value	Company Size	No. of Projects	% of Projects
Critical	Small	1	8
	Medium	1	17
	Large	0	0
Important	Small	2	17
	Medium	1	17
	Large	3	18
Useful	Small	6	50
	Medium	3	50
	Large	7	41
Minor	Small	3	25
	Medium	1	17
	Large	7	41
Total	Small	12	100
	Medium	6	100
	Large	17	100

TABLE 7.6: The Exchange Value of Informal Boundary-Spanning Dyads to the Idea-Generation Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	0	0
	Medium	0	0
	Large	0	0
Important	Small	0	0
	Medium	2	33
	Large	2	12
Useful	Small	7	58
	Medium	2	33
	Large	7	41
Minor	Small	5	42
	Medium	2	33
	Large	8	47

TABLE 7.7: The Exchange Value of Informal Boundary-Spanning Dyads to the Problem-Solving Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	1	8
	Medium	1	17
	Large	0	0
Important	Small	0	0
	Medium	0	0
	Large	2	12
Useful	Small	6	50
	Medium	2	33
	Large	5	29
Minor	Small	5	42
	Medium	3	50
	Large	10	59

TABLE 7.8: The Exchange Value of Informal Boundary-Spanning Dyads to the Field-Testing Process in Relation to Organisational Size			
Exchange Value	**Company Size**	**No. of Projects**	**% of Projects**
Critical	Small	0	0
	Medium	0	0
	Large	0	0
Important	Small	4	33
	Medium	2	33
	Large	2	12
Useful	Small	2	17
	Medium	2	33
	Large	3	18
Minor	Small	6	50
	Medium	2	33
	Large	12	71

6. Summary of Findings

The analysis of the case-material revealed that external inputs sourced informally played a critical or important role in eight (23%) of the innovations, compared to nineteen (54%) with respect to external sources overall. In addition, informal external sources provided useful inputs in a further sixteen (46%) of the projects, with only a third (eleven) considered to have not benefited, or to have benefited to only a minor extent. However, as with the exchange value of external sources in general, the exchange value of external inputs derived informally was found to vary between the various stages of the innovation projects. For example, the analysis of the case-material found that informally derived external inputs were of slightly greater importance during idea-generation than during problem-solving. This result thus lends some support to earlier studies (see section 3 of Chapter 1).

Furthermore, the case-material provided many references, both explicit and implicit, to the importance of informal boundary-spanning relationships between individuals in supporting formally established organisational links. That is, there existed much evidence to corroborate with the contention of Freeman (1991,503) that "behind every formal network, giving it the breath of life, are usually various informal networks".

In analysing the nature of the boundary-spanning exchange activity identified in the previous chapter, it was found that the formality of the process varied in relation to the locus of the external inputs. Thus, while much of the input from users as *the* major external source of external inputs into the idea-generation and field-testing processes was found to be informal, the majority of the critical and important inputs from suppliers as *the* major source of external inputs into the problem-solving process was found to be formal in nature.

In attempting to explain the incidence of informal exchange activity within boundary-spanning links, recourse was made to both economic and social exchange theory. While the analysis of the data found some instances of informal exchange activity motivated by the maximisation of economic rent, particularly those involving suppliers and competitors, much of the informal exchange behaviour could not be explained in such rational terms alone. It was found, however, that many of the informal exchanges could be largely explained in relation to the membership of the respective dyads, and to varying degrees by the social structure in which the dyads were embedded. In addition, the analysis revealed a relatively small number of cases in which neither economic or social exchange theory could provide a completely satisfactory explanation. The only motivator in these instances appeared to be the intrinsic satisfaction gained by the external actor.

Finally, the data suggests (as with external inputs in general) that small and medium-sized firms are more inclined to utilise informal boundary-spanning channels in the overall innovation process than large firms. However, this relationship was found to be less marked in the idea-generation phase of the development process, but more marked with respect to the field-testing of the innovations.

CHAPTER EIGHT: ACTION-SETS, STRATEGIC LINKS AND ATTRIBUTE NETWORKS

1. Introduction

In the previous two chapters the analysis of the case-material focused upon the nature, role and importance of boundary-spanning links in the innovation process. To this end, emphasis was placed on studying the three elements of dyadic relationships in respect of the identified links: actors, relationships, and transaction content. While an important step in the study of networks, such a focus on the dyad ignores the context in which they are embedded. It is thus the intention of this chapter to shift the framework of analysis from the dyad to the network. This is undertaken to achieve two tasks: firstly, to study the morphology of the innovation action-sets; and secondly, to analyze the theoretical concept of strategic links by embedding the dyads "in a context that both constrains and liberates" (Fombrun 1982,281).

This chapter is divided into three main sections: the first presents a graphical representation of each of the thirty five innovation action-sets constructed, and then provides a brief summary of their morphology along four dimensions (size, diversity, stability, and centrality); the second introduces a typology of external socio-centred attribute-defined networks, which were found to play a role in a number of the innovation projects studied; and the third focuses upon the nature of the strategic boundary-spanning relationships that linked the innovators to these external attribute networks during the innovation process (liaisons, bridges, and link-pins).

2. The Nature of Action-Sets in the Innovation Process

An *action-set* is considered as a special kind of instrumentally-activated network, established to achieve some desired end (section 4 of Chapter 3). In this instance, that desired end is taken to be a *successful innovation*. Thus, the action-set for each of the innovations under investigation is considered to be the network of links utilised in each of the respective development projects. Since each of these projects were under-taken by specific focal-actors, each of the action-sets analyzed may be considered as a sub-set of the focal-net or ego-centred transaction network of these actors.

The action-set was chosen as a framework for analysis because it provided the researcher with an approach that engaged with the "multiple sources of information and pluralistic patterns of collaboration" (Freeman 1991,500), while reducing the complexity to a level of analytical manageability. Only in this way, was it felt that a more systematic understanding of boundary-spanning networks employed in the innovation process could be established. For the purpose of this research the action-sets were not constructed as *snap-shots* at a particular point in time, but as the cumulative network of links mobilised and initiated throughout each of the projects.

2.1 The Graphical Representation of the Innovation Action-Sets

This section presents a graphical representation of each of the thirty five innovation action-sets constructed from the case-material. These are grouped into their respective broad industrial classifications (see Table A.4 in the Appendices). Although only a limited amount of information has been encoded within these particular depictions, they illustrate the power of the graphic in encapsulating and conveying dyadic and network data. For example, different types of actors, such as suppliers and users, are represented by different nodal shapes (see *key* in Figure 8.1 overpage). In addition, these actors are positioned to the left of the page where they are *upstream* of the innovator (suppliers), and to the right where they are *downstream* (distributors and users). Solid lines are employed to denote formal links between actors, with dashed lines representing informal dyadic links. Finally, arrow-heads are used to show the direction of flow of transaction content, while dotted lines represent additional actors.

Such illustrations provide more than a useful means for displaying and conveying the innovation action-sets: they are also a valuable analytical tool. A quick glance at the set of network graphics reveals, for example, that the innovation action-sets of software of network graphics reveals, for example, that the innovation action-sets of software products are dominated by links upstream; that the innovation action-sets of engineering products and components, and scientific equipment are typically *well-balanced*, with links both upstream and downstream; and in contrast to pharmaceutical products, the innovation action-sets of electronic, communications and computer products and components, tend to have less linkages than other product groupings.

2.1.1 <u>Chemical Products and Processes</u>

Figure 8.1: The E70A LCD Mixture Innovation Action-Set

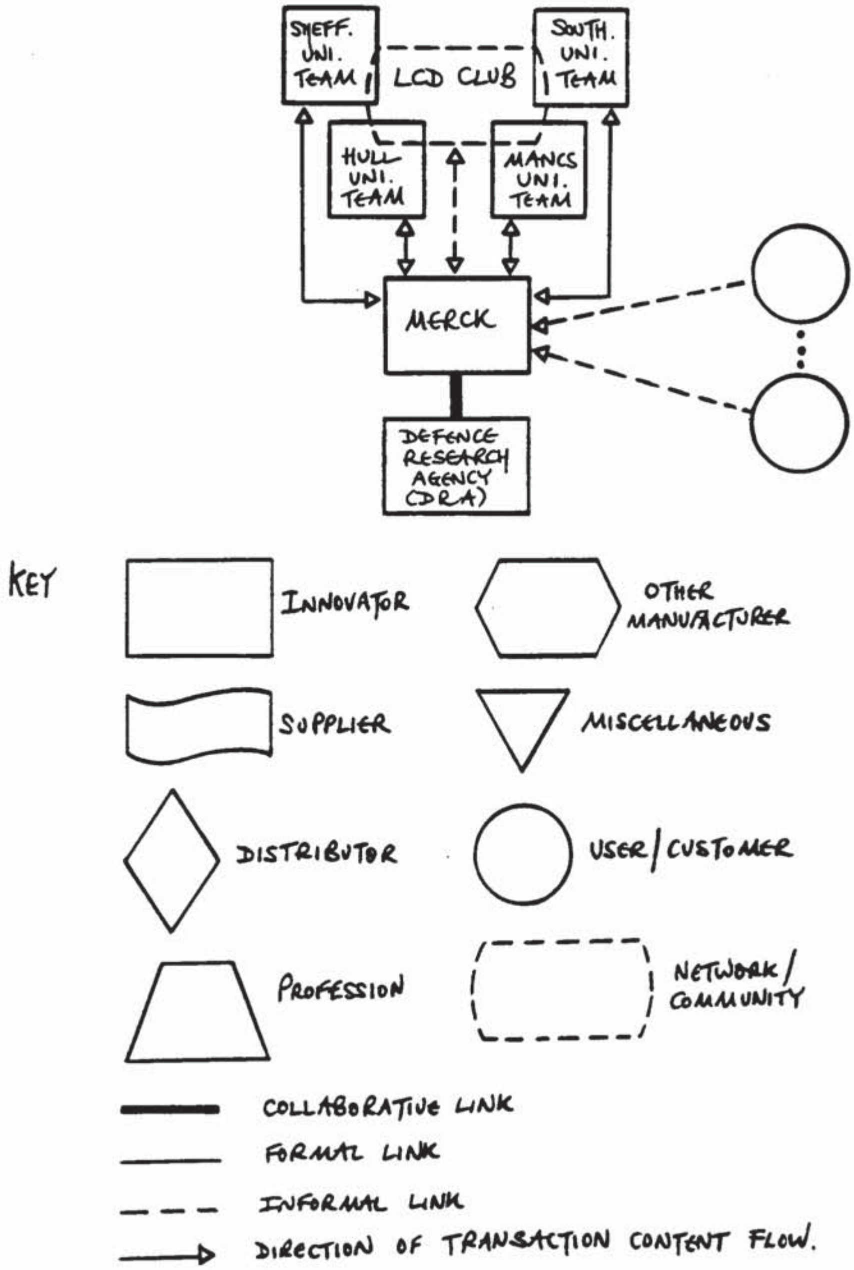


Figure 8.2: The Pyrethroid Insecticides Innovation Action-Set

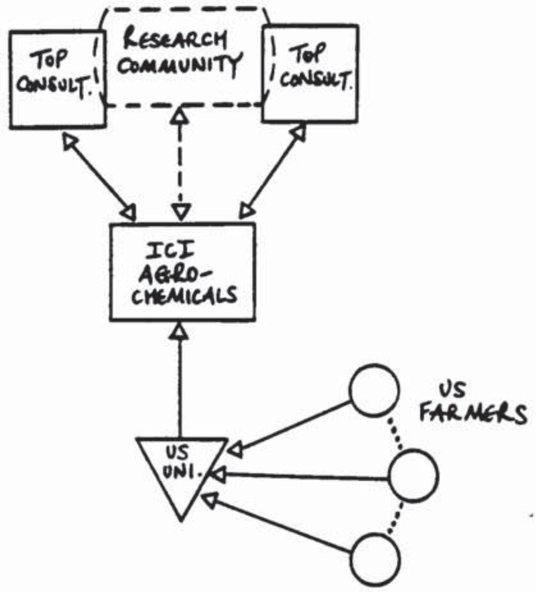
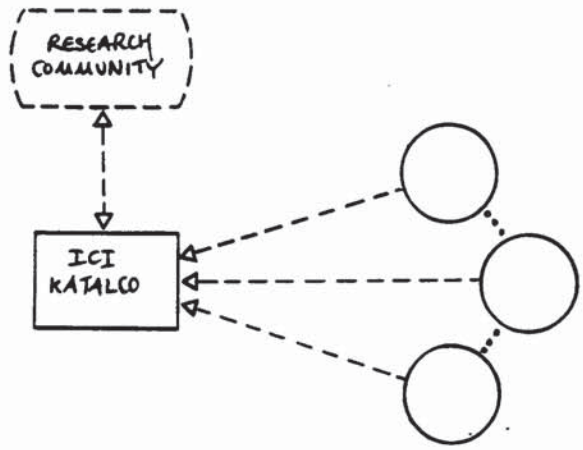


Figure 8.3: The Puraspec Innovation Action-Set



2.1.2 <u>Consumer Goods</u>

Figure 8.4: The Backlite Innovation Action-Set

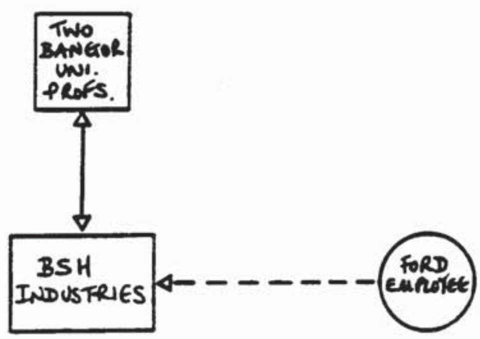


Figure 8.5: The Canned Draught Guinness Innovation Action-Set

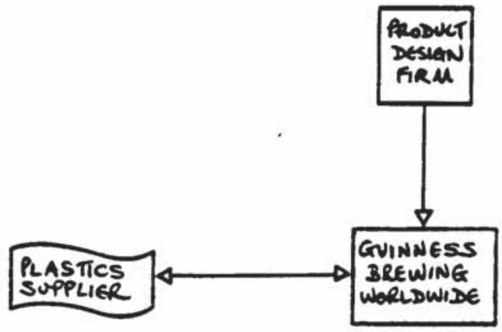


Figure 8.6: The Condor Rucksack Innovation Action-Set

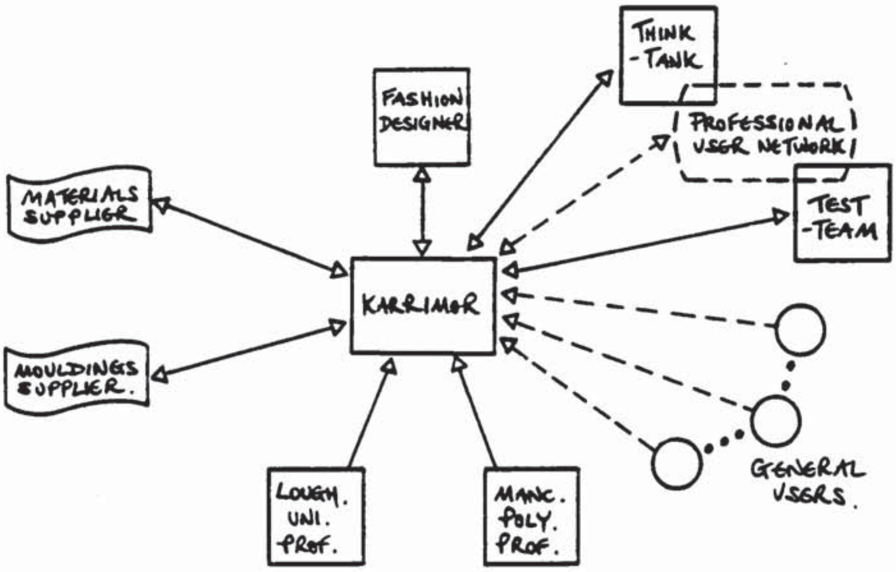
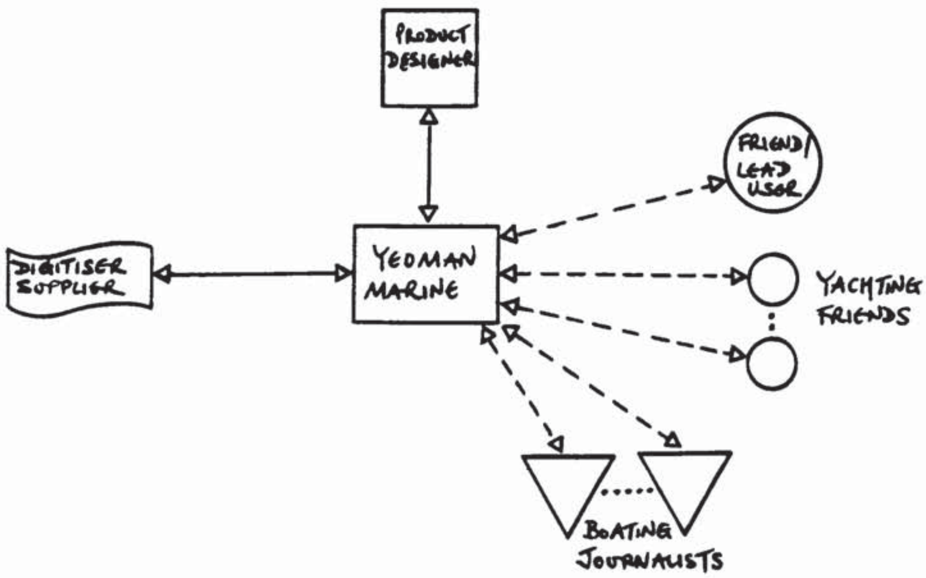


Figure 8.7: The Yeoman Innovation Action-Set



2.1.3 Electronic, Communications and Computer Products and Components

Figure 8.8: The ARM RISC Microprocessor Innovation Action-Set

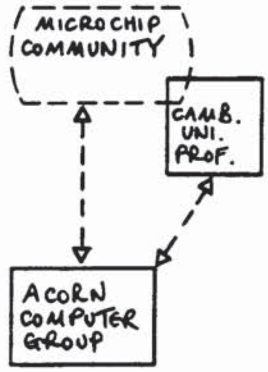


Figure 8.9: The VideoLogic DVA-4000 Innovation Action-Set

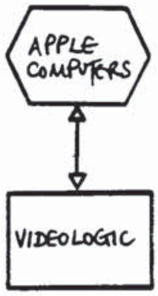


Figure 8.10: The Flexilink Innovation Action-Set

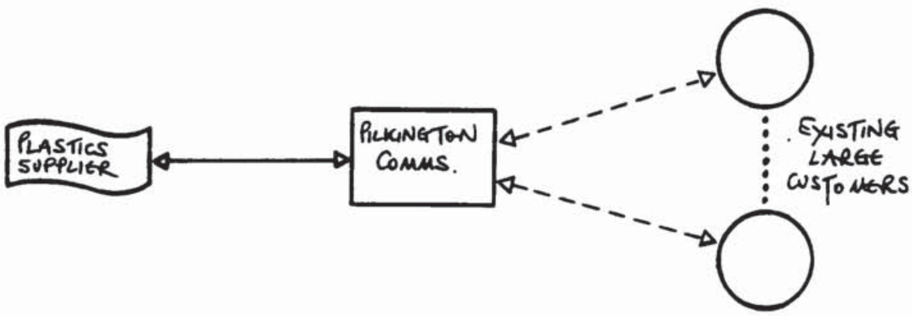


Figure 8.11: The Nicam 728 Broadcasting System Innovation Action-Set

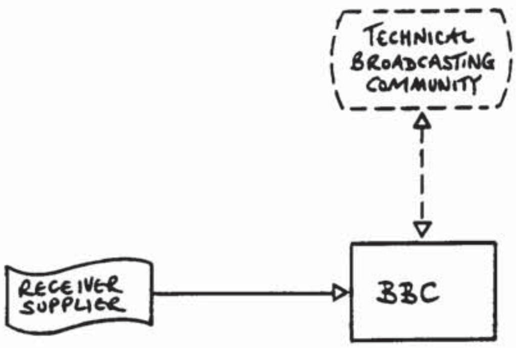


Figure 8.12: The On-line Tape Certification System Innovation Action-Set

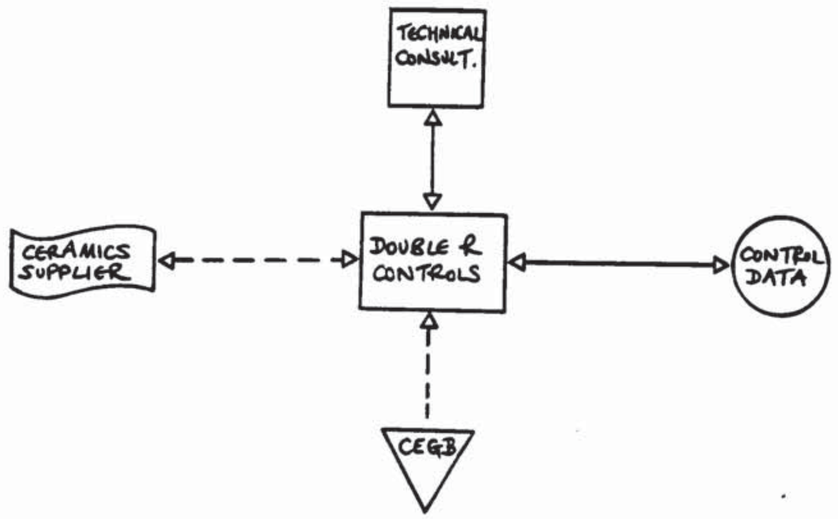


Figure 8.13: The Scimitar H Innovation Action-Set

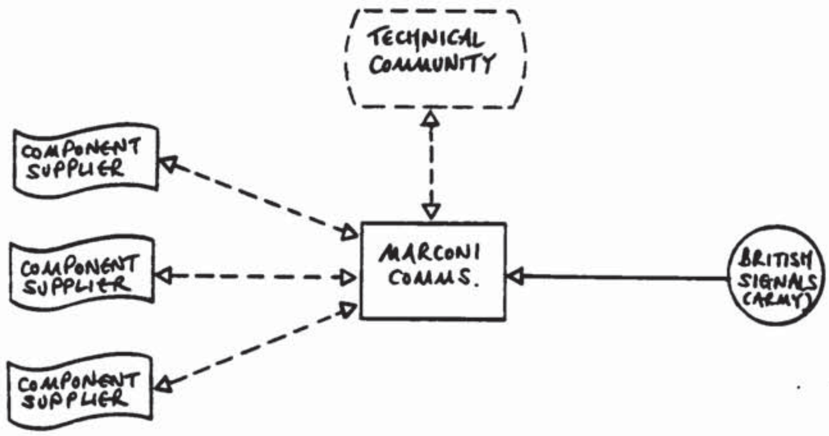
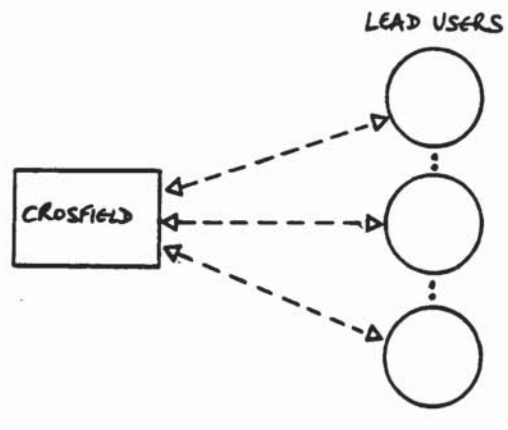


Figure 8.14: The Studio 9000 Innovation Action-Set



2.1.4 Engineering Components

Figure 8.15: The Linear Actuator Innovation Action-Set

Figure 8.16: The Shielded Magnet Innovation Action-Set

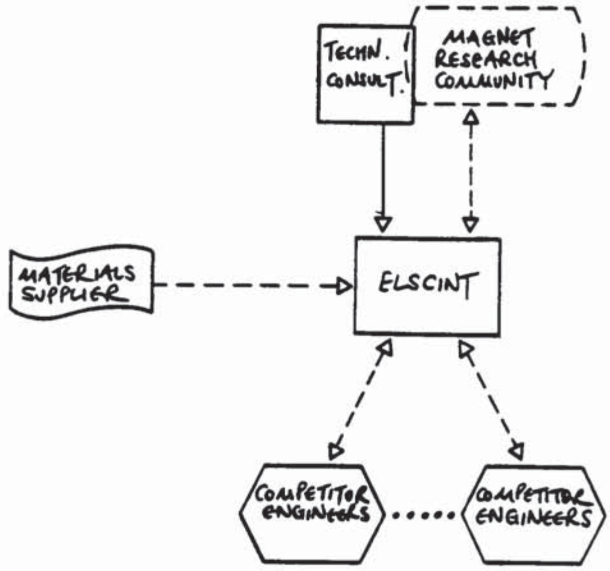
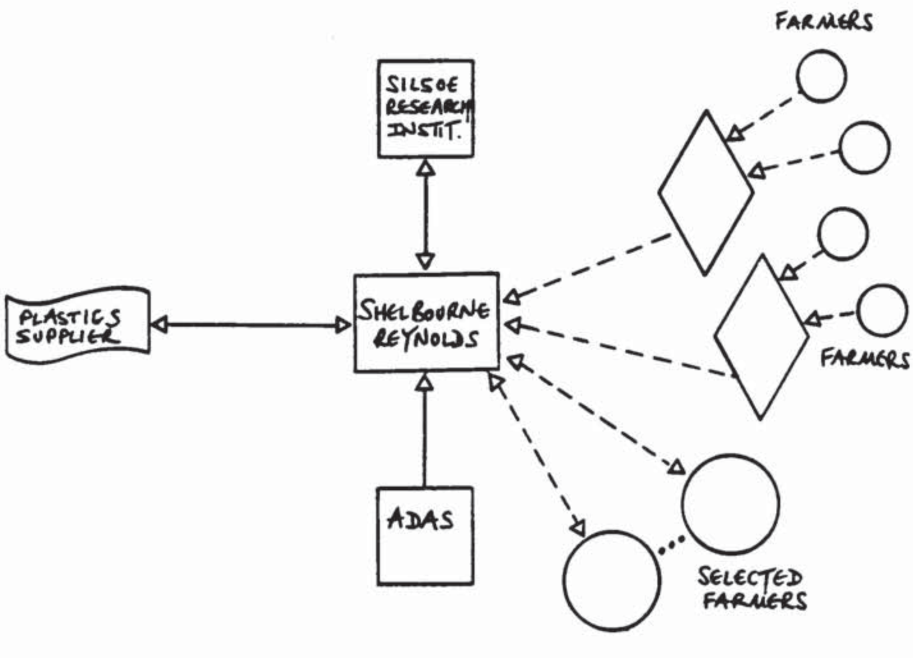


Figure 8.17: The Stripper-Head Innovation Action-Set



2.1.5 Engineering Products

Figure 8.18: The Fastrac Innovation Action-Set

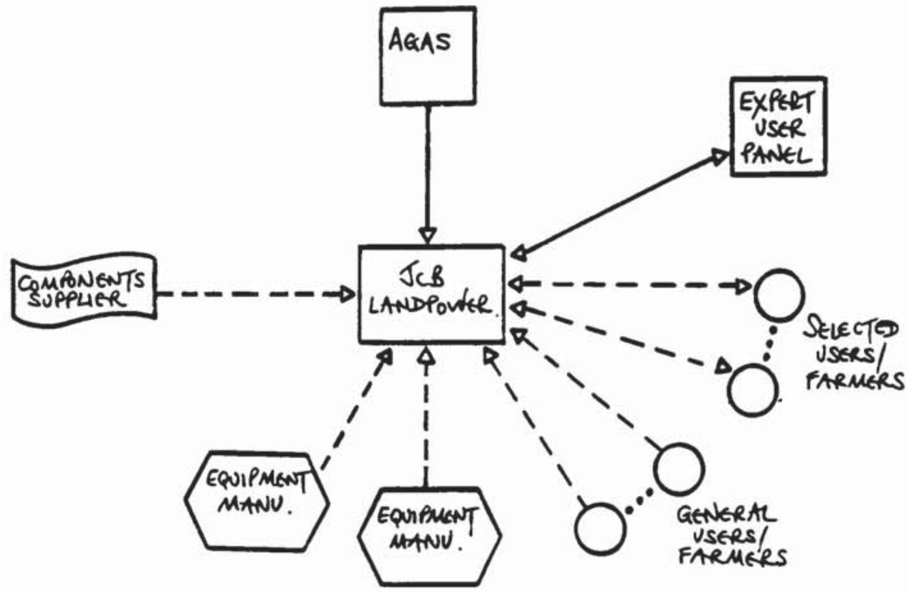


Figure 8.19: The Hydro-Probe Innovation Action-Set

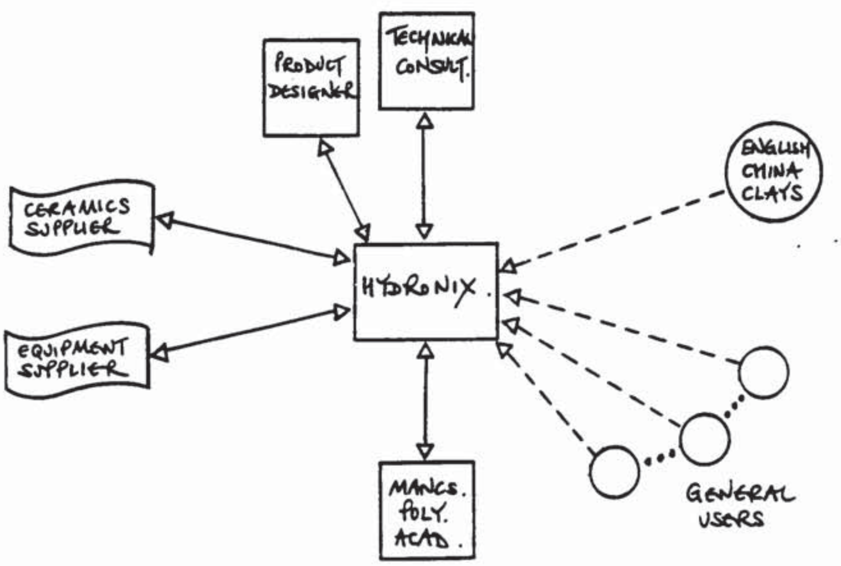


Figure 8.20: The Polifold Innovation Action-Set

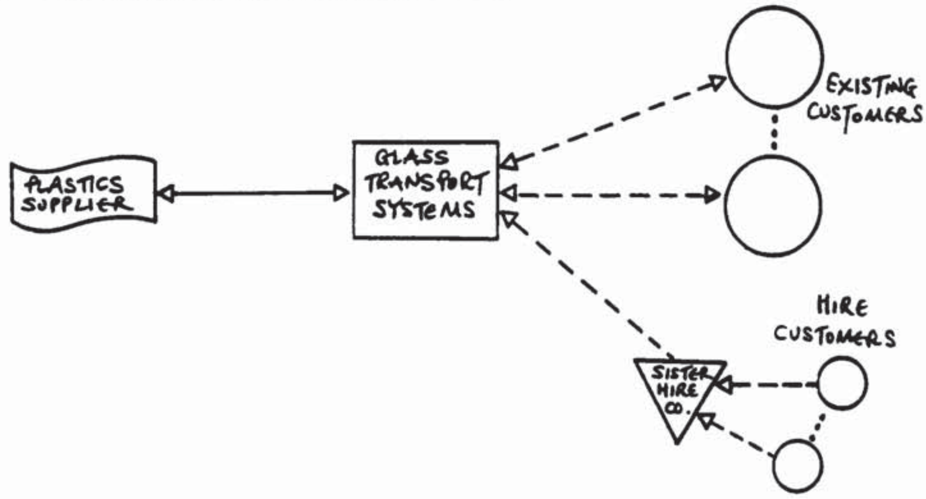


Figure 8.21: The Pullman Series Innovation Action-Set

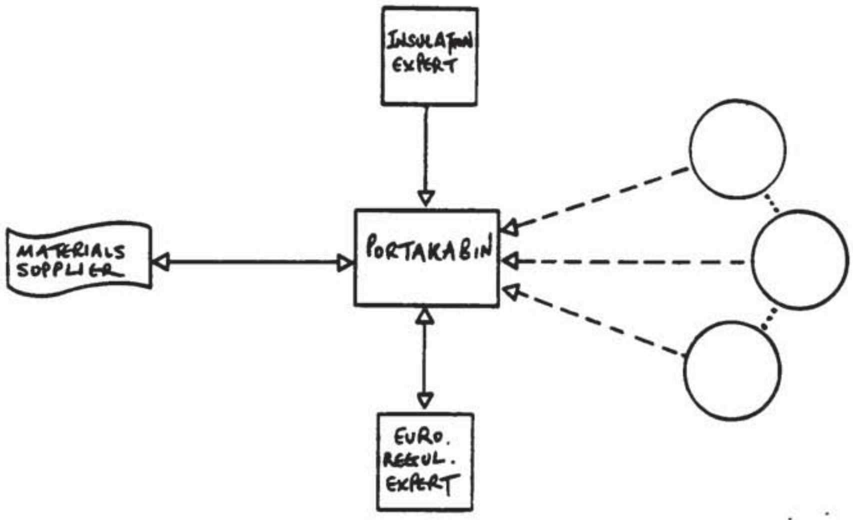
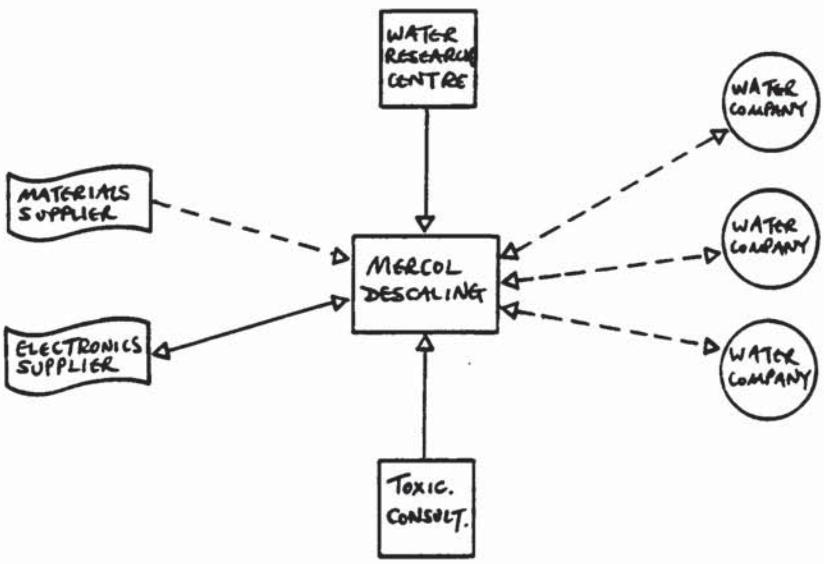


Figure 8.22: The Water-Mains Refurbishment System Innovation Action-Set



2.1.6 Pharmaceutical Products and Processes

Figure 8.23: The Carboplatin Innovation Action-Set

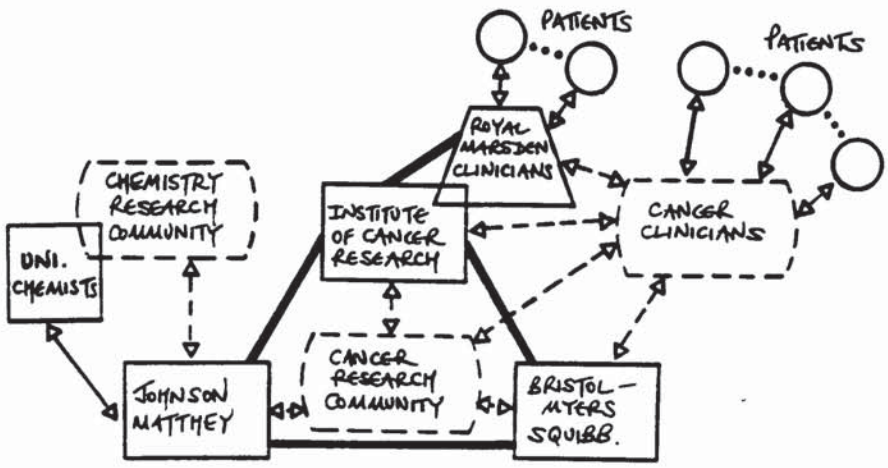


Figure 8.24: The Diflucan Innovation Action-Set

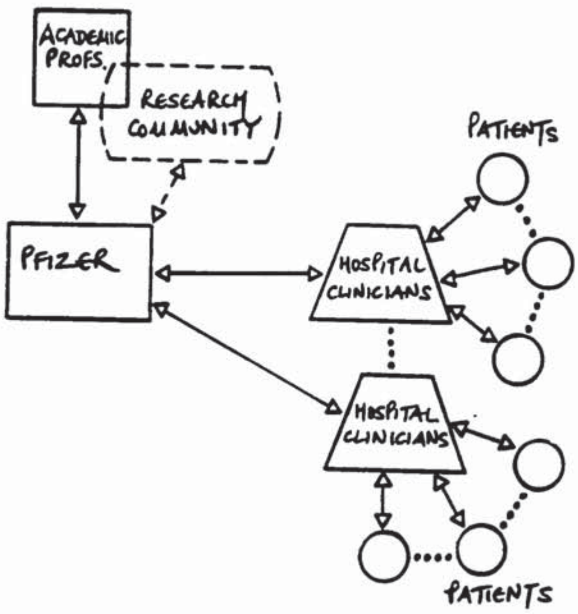
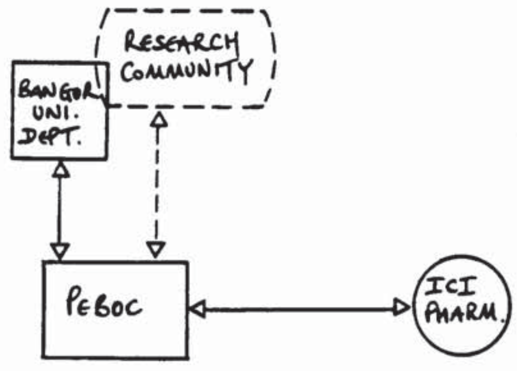


Figure 8.25: The Peboc Process Innovation Action-Set



2.1.7 Scientific, Medical and Educational Equipment

Figure 8.26: The First-Sense Innovation Action-Set

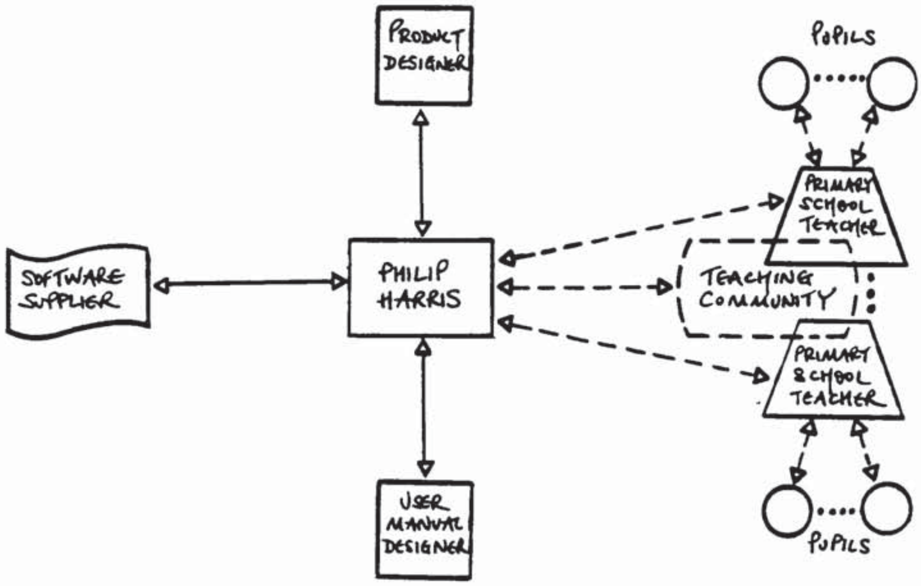


Figure 8.27: The MRC-500 Innovation Action-Set

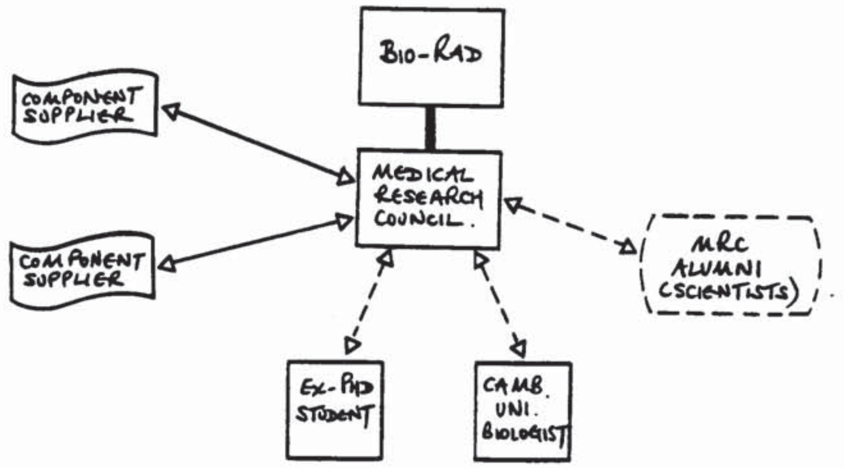


Figure 8.28: The Symphony Innovation Action-Set

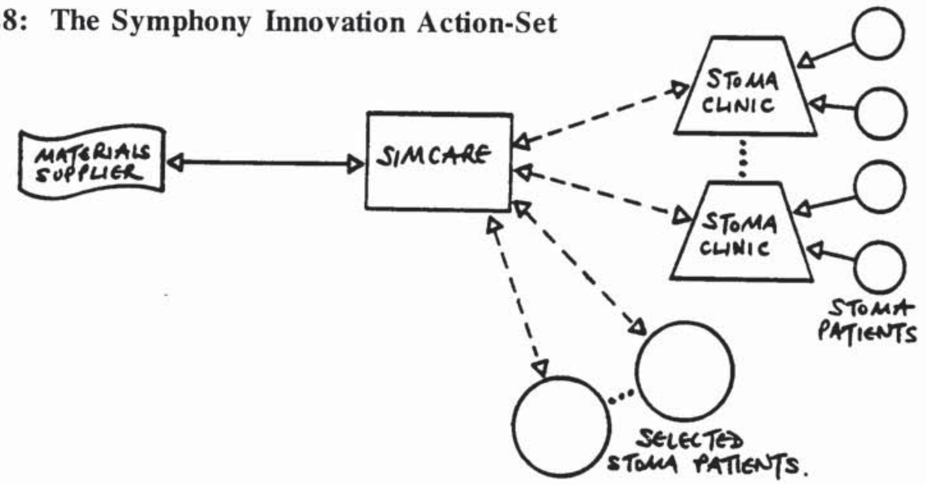


Figure 8.29: The Town and Country III Innovation Action-Set

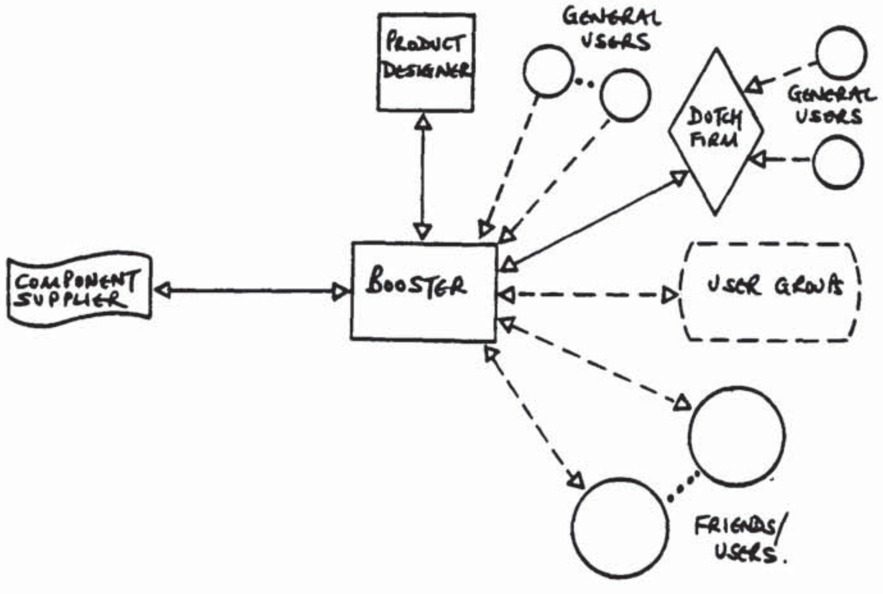
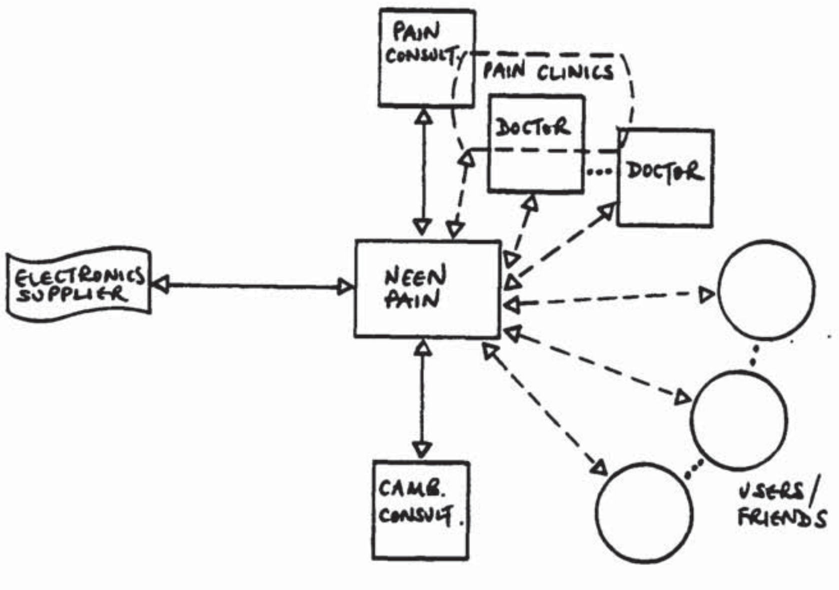


Figure 8.30: The Xenos Innovation Action-Set



2.1.8 Software Products

Figure 8.31: The Amethyst Innovation Action-Set

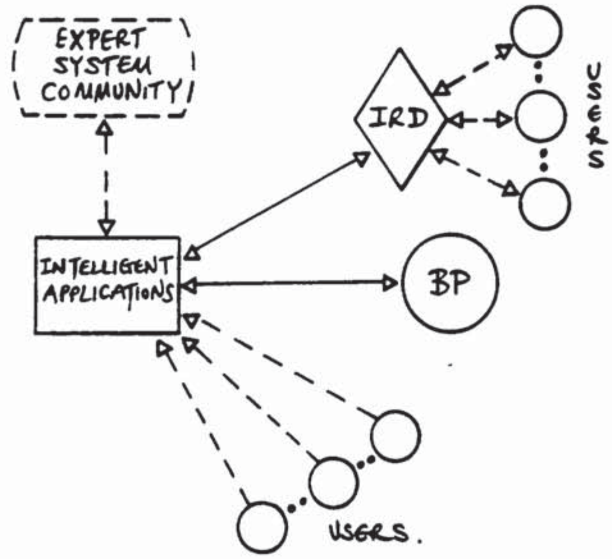


Figure 8.32: The Elektra Innovation Action-Set

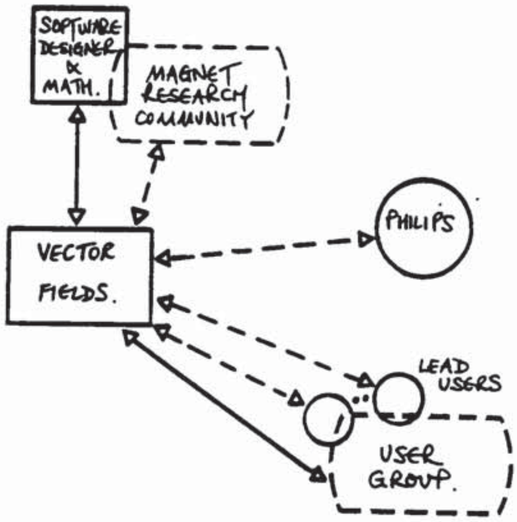


Figure 8.33: The Isoview 3 Innovation Action-Set

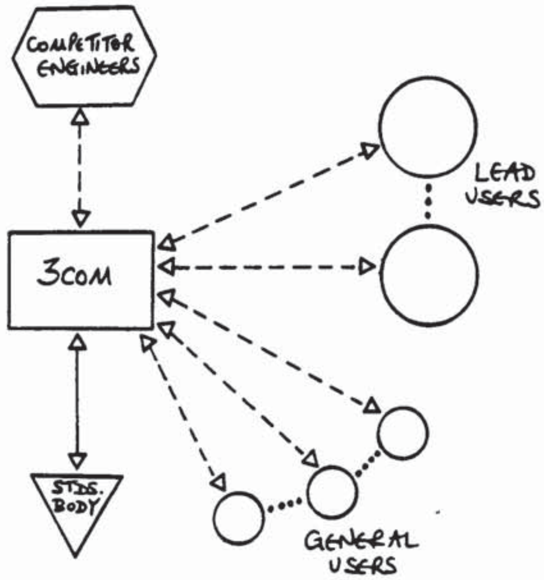


Figure 8.34: The MotorMonitor Innovation Action-Set

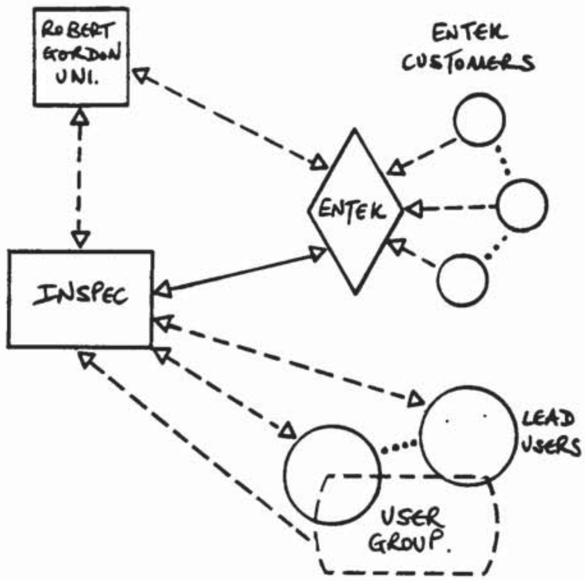
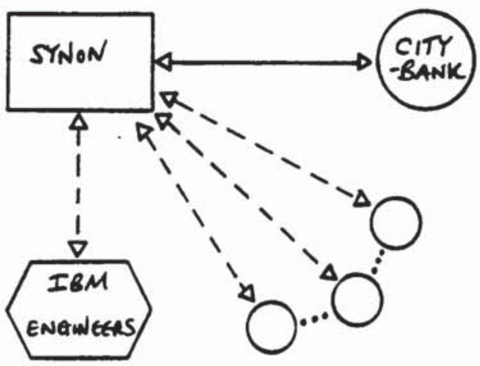


Figure 8.35: The Synon/2 Innovation Action-Set



2.2 The Morphology of the Innovation Action-Sets

Although the breadth of the study, in terms of the number of innovations investigated, has undoubtedly diluted the depth of data available for a comprehensive network analysis of the various individual action-sets, enough information was gathered to obtain a *good feel* for a number of the network attributes discussed in Chapter 3. Indeed, four of these network dimensions are discussed below in relation to the innovation action-sets of the sample as a whole.

2.2.1 Size

The size of each innovation action-set was determined by including all those actors providing direct input into the respective innovation projects. Thus, each innovation-set incorporated a diversity of actors both in terms of the type of actors, such as suppliers and users, and the unit of analysis of actors, such as individuals and organisations.

TABLE 8.36: The Size of the Innovation Action-Sets

No. of Actors	No. of Projects	% of Projects
0	0	0
1 - 5	4	11
6 - 10	4	11
11 - 20	13	38
20 +	14	40
Total	35	100

This analysis revealed that the vast majority (78%) of the projects had mobilised eleven or more actors during the innovation process. Of those projects with innovation action-sets of more than twenty nodes, the majority of the actors were found to be: individuals in the research community (*e.g.* Carboplatin, Diflucan, and the pyrethroid insecticides); consumers or individuals in user organisations (*e.g.* the Condor rucksack, Fastrac, the

Pullman series, and the Town and Country III); or a combination of these two types of actor (*e.g.* Elektra and MotorMonitor).

2.2.2 Diversity

It was noted in section 3.1.3 of Chapter 3 that network diversity refers to both the variety of actor and linkage types within a given network. Of interest here is the diversity of the loci of external actors utilised by the sample of innovators. In order to determine the actor diversity, each of the case-studies were analysed to establish with which of the seven loci (users, suppliers, research establishments, consultants, distributors, the professions, and competitors) relationships had been mobilised or initiated in the development of the respective innovations. The diversity of the actors in each of the innovation action-sets was then calculated by totalling the number of different loci employed in each of the projects. The results of this analysis are provided in Table 8.37 below.

TABLE 8.37: The Diversity of Actors in the Innovation Action-Sets

No. of Different Loci	No. of Projects	% of Projects
0	0	0
1	4	11
2	12	34
3	11	31
4	6	17
5	2	6
6	0	0
7	0	0
Total	35	100

These results indicate the narrowness of the diversity of the loci in which relationships were mobilised or initiated in the innovation projects investigated. For 77% (27) of the projects studied the innovation action-sets constructed were found to incorporate links with actors drawn from only three or less of the external loci listed above. Indeed, none of the innovation projects investigated were found to draw from more than five of the loci originally identified from across all of the cases. The extremes of this actor diversity are represented by the innovation action-sets of the Stripper-Head and Xenos, incorporating five types of actor, and those of the ARM RISC microprocessor, canned draught Guinness, the DVA-4000, and Studio 9000, which include only one actor type (see Table A.9 in the appendices for greater detail).

2.2.3 Stability

Since an action-set is considered to be a special kind of instrumentally-activated network established to achieve some desired end, it is inherently transitory and unstable; for once the desired end has been achieved the action-set ceases to exist. However, it was felt useful to employ the network dimension of stability to compare the proportion of the innovation action-set links that were mobilised from existing relationships of the innovator, with those that were initiated during the development. That is, to what extent did previously existing relationships provide the necessary external inputs into the innovation process.

TABLE 8.38: The Stability of the Innovation Action-Sets

% of Links New	No. of Projects	% of Projects
0 - 25	21	60
26 - 50	5	14
51 - 75	2	6
76 - 100	7	20
Total	35	100

Interestingly, the analysis found that the majority of the links represented in the innovation action-sets existed prior to the establishment of the respective development projects. The results show that for 21 (60%) of the innovations less than one quarter of the mobilised links were initiated during the development process.

2.2.4 Centrality

The network dimension of centrality also has more than one definition (see section 3.1.6 of Chapter 3). However, the term is used here to refer to the degree to which the network of relationships that make up the innovation action-sets were guided by the formal hierarchy. That is, what proportion of the links mobilised during the development process were formally recognised and sanctioned by the innovating organisation.

TABLE 8.39: The Centrality of the Innovation Action-Sets

% of Links Formalised	No. of Projects	% of Projects
0 - 25	22	63
26 - 50	6	17
51 - 75	3	9
76 - 100	4	11
Total	35	100

It is also interesting to note, that the results summarised in Table 8.39 above indicate that for the majority of the projects (63%) over three-quarters of the links in the innovation actions-sets were found to be informal in nature. Only four (11%) of the innovation action-sets (canned draught Guinness, the DVA-4000, the Condor rucksack, and the Stripper-Head) were shown to be predominately formal and officially sanctioned.

3. Socio-Centred Attribute Networks: Towards a Typology

Up to this point in the presentation of the results, the focus has been upon the direct links of the innovator with external sources of inputs into the innovation process: in the previous chapter the emphasis lay on the individual dyadic relationships, with the innovator as recipient, while in the previous section of this chapter the analysis shifted to the action-set, used to encompass the portfolio of these direct links.

However, much evidence was found in the case-material of the importance of indirect links to the innovation process. For example, certain individuals within a number of the innovation projects were found to have provided a strategic link to *socio-centred* or *interlocking* (section 3.2.2 of Chapter 3) attribute networks of external actors. These attribute networks of scientists, doctors or users, for example, can be seen as networks of expertise and ideas that can be tapped by the innovating organisation. Indeed, by plugging into these often sociometrically distant attribute networks, boundary-spanners were found to complement and supplement internal resources by sourcing largely cognitive transaction content that had been generated within and diffused around such networks prior to *crossing* the boundary of the innovating organisation.

TABLE 8.40: The Employment of Various Attribute-Networks

Attribute-Network Type	No. of Projects	% of Projects
R&D	17	49
Profession	5	14
User	6	17
Recreation	4	11
Friendship	3	9

From an analysis of the nature of the attribute networks identified in the innovations investigated, five themes of shared commonality of the network actors emerged; scientific and technical speciality, profession, user or potential user of the innovation, leisure activity, and friendship. These five themes of shared commonality, or key distinguishing network attributes, are the basis of the five informal attribute networks described and illustrated in the following sub-sections: R&D networks, profession networks, user networks, recreation networks, and friendship networks, respectively.

The case-material revealed that around half of the innovating organisations in the sample tapped into external R&D networks, to a lesser or greater, during the development of the award-winning innovations studied. Table 8.40, on the previous page, provides a precis of the incidence of employment of the five attribute-defined networks introduced in the paragraph above. The following sub-sections describe each of these attribute-defined networks in turn.

3.1 R&D Networks

Individuals in this type of informal network are organised around scientific or technological specialities, and have a distinctive set of technical and cognitive norms. They are created, built and nurtured on the strength of the desire of scientists and engineers to interact with others in their field, to show off their ideas, to hear about new ideas and to explore new areas of interest. The *R&D network* category is based on the *invisible college* of Price (1963), but is intended to be broader in its scope, encompassing both scientists and engineers, in either public or private organisational settings. Although this broader grouping was grounded in the case-material, it was spurred by the proposal of Rappa and Debackere (1992) that the behaviour of academic researchers and industrial researchers should be studied at a more holistic level, that is, at the level of the technological community or R&D community (see section 6.1.1 of Chapter 3 for a fuller discussion).

The nature, role and exchange value of the transaction content tapped from external R&D networks was found to vary greatly across the seventeen (49%) projects in which they were identified: from critical solution input exchanged on a multiple and continuous basis during the development of MotorMonitor, to minor background information and feedback in the development of Nicam 728. The range and flexibility in the use of external R&D networks was highlighted by a number of the interviewees, for example:

> "So if we were to identify a possible disease area which we don't work in, one of the first things we do...is go and talk to outside experts in that particular area. So that provides us with all sorts of information...But of course, in research areas where we're doing research work, we would go and consult with experts by telephone...at conferences, and meeting them there on an informal discussion basis..." (Troke: Pfizer 1992)

However, although the case-studies provided evidence of a boundary-spanning community of "scientists and engineers working towards the solution of an inter-related problem set" through which "information and knowledge flow quite freely" (Debackere *et al* 1994,22), particularly in relation to the development of Carboplatin, there was also evidence to support the belief that such R&D communities allow "for openness and secrecy at the same time" (Debackere *et al* 1994,32). For example:

> "Part of the brief of the engineer involved is...to contribute to that [external] arena...but at the same time to draw from that wider environment what information they need. It's a two-way process the whole time...Against that one has to recognise the fact that much of that information may well be commercially sensitive...This is increasingly so. And there's a careful balance to be drawn between doing that [interacting externally] and not being so secretive about what you're doing that it's counter-productive." (Gleave: British Broadcasting Corporation 1992)

3.2 Profession Networks

This type of informal network comprises of individuals within a given profession, such as medicine or education. The informal contribution of such a network to the innovation process is best explained by what has been termed by Freeman (1991) as 'professional ethics of co-operation'. Profession networks were found to be mobilised in five (14%) of the innovation projects studied: Carboplatin, Diflucan, First-Sense, Symphony, and Xenos. In all but one of these instances (First-Sense) the profession network consisted of individuals from the medical profession: clinicians (Carboplatin and Diflucan), doctors (Xenos), and stoma-nurses (Symphony). In the remaining case, the network was drawn from various levels of the education system, from primary school teachers to school inspectors.

The case of the development of Carboplatin provides a good illustration of the mobilisation of a profession network in the innovation process:

> "If you go to international conferences for cancer it'll be the same people, the key people. There's a small number [of cancer clinicians], three or four hundred...It's actually quite a community. They're always swapping ideas. And we work very closely with them and we have a very good relationship, probably much better than any other area I know in the industry...We need them to develop our drugs further and they need us to have the drugs to treat the patients." (Barrett: Bristol-Myers Squibb 1992)

Of the five examples of profession networks identified, two were considered to have contributed important inputs into the innovation process (Carboplatin and Diflucan).

3.3 User Networks

Informal personal networks also evolve between end-users of given products or technologies. This may originate from, or be reinforced by, the more formalised structure of user-groups. These networks can act as mutual technical support mechanisms, as pressure groups to lobby innovators, and as diffusers of innovations and techniques.

Despite the important role played by users in the innovation process, networks of users were found to play a role in only six (17%) of the projects investigated: Elektra, Fastrac, First-Sense, MotorMonitor, the MRC-500, and Stripper-Head. This is because it appears that users tend not to be linked to each other directly in interlocking networks. The more typical network structure would seem to be for users to be linked indirectly, as *spokes* in the radial networks of innovators (*e.g.* the E70A LCD mixture, Isoview 3, Puraspec, and Synon/2), professionals (Carboplatin, Diflucan, Symphony, and Xenos), and overseas distributors (Stripper-Head and the Town and Country III), to which they are linked directly.

In the cases of the development of Elektra and MotorMonitor, the exchange of ideas and information between users in the user network was facilitated by the establishment and maintenance of a user-group by the respective innovating organisations:

> "It's only through user meetings, that user A finds out what user B has been doing..." (Simkin: Vector Fields 1992)

> "At users meetings, there's people who have been using it for five years, people who have been using it five months, so it gives them a chance just to speak to those who have been using it for a while and maybe learn something from them or whatever...Over the years now, they've all gotten to get to know one another as well. So it's a semi-sociable event for them as well." (Leith: Inspec 1992)

The formation of such user-groups was seen as an important mechanism for the creation and development of an informal user network, which could potentially be a rich vein of ideas and information available to the innovating organisation to exploit.

3.4 Recreation Networks

The cohesion in this type of informal network results from the mutual sense of attachment to some recreational activity, such as sailing, mountaineering and rugby, where the feelings of challenge, achievement and comradery through participation, create and maintain personal bonds. Friendship is no doubt an important factor in this type of network, but it is not its *raison d'être*.

An analysis of the case-material revealed four projects (Amethyst, the Condor rucksack, the Town and Country III, and Yeoman) in which recreation networks had provided input into the innovation process. In the development of the Condor rucksack and Yeoman, important transaction content was found to have been sourced from such a network in both the idea-generation and field-testing stages.

> "There are a lot of other companies who manufacture marine products and I know (some)...don't even have a sailing enthusiast on their staff. They're all matheticians and electronics engineers. And they think they know what the marine world wants.

They know electronically how to produce a position on the screen, but they don't know how the end-user uses it...and it's evident from the number of button pushes you've got to do to do something that's quite a simple function...Sailing friends we had and trusted [were approached to test the prototype], and we used to take it out in their boats and get their comments, their feedback...it's the only way to do it." (Parfitt: Yeoman Marine 1992)

"Another set of networks, are things like mountain-climbing, and friends that go mountain-climbing...The link was built because one of the people and I go rock-climbing together a lot...After a couple of years of this, we got to know enough about each others technical interests...So the whole relationship that led to the project couldn't have happened without rock-climbing. It was a different friend that introduced us, by accident." (Milne: Intelligent Applications 1992)

3.5 Friendship Networks

This type of informal network simply refers to the personal networks of individuals based predominantly on friendship. The research data revealed three (9%) projects (Backlite, Hydro-Probe, and the on-line tape certification system) in which purely affective or friendship links were mobilised in the innovation process, for example:

"David, who had come to work for me, used to work for CEGB, and he knew somebody called Greg. And Greg had gone up in CEGB. He phoned Greg and said 'Look, we need to borrow a piece of equipment' and Greg said 'Right. OK!'" (Rothwell: Double R Controls 1992)

In addition, the friendship network of an individual will tend to overlay many of their dyadic and network links, due to the dynamic nature of relationships highlighted in section 2.2.5 of Chapter 2. That is, there is a tendency for single-stranded links to become multi-stranded where they persist over time.

4. Strategic Links within Innovation Action-Sets

Having introduced a typology of interlocking attribute-defined networks grounded in the case-material, this section moves on to discuss the manner in which the innovating organisations were found to bridge the gap between their internal networks and these various external networks. These links have been termed *strategic links* (section 6.3 of Chapter 2). In addition, to bridging the gap between internal and external interlocking networks, strategic links were also identified with external actors who may be considered as *stars* (section 3.3 of Chapter 3). Links with such stars were found to allow the innovating organisations to tap the *focal-nets* or *radial* (section 3.2.2 of Chapter 3) networks of these important network actors.

4.1 From Liaisons to Overlapping Personal Networks

It is the intention of this section to focus upon the various types of strategic links identified within the action-sets established for each of the innovations investigated. Indeed, the case-material provides many examples of the relationships of one or a few individuals within the innovating organisation providing strategic links to networks or portfolios of external actors. The typology of strategic link types which was set out in section 6.3 of Chapter 2 will be employed here: *liaisons*, *bridges* and *link-pins*.

4.1.1 Liaisons

Analysis of the various dyadic links within each of the action-sets revealed eight examples of actors linking the innovating organisation indirectly to further sources of ideas, information and feed-back. These *liaisons* were found to be individuals from the professions, such as doctors (Carboplatin, Diflucan, Symphony, and Xenos), distributors (Amethyst, Stripper-Head, and the Town and Country III), or research establishments (pyrethroid insecticides). In all but one of these examples (Stripper-Head) the actor provided a link to a radial rather than an interlocking user network.

In the development of Xenos, for example, a small group of doctors and physio-therapists within the pain-clinics provided a channel for the flow of transaction content between their patients and the developers, with whom they had informal and friendly links. A very similar pattern was identified in the development of Carboplatin, Diflucan and

Symphony. In the case of Symphony, a small group of stoma-nurses provided an indirect link between the developers and stoma patients. While in the mandatory *in vivo* clinical trials of the Carboplatin and Diflucan drugs, clinicians and doctors were seen to provide the important liaison role between drug developer and patient, through multiple and continuous interaction with both parties.

In contrast, the distributor was seen to provide the key channel between the innovator and the end-user during the innovation process of the Amethyst, Stripper-Head, and the Town and Country III. In the cases of the Town and Country III and the Stripper-Head, this role was particularly prevalent in relation to distributors serving overseas markets: Holland and France, respectively. In the development of Amethyst, the distributor was able to liaise with end-users in a product market in which the innovator had no knowledge or contacts, allowing critical input to be channelled into the innovation process.

In the final example, the liaison role was played by a number of individuals within the agricultural department of a US university, who co-ordinated the field-trials of the pyrethroid insecticides on a number of farms and field-stations, and channelled the feedback to the innovators.

The strategic links identified above were thus seen in most instances to provide access to what may be termed the radial networks of *strategically located* actors. That is, the patients and/or end-users of the innovations were linked to the liaison, but were not linked to each other or the innovator directly.

4.1.2 Bridges

The analysis also found the presence of fourteen instances of strategic links that may be classified as *bridges*, relating to eleven (31%) cases. These bridges were found to link the innovating organisation to a variety of interlocking attribute-defined networks, including: networks of scientists, (Backlite, Carboplatin, the Condor rucksack, MotorMonitor, and the Pullman series); networks of professionals (Carboplatin, Diflucan, First-Sense, Symphony, Xenos); networks of users (Fastrac and First-Sense); and networks of enthusiasts (the Condor rucksack and the Town and Country III).

Those links that were identified as bridging the gap between the innovator and the scientific community were most often found to be formal consultancy links, channelling expert knowledge and advice to the development team. A good example of a formal bridge is provided by the commercialising partner in the development of the anti-cancer drug, Carboplatin:

> "As regards external [links], we have an advisory panel of opinion leaders from Europe. So we have one from each of the countries. We would sit down with them every six months and discuss what's going on in the treatment of cancer, any developments that they hear about. We tell them what we're doing and we ask their advice on our plans. So we get input from the opinion leaders...It's formalish, in that they are paid." (Barrett: Bristol-Myers Squibb 1992)

While the relationship between the project leader within Inspec and the scientists within the Robert Gordon Institute of Technology (RGIT) provides a good example of an informal bridge, originating from previously existing friendship based links. Critical input into the problem-solving process was channelled across this informal bridge throughout the development of MotorMonitor.

In the cases of First-Sense, Symphony, and Xenos, the identified bridges linking the innovator to the profession networks were largely informal and friendship based, having been built-up over a number of years:

> "[The links were] Extremely informal. We've got twelve representatives in the field, all gone through education in some form or other. Most of them have been with us for a fair time, I would think the average is ten years...So they tend to know all the teachers...through to inspectors, head-teachers, heads of departments, even Her Majesty's Inspectorate." (Foley: Philip Harris 1992)

> "We've built up a lot of contacts with doctors who run the pain-clinics...A lot of good friends...With professional people, once you've built up your reputation and a relationship with them, they are very loyal...We have a couple we actually pay as

consultants and it means that it puts it all on a more formal footing." (Sherlock: Neen Pain 1992)

However, in the clinical testing of Diflucan, Pfizer was moving into the area of anti-fungal agents and thus had to build up new contacts with doctors. The resulting bridges which Pfizer built between itself and the networks of doctors in the field were initially formal, although overtime these have become multiplex as friendship and trust has developed between particular individuals.

> "We have a UK advisory panel of doctors, which advises us on what we're doing and what we shouldn't be doing. And again, that's a formal thing where we pay them, but they're very happy to help, not because we pay them, I think they'd probably do it for nothing because of our relationships, but obviously we've got to give them something for their time. That works very well...We need them to develop our drugs further and they need us to have the drugs to treat the patients." (Barrett: Bristol-Myers Squibb 1992)

Finally, two examples of bridges between innovators and recreation networks were also identified in the case-studies. The first example concerns the informal friendship based link between the Managing Director of Karrimor and a number of high profile professional walkers and mountaineers utilised during the development of the Condor rucksack. This bridge was partially formalised in the form of the Think Tank and Test Team. This multiplex bridge has proved very effective in providing important input into the idea-generation and field-testing phases of the innovation process of the Condor rucksack. The second example is provided by the link between the design engineer of the Town and Country III, and a number of local branches of disabled associations, such as the MS Society.

In contrast to the radial networks of liaisons, the strategic links identified above were seen to provide access to what may be termed the interlocking networks of actors within strategically important attribute networks. These attribute networks were found to be principally scientific and profession networks, with the bridges to these networks being largely formal in the former and informal in the latter.

4.1.3 Link-Pins

The case-material also revealed a total of eleven examples of actors within the respective development projects providing a *link-pin* between the internal network of the innovating organisation and one or more external interlocking networks, by virtue of their membership of the respective groupings of individuals. These instances of link-pins were also found to link the innovating organisation to a variety of socio-centred or interlocking attribute-defined networks, including: networks of scientists, (Amethyst, the ARM RISC microprocessor, the Peboc process, Puraspec, the shielded magnet, and Synon/2); networks of users (Elektra and MotorMonitor); networks of enthusiasts (Amethyst); and networks of friends (Backlite and Hydro-Probe).

The link-pins that were identified as linking the innovating organisation to the scientific community were found to be informal and reciprocal in nature: the link-pin actors themselves being part of the scientific community. A good illustration of such a strategic relationship is provided with reference to the development of the ARM RISC microprocessor. In this case, the founder of the company acted as the link-pin to a world-wide external network of computer scientists which provided the fundamental ideas for the project:

> "Herman was the [company] founder and he was very good at nurturing ideas. Basically the ARM microchip...was created as a result of him...He regularly keeps in touch with various [research] centres around the world. And he'd come back from the US and said 'This RISC idea looks good, we ought to be looking at it'. That's how the ARM was born." (Urquhart: Acorn Computer 1992)

Similarly, individual engineers within the shielded magnet project provided an array of link-pins to a number of highly technical and specialised fields:

> "The ideas that we're getting are coming back mainly from conferences that we're attending...each in our own speciality...At the level of technology we're talking about people don't usually give exhibitions. You're talking about being at the same conference really as particle-physicists, for instance...We would talk to...basic research scientists working in the field." (Bird: Elscint 1992)

Two of the case-studies (Elektra and MotorMonitor) provided examples of individuals acting as link-pins between the innovating organisation and a network of users. In both of these instances the user network had originiated through, and was at least partly maintained and expanded by, a semi-formal user-group. These two user-groups had been established and were co-ordinated by the key design engineer within each of the innovating organisations. The remaining three examples identified involved informal and opportunistic transactions between individuals within the development team and their own personal leisure or friendship networks.

As with the examples of bridges discussed in the previous subsection, the identified link-pins were seen to provide access for the innovating organisation to interlocking networks of actors within strategically important attribute networks, in particular, those of scientists and users. However, in contrast to the formality of bridge ties, the link-pin ties were found to be informal in nature. This informality may be attributed to the fact that link-pins are themselves members of the respective network, within which they have reciprocal relationships.

4.1.4 Overlapping Personal Networks

In addition to the relatively fragile links between the innovating organisation and external networks of individuals discussed in the above three subsections, the case-material also revealed eleven examples, relating to nine (26%) of the innovations, where there existed an overlap in the internal and external network. This network *integration* (section 3.1.9 of Chapter 3) was most notable in relation to the overlap in the internal network of engineers and scientists, and one or more external scientific or technological communities, within which a number of the project team members played an active part. Indeed, of the eleven examples identified of network integration eight involved an overlap with external scientific or technological communities: the ARM RISC microprocessor, Carboplatin, Diflucan, the E70A LCD mixture, Elektra, the MRC-500, Nicam 728, and the pyrethroid insecticides. In the development of Carboplatin, we see an overlap with the scientific community:

"Conferences are also very important, particularly specialist ones...Bouncing ideas, sharing views, talking about experiments that should be done...There's a world-wide network of informal contacts, collaborators, friends. You make many very good friends in science." (Harrap: Institute of Cancer Research 1992)

"Each person...tends to pick up one or two people [academics] that they talk to more freely...as a spring-board to understanding what's happening in university ...what the problems are...You've got that...which is a very personal link...The rest...I think we have just a very broad network of contacts with the universities. It's a very free two-way exchange of ideas." (Barnard: Johnson Matthey 1992)

Whereas the case-studies of the development of Nicam 728 and Scimitar H, for example, provide good examples of an overlap between an internal network of engineers and the respective external technological communities:

"At the annual and bi-annual conventions that take place, it's akin...to a sort of academic environment...If you pick a particular topic...researchers within that area would be in close contact at a professional level with people involved in similar sets of work all over the place. Many of whom will be partners in collaborative ventures and some just out of straight point-of-contact from other sources." (Gleave: British Broadcasting Corporation 1992)

"Although probably the majority of the R&D links are forged at the engineer-level, directly between engineers in different companies, we do within the Engineering Department actually go to conferences. We're not in complete isolation. And we involve ourselves in synopsia and things like that, especially with the IEE...Certainly in this particular project there was a high level of direct involvement with these." (Conley: Marconi 1992)

It was noted in Chapter 3 (sections 6.1.2 and 6.2) that the concept of *enforced localism* among technologists, proposed by Allen (1977), had become increasingly constraining, and that the behaviour of academic and industrial researchers should be studied at a more holistic level (Rappa and Debackere 1992). The incidence of overlapping personal networks noted above, incorporating both internal and external networks of scientists and engineers, would appear to support this view.

The remaining examples of network integration identified in the case-studies involved an overlap between the development team and a clinician community (Carboplatin), a user community (MRC-500), and sailing community (Yeoman). While in the latter two examples the integration was seen to develop and be maintained in an informal manner, the overlap in the case of Carboplatin was found to be both conscious, formalised, and in line with the traditional link between drug developer and hospital:

> "The Institute of Cancer Research is sited at Sutton, on the same site [as the Royal Marsden Hospital], and there are various clinicians who are both members of the hospital staff and the Institute of Cancer Research staff. So that provides a good link for bringing compounds and new developments into the hospital. So a lot of the initial contacts with clinicians, are actually through those who have a role with the Institute of Cancer Research. It exists around the world...in the UK you have combinations of teaching hospitals with research groups associated with them." (Barnard: Johnson Matthey 1992)

The existence of such overlapping personal networks was also found to be an effective way of innovating organisations tapping into external networks.

4.2 <u>The Importance of Individuals as Strategic Boundary-Spanners</u>

The importance of friendship and trust built-up over time between boundary-spanners and external actors in the effective functioning of liaisons, bridges and link-pins, highlights the importance of individuals rather than organisational roles or positions in boundary-spanning activity. That is, the strategic links that were identified were often found to be the *property* of the individual rather than the role or position that they occupied in the innovating organisation. This point was implied by a number of the interviewees, for example:

> "Like in any society, some people enjoy developing and nurturing personal links and go out do so, some people tend not to...I think it's driven just by the personalities of the people...It's informal. It's individual to individual. Companies don't keep in touch, people in companies do. So it's just down to people." (Urquhart: Acorn Computer 1992)

> "I think it is the individuals who make the link...Our scientists are all encouraged

> to maintain close contacts with people...in other countries...in government research departments...on an informal basis." (Troke: Pfizer 1992)

In addition, certain individuals were seen to play a critical boundary-spanning role, not only in the development of some of the innovations studied but also in the more general innovative capacity of their department or organisation:

> "Michael Cleare...essentially he set up a network of contacts with universities and interested parties in cancer development at the time...[He] was co-ordinator for a lot of research support over this side of the Atlantic...*pump-priming*, trying to keep people investigating and sort of co-ordinating the enthusiasm of a few people who thought there was something worthwhile and should be pursued, each in their own particular areas of interest. To ensure that the compound continued to receive attention." (Barnard: Johnson Matthey 1992)

The reliance of innovating organisations on certain individuals to maintain potentially strategically important liaisons, bridges and link-pins with external networks of actors, highlights the vulnerability of such organisations with respect to informal person-to-person relationships and hence fragile boundary-spanning links.

5. Summary of Findings

The depictions of each of the thirty five innovation action-sets constructed from the case-material provide a good illustration of the power of the graphic in encapsulating and conveying dyadic and network data. In addition, such illustrations were found to be a potentially valuable analytical tool.

From an analysis of the innovation action-sets along a number of network dimensions, it was found that such networks typically included eleven or more actors from a narrow range of loci, and that the relationships with these actors were largely informal and existed prior to the establishment of the respective development projects.

A small number of the dyads in around half of the innovation action-sets constructed from the study were found to be of strategic importance to the innovating organisations. The strategic importance of these dyads arose by virtue of their linking the innovating organisation indirectly to many additional external actors, either through access to socio-centred or interlocking networks, or the focal-nets or radial networks of *star* actors. By plugging into these often sociometrically distant attribute networks, boundary-spanners were found to complement and supplement internal resources.

From an analysis of the characteristics of the external networks identified in the innovations investigated, five themes of shared commonality of the network members emerged; scientific and technical speciality, profession, user or potential user of the innovation, leisure activity, and friendship. These five themes of shared commonality, or key distinguishing network attributes, form the basis of a typology of attribute-defined networks: R&D networks, profession networks, user networks, recreation networks, and friendship networks, respectively. The case-material revealed that external R&D networks were the most commonly utilised, being employed in around half of the award-winning innovations studied.

Four types of links were found to bridge the gap between the internal network of the project team and the five external attribute-defined networks identified above: liaisons, bridges, link-pins, and overlapping personal networks. Liaisons representing the most *fragile* links, since the connection is indirect. This is in contrast to the *strength* of overlapping personal networks, where there is a degree of integration between the internal and external network membership. The analysis revealed the informality of much of the exchange activity through these strategic channels, and the importance of individuals in maintaining the links. Indeed, these strategic links were found to be the *property* of individuals rather than that of the organisational positions they occupied.

CHAPTER NINE: IMPLICATIONS FOR THE MANAGEMENT OF INNOVATION AND POSSIBILITIES FOR FUTURE RESEARCH

1. Introduction

The concept of *network* has been employed to examine many configurations in science and technology since the early 1960s. Wolek and Griffith (1974) argue that much of this research has been encouraged by the search for ways to stimulate science and technology, and as such has received extensive support from policy-makers. However, prior to the recent government White Paper entitled "Realising Our Potential" (Chancellor of the Duchy of Lancaster 1993), Allen *et al* (1983,208) had contended that "the overwhelming dominance of personal contact in technology transfer has been replicated in study after study, yet it is consistently ignored by policy-makers". Despite this long awaited acknowledgement, for policy-makers to implement policies to encourage informal transfer they need first to have a clearer understanding of the channels and mechanisms through which the process occurs. This need is articulated by Wolek and Griffith (1974,420), who argue that "for policy-makers to effect improvements and changes in the flow of information, they must have a firm understanding of the existing and desired relationships which bind groups of professionals into productive communities".

Through employing a network perspective, this research has sought to reveal and build upon our knowledge of the informal channels and mechanisms through which ideas enter the innovation process. The value of the research lies in the belief that "the social structure revealed by network analysis is generally invisible to the participants in the system of study" (Rogers 1987,8).

2. Summary of Findings

2.1 The Role, Importance and Locus of External Inputs

The analysis of the thirty-five innovations investigated in this research revealed that only seven (20%) were considered to have been developed almost entirely in-house. At the other extreme, input from external sources was considered to have been critical in seven (20%) other developments. Indeed, external inputs were considered to have been either important or critical to the innovation process in 54% (nineteen) of the sample. Thus, the aggregate results of the qualitative analysis of the case material support the evidence of earlier research, that demonstrates the importance of external sources to the innovation process. The results also support the findings of earlier studies that suggest external sources are an important complementary source of inputs into the innovation process, rather than a substitute for indigenous innovative activity.

In addition, the analysis of the case-material found that external inputs were of higher exchange value during the problem-solving process (solution inputs) and field-testing than during the idea-generation process (inputs into the features and functionality of the innovation). In both of the first two functions, external sources were found to contribute important or critical inputs in fourteen (40%) of the cases, but in only eight (23%) with respect to idea-generation. An analysis of these external inputs found that the transaction content was primarily cognitive in relation to idea-generation, but a combination of cognitive, service and material transaction content in problem-solving and field-testing.

In relation to the locus of the external inputs into the innovation process, the analysis found that the user was *the* major external source of inputs into the idea-generation and field-testing phases of the innovation projects, with suppliers as *the* major external source of inputs into the problem-solving process. In addition, research establishments were seen to be utilised in twenty (57%) of the projects, though often in more peripheral roles. This finding is contrary to earlier findings, such as those of Langrish *et al* (1972). Technical and design consultants were also employed in 46% of the developments, the former largely in relation to problem-solving, the latter with respect to aesthetics and ergonomics. Distributors and professionals (such as doctors and educationalists) were seen to play a more limited role, as were competitors, as a source of external inputs.

Finally, although the sample is small, the data suggests that small and medium-sized firms are more inclined to utilise external inputs in the innovation process. This relation was found to be strongest for medium-sized innovators with respect to field-testing. Variations in the exchange value and origin of external inputs with respect to the product groupings were less clear-cut, but once again the sample is small.

2.2 The Role and Importance of Informally Derived Inputs

The analysis of the case-material revealed that external inputs sourced informally played a critical or important role in six (17%) of the innovations, compared to nineteen (54%) with respect to external sources overall. In addition, informal external sources provided useful inputs in a further seventeen (49%) of the projects, with only a third (twelve) considered to have not benefited, or to have benefited to only a minor extent. However, as with the exchange value of external sources in general, the exchange value of external inputs derived informally was found to vary between the various stages of the innovation projects. For example, the analysis of the case-material found that informally derived external inputs were of slightly greater importance during idea-generation than during problem-solving. This result thus lends some support to earlier studies. Furthermore, the case-material provided many references, both explicit and implicit, of the importance of informal boundary-spanning relationships between individuals in supporting formally established organisational links. That is, there existed much evidence to corroborate with the contention of Freeman (1991,503) that "behind every formal network, giving it the breath of life, are usually various informal networks".

In analysing the nature of the boundary-spanning exchange activity identified in the previous chapter, it was found that the formality of the process varied in relation to the locus of the external inputs. Thus, while much of the input from users as *the* major external source of external inputs into the idea-generation and field-testing processes was found to be informal, the majority of the critical and important inputs from suppliers as *the* major source of external inputs into problem-solving were found to be formal. The data also suggests that small and medium-sized firms are more inclined to utilise informal boundary-spanning channels in the overall innovation process than large firms. This relationship was found to be less marked in the idea-generation phase, but more marked with respect to the field-testing of the innovations.

2.3 Explaining Informal Exchange Activity

In attempting to explain the incidence of informal exchange activity through boundary-spanning links, recourse was made to both economic and social exchange theory. While the analysis of the data found some instances of informal exchange activity motivated by the maximisation of economic rent, particularly that involving suppliers and competitors, much of the informal exchange behaviour could not be explained in rational economic terms alone. It was found, however, that many of the informal exchanges could be largely explained in relation to the membership of the respective dyads, and to varying degrees by the social structure in which the dyads were embedded.

2.4 The Morphology of Innovation Action-Sets

From an analysis of the innovation action-sets along a number of network dimensions, it was found that such networks typically included eleven or more external actors from a narrow range of loci, and that the relationships with these actors were largely informal and existed prior to the establishment of the respective development projects. Network depictions were found to be a useful tool for encapsulating, conveying and analysing the morphology of these innovation action-sets.

2.5 External Attribute Networks and Strategic-Links

A small number of the dyads in around half of the innovation action-sets constructed from the study were found to be of strategic importance to the innovating organisations. The strategic importance of these dyads arose by virtue of their linking the innovating organisation indirectly to many additional external actors, either through access to socio-centred or interlocking networks, or the focal-nets or radial networks of *star* actors. By plugging into these often sociometrically distinct and distant attribute networks, boundary-spanners were found to complement and supplement internal resources.

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Four types of links were found to bridge the gap between the internal network of the project team and the five external attribute-defined networks identified above: liaisons, bridges, link-pins, and overlapping personal networks. Liaisons representing the most *fragile* links, since the connection is indirect. This is in contrast to the *strength* of overlapping personal networks, where there is a degree of integration between the internal and external network membership. The analysis revealed the informality of much of the exchange activity through these strategic channels, and the importance of individuals in maintaining the links. Indeed, these strategic links were found to be the *property* of individuals rather than the organisational positions they occupied.

3. Implications for the Management of Innovation

Informal boundary-spanning links and networks have been shown in this study, and in earlier research, to be a valuable channel through which fresh ideas filter into the innovation process. As such, these boundary-spanning links represent an important intangible organisational resource which is difficult to replicate by competitors (Saxenian 1991, Hall 1992). Further, with the exponential growth in knowledge and the proliferation of scientific and technical specialities, as well as their fusion and cross-fertilisation, in the post-war period (section 3.3 of Chapter 2), organisations in many industrial sectors can no longer seek to internalise all the necessary knowledge, skills and technology, to undertake innovative projects. As noted earlier, Rogers and Kincaid (1981,344) contend that:

> "Such information overload is often handled by the structuring of interpersonal network links by individuals. *Knowwho* thus begins to replace *knowhow* as one of the main determinants of individual effectiveness."

Thus, it may be argued that the collective *knowwho* of employees is beginning to replace their collective *knowhow* as the main determinant of their organisation's effectiveness.

However, the operation of informal boundary-spanning links and networks generates a number of concerns for the organisation that need to be addressed. Indeed, Wolek and Griffith (1974,411-412) argue that "this reliance is somewhat troublesome, for it is the formal channels which seem to be much more amenable to control and institutional support", while informal channels are "sometimes interpreted as a sign of both weakness and need for better formal systems". These concerns and their implications for the management of innovation are discussed below.

3.1 Fostering Informal Boundary-Spanning Activity

The importance of fostering a large network of informal boundary-spanning relationships was stressed in a number of the interviews, but perhaps was most clearly expressed by the founder of Intelligent Applications, a small expert-system company:

> "Networking is absolutely vital. In all our successful innovations it's been a combination of networking and serendipity...We actually have huge networks...and we've had just a few cases where two nodes have basically come together, and something has popped out of it...it's unpredictable where out of the network the opportunity arises. So you've just got to cast the net and not be too judgemental, and see what happens...<u>The trick to being in the right place at the right time, is to be in a lot of places</u>!" (Milne: Intelligent Applications 1992)

Although a certain amount of personal boundary-spanning will always take place irrespective of the organisation's position on such activity, the innovative organisation must be prepared to take *positive* action to foster external relationships in order to cast the net further. The organisation should, for example, promote a culture of interaction and communication that spans both internal and external boundaries. For such activity to flourish the organisation must also be prepared to provide the necessary resources in terms of both time and funding. These resources are particularly important with respect to external links, to allow the membership of professional bodies and attendance at conferences, workshops, and standards meetings, for example.

3.2 Recognising the Importance of the Individual

Given the importance of boundary-spanning activity to the innovation process and the reliance of the innovator on a small number of specific individuals acting as *boundary-spanners* (Allen 1977), the innovative capacity of the organisation may be viewed as unpredictable and vulnerable. Indeed, Lawton-Smith *et al* (1991,466) argue that "the downside of the key role which personal relationships play in collaborative ventures is over-dependence on certain individuals". However, in his study of the communication patterns of engineers, Allen (1977) found that gatekeepers were easily recognised by the organisation, with an overlap between guesses of the management and the study data of around 90%. Thus, if the key boundary-spanners can be identified then there exists the potential for the monitoring and supervision of their boundary-spanning activity.

In addressing this issue, Allen (1977,161) argues against formalising the role of boundary-spanners, which he believes "seems unnecessary and could even prove undesirable", favouring "recognition be afforded on a private, informal basis". Wolek and Griffith (1974,416) support this view, contending that "formally recognised purposes, and formally sanctioned relationships, are not necessarily the ones which professionals feel to be important to their work". Thus, management should first identify the organisation's key boundary-spanners, and then seek to supervise, motivate and recognise them on an informal and flexible basis.

3.3 Managing and Guiding Informal Boundary-Spanning Activity

The interaction patterns within informal networks are inherently unpredictable, unseen and uncontrollable. Carter (1989,155), for example, argues that "because knowhow trading is informal and off-the-books such trading is difficult for the firm to evaluate and to manage". In addition, Kreiner and Schultz (1991,24), in their study of the Danish bio-technology sector, found that "the norms governing the interaction seem to reside in the network itself rather than in any of the participating organisations". Yet, even where informal links are controllable, Lawton-Smith *et al* (1991,467) argue that while "formalisation legitimises what has occurred informally", the formalisation of informal links "can also be a significant barrier to successful collaboration, with small firms particularly vulnerable to adverse decisions made by people in authority above the level of the technical collaborators". However, despite the nature of such informal links, organisations can undertake measures to guide, if not control, boundary-spanning activity.

A particular concern of management relating to boundary-spanning activity, for example, involves the flow of information across the organisational boundary. Informal boundary-spanning relationships not only provide for the sourcing and acquisition of information and know-how, but also result in information leakage. Mansfield (1985), for example, argues that the rapid diffusion of technology via informal channels is one reason why many firms have difficulty in appropriating benefits from their innovations. While Carter (1989,158) argues that:

> "Exchangers of information do incur costs. The cost to the trader...is not the loss of the information itself, but rather the competitive back-lash, profits that are sacrificed when the monopolistic position of the innovator is diluted by sharing."

The information transfer behaviour of an employee therefore, can not necessarily be assumed to be in accordance with the economic interests of their employer. This is because the trading or sharing of knowhow may be guided by purely personal objectives (Rogers 1982), or even misguided, due to the insufficient availability of managerial information to enable well-informed decisions to be made (Schrader 1991). While Hamel *et al* (1989) suggest measures to restrain informal boundary-spanning activity, Schrader (1991) argues that an organisation should employ mechanisms to induce desirable information transfer behaviour. This may include incentive schemes to motivate employees to act in the interests of the organisation, and mechanisms to diffuse information internally.

3.4 Strengthening Weak-Ties

A further concern is the fragility of bridges between the organisation and external information networks. But here in lies the paradox. Granovetter (1973,357-358,351) contends that bridges "are the channels through which ideas, influences, or information socially distant from ego [a given nodal actor] may reach him" but argues that "all bridges are weak ties". Thus, by strengthening and multiplying the number of personal links between the organisation and the external network, there is a danger that the freshness and uniqueness of the input from that external network will be diluted as a result of isomorphism.

However, two of the innovations studied provide particularly interesting and novel attempts by the innovators to overcome this paradox. The first of these involves the development of the Condor rucksack by Karrimor International. The creation of a think-tank and a test-team, made up of very experienced and professional mountaineers and walkers, allowed the company to formalise, though not internalise, part of this informal network of users. This set-up therefore provided a *bridgehead* within the user network, from which the innovator could tap into the experience and ideas of others informally and indirectly. A similar set up was employed in the development of the Fastrac by JCB Landpower. Here a user-panel was established from lead-users and agricultural experts, to provide the company with a blue-print for a new generation of tractor.

4. Possibilities for Future Research

4.1 Power and the Social Construction of Technological Artifacts

In relation to the *flow* through the network this study focused on identifying the cognitive (*e.g.* information and know-how), material (*e.g.* money and technology), and expressive (friendship) transaction content relevant to the development of specific innovations. The flow of power and influence (instrumental transaction content) alongside information and goods, for example, was not explicitly investigated. However, implicit in the resource dependence of the innovator upon other organisations in some of the cases investigated and the relative size of end-users in others, is the importance of the flow of power through the innovation action-set in influencing the design and functionality of the innovation. This would appear to be a very fruitful area for future research.

The late 1980s have seen the emergence of two related perspectives within the sociology of science field that offer useful insights into the way power and influence may shape the innovation process: *actor network theory* (Callon 1986, Law and Callon 1988) incorporating the concept of *techno-economic systems* or *TENS* (Callon 1992), and the *social construction of technology* (Bijker 1987, Pinch and Bijker 1987). Although these two approaches in common with social network analysis seek to understand actors and their relationships, their emphasis is *contextual* rather than *structural*. Thus, unlike social network analysis, actor network theory is not primarily concerned with mapping interactions between individuals. Rather it is concerned with mapping

> "...the way in which they [individuals] define and distribute roles, and mobilise or invent others to play these roles. Such roles may be social, political, technical, or bureaucratic." (Law and Callon 1988,225)

That is, while social network analysis is orientated toward *structure* and the *flow* through that structure, actor network theory highlights the dynamic and political nature of interactions between actors. Further, Callon (1986,20) argues that:

> "...the development of scientific knowledge and technical systems cannot be understood unless the simultaneous reconstruction of the social contexts of which they form a part is also studied."

This view is similar to the fundamental concepts that underlie the social construction of technology perspective: *interpretative flexibility* and *technological frame*. The notion of interpretative flexibility asserts that the social context in which a technology is embedded in its development and diffusion not only dictates the social meaning of that technology but also its actual technical content:

> "...technological artifacts are culturally constructed and interpreted...By this we mean not only that they is flexibility in how people think of or interpret artifacts but also that there is flexibility in how artifacts are *designed*. There is not just one possible way or one best way of designing an artifact." (Pinch and Bijker 1987,40)

While the notion of technological frame refers to:

> "...the concepts and techniques employed by a community in its problem solving...encompassing within it the recognition of what counts as a problem as well as the strategies available for solving the problems and the requirements a solution has to meet." Bijker (1987,168)

Although Bijker (1987) argues that technological frames strongly influence how individuals within them define problems and solutions, he also notes that this influence is not pervasive since actors will have different degrees of inclusion within a frame and may well be members of more than one technological frame. This latter point is reminiscent of the strategic role attributed to boundary-spanners.

Thus, both the actor network and social construction perspectives have much to offer any attempt to incorporate an understanding of the role of power and influence in the innovation process. However, incorporating the core elements of these approaches would demand the collation of a far greater amount of contextual data for a given innovation project: the identification of political and bureaucratic roles; the flow of power between actors; the evaluation of variations in interpretative flexibility and technological frame of actors and networks of actors found to influence the innovation process. Such an eclectic approach, focusing on structure, power and context, would undoubtedly necessitate interviews with external actors as well as the focal innovator in order to obtain the richness of data required.

4.2 Studying Innovation Networks Over-Time

As noted in section 5 of Chapter 3: networks are not static structures. A number of researchers have highlighted the importance of studying networks over time, in order to generate greater understanding of their dynamism (Aldrich 1979, Aldrich and Whetten 1981, Cook 1982, Auster 1990, Birley *et al* 1991, Lawton-Smith *et al* 1991, Stork 1991, Hagedoorn and Schakenraad 1992, McPherson *et al* 1992, Kreiner and Schultz 1993). While a number of studies have been undertaken in recent years, Auster (1990,86) calls for further "comprehensive, longitudinal data on large samples of linkages, organisation-sets, or networks".

However, existing network studies of a longitudinal nature have tended to either provide a mathematical analysis of various quantitative attributes of the network structure over time, such as size and density (Stork 1991, Hagedoorn and Schakenraad 1992), or deliver anecdotal narratives concerning various qualitative attributes, such as changes in the degree of formality (Lawton-Smith *et al* 1991, Kreiner and Schultz 1993). What is needed to complement and supplement these types of studies is research that takes a middle ground, in much the same way that this project has attempted to do in relation to studying innovation action-sets, by providing a systematic study of both quantitative and qualitative network attributes over time.

4.3 Evaluating the Relevance of the *Enforced Localism* Concept in the 1990s

Although the sample of innovations employed in this research project is heavily biased toward commercial organisations with well defined missions, the case-material revealed a great deal of informal boundary-spanning exchange activity. Therefore, this study provides evidence that is contrary to that of Allen (1977), who identified the existence of *enforced localism* within such organisations. This research is indicative of changing patterns of communication within commercial organisations and supports the contention of Debackere *et al* (1994) that the boundary between what has often been referred to as the *scientific community* and *technological activity* is fading. It is also likely that the changes occurring in the various public research organisations are bringing about changes in the communication patterns of scientists, such that the traditional communication patterns of both scientists and technologists are being compromised and meeting half-way. Research concerning the communication patterns and network structures of both engineers and scientists, along the lines of studies such as those of Griffith and Miller (1970), Crane (1972) and Allen (1977) in the late 1960s and early 1970s, once again appear to be of interest.

4.4 Depicting Innovation Networks

The figures representing the innovation action-sets in Chapter 8 illustrate the power of the graphic in encapsulating and conveying a variety of quantitative and qualitative information at the level of both the individual dyad and the overall network: for example, size, diversity and formality. However, little research has focused on the graphic representation of such network data. Preliminary work has recently been undertaken to review and synthesize existing approaches and styles in depicting networks (Steward *et al* 1993,1994a), as well as to provide a palette of options for encoding both quantitative and qualitative data concerning nodes, links, and transaction content (Conway and Overton 1994, Steward *et al* 1994b). This area provides the scope for further interesting, original and useful study, not least in the suggestion of graphical conventions typical of the pictorial representations of chemists and cartographers.

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TABLE A.1: The Sample of Innovations Investigated in the Study

Innovation	Innovator/s	Award	Year
Amethyst	Intelligent Applications Ltd	QA	1991
ARM RISC Microprocessor	Acorn Computer Group	QA	1992
Backlite	BSH Industries Ltd	QA	1991
Canned Draught Guinness	Guinness Brewing Worldwide	QA	1991
Carboplatin	Bristol-Myers Squibb Institute of Cancer Research Johnson Matthey	QA	1991
Condor Rucksack	Karrimor International Ltd	DA	1991
Diflucan	Pfizer Ltd	QA	1991
DVA-4000	VideoLogic Ltd	QA	1992
E70A LCD Mixture	Merck Ltd	QA	1992
Elektra	Vector Fields Ltd	QA	1992
Fastrac	JCB Landpower Ltd	DA	1992
First-Sense	Philip Harris Ltd	DA	1992
Flexilink	Pilkington Communication Systems Ltd	QA	1992
Hydro-Probe	Hydronix Ltd	DA	1992
Isoview 3	3Com Ltd	DA	1992
Linear Actuator	Hydraulic Projects Ltd	DA	1991
MotorMonitor	In-Spec Manpower & Inspection Services Ltd	QA	1992
MRC-500	Bio-Rad Microscience Ltd Medical Research Council	QA	1991
Nicam 728	British Broadcasting Corporation	QA	1992

On-line Tape Certification System	Double R Controls Ltd	QA	1992
Peboc Pharmaceutical Intermediate Process	Peboc Ltd	QA	1992
Polifold	Glass Transport Systems Ltd	DA	1992
Pullman Series	Portakabin Ltd	QA	1992
Pyrethroid Insecticides	ICI Agrochemicals	QA	1992
Puraspec	ICI Kataloc	QA	1991
Scimitar H	Marconi Communication Systems Ltd	QA	1991
Shielded Magnet	Elscint Cryomagnetics Ltd	DA	1991
Stripper-Head	Shelbourne Reynolds Engineering Ltd	DA QA	1991 1992
Studio 9000	Crosfield Electronics Ltd	QA	1992
Symphony	Simcare	QA	1991
Synon/2	Synon Ltd	QA	1991
Town & Country III	Booster Electric Vehicles Ltd	DA	1992
Water-Mains Refurbishment System	Mercol Descaling Company Ltd	QA	1992
Xenos	Neen Pain Management Systems	DA	1991
Yeoman	Yeoman Marine Ltd	DA	1991

KEY: QA = Queen's Award for Technological Achievement
DA = British Design Council Award

TABLE A.2: A List of Innovators, and their Size & State of Dependence During the Development of the Respective Innovations in the Study

Innovator/s	Innovation	Orgn. Size	Indep-endent
Acorn Computer Group	ARM RISC Microprocessor	Medium	Yes
British Broadcasting Corporation	Nicam 728	Large	No
Bio-Rad Microscience Ltd	MRC-500	Large	Yes
Booster Electric Vehicles Ltd	Town & Country III	Small	Yes
Bristol-Myers Squibb	Carboplatin	Large	Yes
BSH Industries Ltd	Backlite	Small	Yes
Crosfield Electronics Ltd	Studio 9000	Large	Yes
Double R Controls Ltd	On-line Tape Certification System	Small	Yes
Elscint Cryomagnetics Ltd	Shielded Magnet	Large	Yes
Glass Transport Systems Ltd	Polifold	Small	Yes
Guinness Brewing Worldwide	Canned Draught Guinness	Large	No
Hydronix Ltd	Hydro-Probe	Small	Yes
Hydraulic Projects Ltd	Linear Actuator	Small	Yes
ICI Agrochemicals	Pyrethroid Insecticides	Large	No
ICI Kataloc	Puraspec	Large	No
In-Spec Manpower & Inspection Services Ltd	MotorMonitor	Medium	Yes
Institute of Cancer Research	Carboplatin	Large	No
Intelligent Applications Ltd	Amethyst	Small	Yes
JCB Landpower Ltd	Fastrac	Large	Yes
Johnson Matthey	Carboplatin	Large	Yes
Karrimor International Ltd	Condor Rucksack	Medium	Yes

Marconi Communication Systems Ltd	Scimitar H	Large	No
Merck Ltd	E70A LCD Mixture	Large	Yes
Mercol Descaling Company Ltd	Water-Mains Refurbishment System	Medium	Yes
Medical Research Council	MRC-500	Large	No
Neen Pain Management Systems	Xenos	Small	Yes
Peboc Ltd	Peboc Pharmaceutical Intermediate Process	Medium (Large)	No
Pfizer Ltd	Diflucan	Large	Yes
Philip Harris Ltd	First-Sense	Medium	Yes
Pilkington Communication Systems Ltd	Flexilink	Medium (Large)	No
Portakabin Ltd	Pullman Series	Large	Yes
Shelbourne Reynolds Engineering Ltd	Stripper-Head	Medium	Yes
Simcare	Symphony	Medium (Large)	No
Synon Ltd	Synon/2	Small	Yes
Vector Fields Ltd	Elektra	Small	Yes
VideoLogic Ltd	DVA-4000	Small	Yes
Yeoman Marine Ltd	Yeoman	Small	No
3Com Ltd	Isoview 3	Large	Yes

TABLE A.3: A List of Interviewees in the Study

Innovator	Interviewee/s	Position During Development	Date of Interview
Acorn Computer Group	James Urquhart	Circuit-Board Design Engineer	28-Jul-92
British Broadcasting Corporation	Mike Gleave	Assistant Head of Engineering	13-Jul-92
Bio-Rad Microscience Ltd	Dr. Andrew Dixon	Business Unit Manager	11-Feb-92
Booster Electric Vehicles Ltd	Peter Baker	Co-Founder/ Co-Designer	29-Jun-92
Bristol-Myers Squibb	Dave Barrett	Marketing Manager for Cancer Drugs	03-Sep-92
BSH Industries Ltd	Derek Waller	Co-Founder	20-Feb-92
Crosfield Electronics Ltd	Gary Stamp	Project Manager	09-Jul-92
Double R Controls Ltd	Mr. Rothwell	Founder/Inventor	08-Aug-92
Elscint Cryomagnetics Ltd	John Bird	Senior Engineer	01-Apr-92
Glass Transport Systems Ltd	Chris Eastlake	Design Engineer	29-Jul-92
Guinness Brewing Worldwide	Dr. Alan Forage	Director of Product Development/ Inventor	23-Mar-92
Hydronix Ltd	Rolf Laffan	Founder/Project Co-ordinator	19-Aug-92
Hydraulic Projects Ltd	Ray Hammond	Founder/Designer	31-Mar-92
ICI Agrochemicals	Martin Bushell	R&D Manager	27-Jul-92
ICI Kataloc	Pat Denny Peter Carnell	Principal Scientist Business Manager	11-Mar-92
In-Spec Manpower & Inspection Services Ltd	Dr. Douglas Leith	Product Manager/ Software Engineer	23-Jun-92

Institute of Cancer Research	Prof. Ken Harrap	Project Co-ordinator	14-Apr-92
Intelligent Applications Ltd	Dr. Robert Milne	Founder/Designer	06-Apr-92
JCB Landpower Ltd	Ivan Tatt	Product Manager	21-Jul-92
Johnson Matthey	Dr. Chris Barnard	Principal Scientist	09-Mar-92
Karrimor International Ltd	Dr. Andy Pickard	Product Manager	18-May-92
Marconi Communication Systems Ltd	Eric Conley	Technical Director	25-Mar-92
Merck Ltd	Martin Pellatt David Coates	Product Manager Research Manager	07-Sep-92
Mercol Descaling Company Ltd	Noel Miller	Technical Director	18-Aug-92
Medical Research Council	Dr. John White Dr. Brad Amos	Co-Inventor Co-Inventor	18-Feb-92
Neen Pain Management Systems	Roy Sherlock	Project Coordinator/ Co-Designer	23-Apr-92
Peboc Ltd	Stan Higgins	R&D Manager	02-Jul-92
Pfizer Ltd	Dr. Peter Troke	Senior Biologist	10-Mar-92
Philip Harris Ltd	John Foley	Project Director	08-Jul-92
Pilkington Communication Systems Ltd	Glyn Hughes	Design Engineer/ Inventor	02-Jul-92
Portakabin Ltd	Mr. Stericker	Technical Director	11-Sep-92
Shelbourne Reynolds Engineering Ltd	Paul McCredie	Project Manager/ Design Engineer	13-Mar-92
Simcare	David Cross	R&D Manager	04-Mar-92
Synon Ltd	Nick Knowles	Co-Founder/ Software Engineer	03-Feb-92
Vector Fields Ltd	John Simkin	Co-Founder/ Designer	07-Jul-92
VideoLogic Ltd	Gail Allen	Marketing Manager	06-Aug-92

Yeoman Marine Ltd	Gwyn Parfitt Roger Woolley Hugh Agnew	Senior Engineer Technical Director Company Director	15-Apr-92
3Com Ltd	Tim Jallard Peter Wilson	Software Engineer Software Engineer	09-Jul-92

TABLE A.4: The Innovations Grouped by Broad Industrial Classification

Classification	Innovation	Innovator/s
Chemical Products and Processes	E70A LCD Mixture	Merck Ltd
	Pyrethroid Insecticides	ICI Agrochemicals
	Puraspec	ICI Kataloc
Consumer Goods	Backlite	BSH Industries Ltd
	Condor Rucksack	Karrimor International Ltd
	Draught Canned Guinness	Guinness Brewing Worldwide
	Yeoman	Yeoman Marine Ltd
Electronic, Communications and Computer Products and Components	ARM RISC Microprocessor	Acorn Computer Group
	DVA-4000	VideoLogic Ltd
	Flexilink	Pilkington Communication Systems Ltd
	Nicam 728	British Broadcasting Corporation
	On-line Tape Certification System	Double R Controls Ltd
	Scimitar H	Marconi Communication Systems Ltd
	Studio 9000	Crosfield Electronics Ltd
Engineering Components	Linear Actuator	Hydraulic Projects Ltd
	Shielded Magnet	Elscint Cryomagnetics Ltd
	Stripper-Head	Shelbourne Reynolds Engineering Ltd
Engineering Products	Fastrac	JCB Landpower Ltd
	Hydro-Probe	Hydronix Ltd
	Polifold	Glass Transport Systems Ltd
	Pullman Series	Portakabin Ltd

	Water-Mains Refurbishment System	Mercol Descaling Company Ltd
Pharmaceutical Products and Processes	Carboplatin	Bristol-Myers Squibb Institute of Cancer Research Johnson Matthey
	Diflucan	Pfizer Ltd
	Peboc Pharmaceutical Intermediate Process	Peboc Ltd
Scientific, Medical and Educational Equipment	First-Sense	Philip Harris Ltd
	MRC-500	Bio-Rad Microscience Ltd Medical Research Council
	Symphony	Simcare
	Town & Country III	Booster Electric Vehicles Ltd
	Xenos	Neen Pain Management Systems
Software Products	Amethyst	Intelligent Applications Ltd
	Elektra	Vector Fields Ltd
	Isoview 3	3Com Ltd
	MotorMonitor	In-Spec Manpower & Inspection Services Ltd
	Synon/2	Synon Ltd

TABLE A.5: The Identified Sources/Channels of Transaction Content Utilised in the Respective Innovation Projects in the Study

Amethyst

Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Distributor (IRD)	I/A	F	T	Yes	C/M/S	C	Fax/Modem/ Phone
Transaction Content	Feedback from running prototype tests with own customers & knowledge of application area (m/c vibration)						
Customer (BP)	I	F	T	Yes	C	U	Personal Visit/Phone
Transaction Content	Broad specification: early ideas on features and functionality						
Expert Sys. Community	A/M	I	T	No	C	U	Conferences/ Journals
Transaction Content	Technical/theoretical inputs into building expert-systems						
Various Users	I	I	O	Yes	C	U	Personal Visit/Exhibit.
Transaction Content	Feedback on product performance through usage and input into new features and functionality						

ARM RISC Microprocessor

Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Chip Community	A/M	I	T	No	C	U	Conferences/ Journals
Transaction Content	Ideas for designing new type of microprocessor based on RISC instruction-set of Stanford/Berkeley Universities						
Cambridge Uni. Prof.	A	I	O	No	C/S	M	Personal Contact
Transaction Content	Reviewed late proto-type design of RISC microprocessor						

Backlite							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Two Bangor Uni. Profs.	I	F	T	Yes	C/S	I	Personal Visits
Transaction Content		Technical advice, testing of product with expensive analyser, and optimisation of design					
Friend/ Ford employ.	A	I	O	Yes	C/S	I	Personal Contact
Transaction Content		Tuning of antenna for operation with the then new Ford Orion model					
Canned Draught Guinness							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Plastics Supplier	I	F	T	Yes	M	U	Direct Contact
Transaction Content		Design of plastic insert					
Design Consultant	I	F	O	Yes	S/C	U	Contact/ Reports
Transaction Content		Design and evaluation of some 100 alternatives relative to the internally designed solution					
Carboplatin							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Cancer Scientists	M/A	I	T	No	C	I	Conferences/ Journals
Transaction Content		Relevant findings of other research work diffused around scientific network. Thoughts on carboplatin project.					
Chemistry Scientists	A/I	I/F	T	No	C	I	Conferences/ Journals
Transaction Content		Relevant findings of other research work diffused around scientific network. Thoughts on carboplatin project.					

Royal Mars. Clinicians	I/A	F	T	No	S/C	I	Personal Contact
Transaction Content	Field-trials of drug: feedback concerning tests of various dosages and in various combinations with other drugs						
Cancer Clinicians	I/A	I	T	No	S/C	I	Contact/ Reports
Transaction Content	Field-trials of drug: feedback concerning tests of various dosages and in various combinations with other drugs						
			Condor Rucksack				
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Think-Tank/ Friends	A/I/ M	F	T	No	C/S	I	Meetings/Per-sonal Visits
Transaction Content	Product blue-print from personal experience, continuous input and feedback on design, and performance testing						
Test-Team/ Friends	A/I/ M	F	T	No	C/S	U	Meetings/ Visits/Reports
Transaction Content	Formal (standard report) feedback of performance and utility of rucksack from vigourous usage						
Prof. User Network	A/M	I	T	No	C	U	Personal Visits
Transaction Content	General input into features and product performance						
General Users	-	I	O	No	C	M	Exhibitions/ Spon. Events
Transaction Content	General input into features and product performance						
Materials Supplier	I	F	T	No	C/M	I	Personal Visits
Transaction Content	Design of special water and wear resistant fabric for rucksack to meet stringent performance criteria						
Mouldings Supplier	I	F	T	No	C/M	U	Personal Visits
Transaction Content	Design of new buckle for rucksack to meet certain performance and utility requirements						
Lough. Uni. Professor	I	F	O	Yes	C/S	U	Visit/Phone/ Report
Transaction Content	Report detailing optimisation of ergonomic design of rucksack for intended usage						

Manchester Poly. Prof.	I	F	O	Yes	C/S	U	Visit/Phone/ Report
Transaction Content	Report detailing results of performance testing of fabric and sewing/seams						
Fashion Designer	I	F	T	Yes	C/S	U	Personal Visits
Transaction Content	Industrial design drawings of rucksack						
Diflucan							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Academic Consultants	A/I	F	T	No	C/S	U	Meetings/ Reports
Transaction Content	Early input into the idea-generation process, in relation to both features of the drug and direction of research						
Research Community	A/M	I	T	No	C	U	Conferences/ Journals
Transaction Content	Relevant findings of other research diffused around scientific network. Thoughts on Diflucan project.						
Hospital Clinicians	I	F	T	Yes	S/C	I	Reports/ Contact
Transaction Content	Field-trails of drugs						
Fungal Drug Competitors	-	-	-	-	-	M	Patents/ Reports
Transaction Content	Features and technical background to existing products on the market to review approach and ensure uniqueness						
DVA-4000							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Apple Computer	I	F	O	Yes	C	M	Phone/ Contact
Transaction Content	Privileged information concerning hardware specifications of existing and forthcoming Apple computers						

E70A LCD Mixture							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
DRA # Partner	# I/M	F	T	No	C/M/S	C	Intense Contact/Phone
Transaction Content		Critical input in relation to theoretical physics/modelling concerning the properties of various LCD mixtures					
Hull Uni. Prof.	I/A	F/I	T	No	C/M	U	Direct Contact/Reports
Transaction Content		Formal development of a couple of minor compounds to Merck specification. Informal technical input					
Sheff./South./ Mancs. Uni.	I/A	F/I	T	No	C/S	U	Direct Contact/Reports
Transaction Content		Small number of fundamental science projects funded by Merck, yielding background info. Informal technical input					
LCD Club	A/M/I	F	T	No	C	U	Meetings/ Reports
Transaction Content		Information concerning existing projects in field and feedback on E70A project					
Customers	I	I	O	No	C	U	Customer Visit/Phone
Transaction Content		Information concerning the applications of the new mixture and variations required of the original mixture					
Elektra							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Lead User (Philips)	I/A	I	T	No	C/S	I	Direct Contact/Phone
Transaction Content		Input into initial product blue-print, and multiple & continuous feedback of various prototype (alpha/beta) versions					
Lead Users (about 10)	I/A	I	T	No	C/S	U	Direct Contact/Phone
Transaction Content		Feedback concerning performance and features of late prototype (beta) versions					

Technical Consultant	I/A	F	T	No	C/M	U	On-Site Work Visits
Transaction Content	Input into theoretical mathematics and physics in relation to modelling magnetic fields						
Magnet Community	M/A	I	T	No	C	U	Conference/ Phone/Jour.
Transaction Content	Input into theoretical modelling of magnetic fields and from research into specific idiocryncracies of magnetism						
Users/User Group	I/A	F	T	No	C	U	Phone/User Meetings
Transaction Content	Feedback regarding the performance of software in obscure situations and ideas for future features						
Fastrac							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Expert User-Panel: 5 usrs	I	F	T	Yes	C/S	I	Meetings On-Site
Transaction Content	Established blue-print for product, including mechanical performance and comfort						
AGAS Erg-onmics Div.	I	F	O	Yes	C/S	U	Report
Transaction Content	Optimal ergonomic layout of the cab for the given specification						
Components Supplier	I	I	O	No	C	M	Literature/ Phone
Transaction Content	Information concerning tolerances of various components						
Other Equip. Producers	I	I	O	No	C	M	Literature/ Phone
Transaction Content	Information concerning the specifications of add-on equipment to Fastrac by other suppliers						
Selected Users	I	I	T	Yes	C/S	I	Evaluator Panels
Transaction Content	Feedback concerning mechanical performance and features following extensive field-trials (upto 2 months)						
General Users	-	I	O	No	C	M	Exhbitions/ Demos
Transaction Content	General feedback concerning specification						

First-Sense							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Teaching Community	A	I	T	No	C	M	Conferences/ Visits/Exhit.
Transaction Content	Information concerning requirements and changes in the science curriculum: input to range of sensors required						
Design Consultant	I	F	T	Yes	C/S	U	Drawings/ Meeting
Transaction Content	Undertook the industrial product design providing drawing following own research of design features with children						
Two College Lecturers	I/A	F	O	Yes	C/M	U	On-Site Meetings/Post
Transaction Content	Wrote the First-Sense product manual for use by primary school children and teachers						
Software Consultant	I	F	T	Yes	C/M	I	On-Site Meetings
Transaction Content	Software for First-Sense written on a variety of computer platforms: Apple, Acorn, IBM compatiable & BBC micro						
Primary Tea-chers/Friends	A/M	I	T	No	C/S	U	Classroom/ School Visits
Transaction Content	Input concerning equipment available to primary schools, range of sensors & time for use, & field-trial observations						
Primary Sch. Children	-	I	O	Yes	C/S	U	Classroom Field-Trials
Transaction Content	Feedback concerning the ease of use of the sensors, software & manuals. Ideas for other features.						

Flexilink							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Existing Customers	I/A	I	T	No	C	M	Personal Contact
Transaction Content	Input concerning the need for a product that was easier to install and cheaper						

Plastics Supplier	I	F	T	Yes	M	M	On-Site Contact
Transaction Content	Design and production of the plastic moulding of the product to the specification of Pilkington Comms.						
Hydro-Probe							
Actor	Tie-Type	Form -ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Pascal Scientific Ltd	I	F	T	Yes	M	C	Personal Contact
Transaction Content	Design and development of control equipment for Hydro-Probe to Hydronix specification						
Technical Consultant	I/A	F	T	No	C	U	Contact/ Phone
Transaction Content	Technical information concerning the application of micro-wave technology						
Ceramic Supplier	I	F	T	Yes	C/M	I	On-Site Visit
Transaction Content	Series of refinements to the ceramic head of the product						
Design Consultant	I/A	I	T	No	C/S	U	Contact/ Drawings
Transaction Content	Industrial product design of the Hydri-Probe						
English China Eng.	I	I	O	Yes	C/S	I	Phone/ Report
Transaction Content	Feedback following a systematic and thorough testing of Hydro-Probe under varied industrial conditions						
General Users	-	I	O	Yes	C	U	Phone/ Exhibitions
Transaction Content	Feedback following usage: concerning features, performance and conditions of product failure						
Mancs. Poly Academic	I	F	T	Yes	C	U	Visit/ Report
Transaction Content	Gap-filling science project sponsored by Hydronix yielding greater understanding of background micro-wave theory						

Isoview 3							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Lead Users	I/A	I	T	No	C/S	I	Personal Con-tact/Phone
Transaction Content	Important feedback to initial product blue-print but limited feedback during beta-site testing						
Standards Bodies	I	F	T	No	C	I	Std. Meetings /Documents
Transaction Content	International standards for data communication between computers (influenced by 3Com through membership)						
General Users	I	I	T	No	C	U	Demos/ Visits
Transaction Content	Specific feedback on user-interface of pre-development mock-up screen demos, and feedback from earlier versions						
Competitor Engineers	I/A	I	T	No	C	M	Std. Meetings /Exhibitions
Transaction Content	Features and performance of existing and forthcoming competitor products as benchmark for Isoview 3						

Linear Actuator							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Cetrek (Customer)	I/A	F	T	No	C	U	Personal Contact
Transaction Content	Provision of initial need/requirement and feedback from field-testing of late prototype versions						
Component Supplier	I/A	I	O	No	C	M	Phone/ Literature
Transaction Content	Information concerning tolerances of certain materials and components						

MotorMonitor							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Robert Gordon Uni.	A/I	I	T	No	C/S	C	Personal Contact/Phone
Transaction Content	Multiple and continuous input throughout project, initially theoretical and later trouble-shooting specific problems						
Distributor (Entek)	I/A	F	T	Yes	M	C	Visits/Phone/ Meetings
Transaction Content	Provision of first version of the software, developed with multiple & continuous application input from Inspec/RGU						
Lead Users (about 10)	I/A	I	T	No	C/S	I	Personal Contact/Phone
Transaction Content	Feedback on features and performance of beta-versions and a few suggestions to solving specific problems						
Users/User Group	I	I	O	No	C/M	I	Visits/User Grp Meetings
Transaction Content	Sample of worn m/cs to build-up knowledge-base & test theory. Feedback on features & performance from usage						

MRC-500							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Camb. Uni. Biologist	A/I	I	T	Yes	M/C	I	Working On-Site
Transaction Content	Input into refinement of the mechanical and optical design of the MRC-500 over a period of some time						
Ex-Phd of Inventor	A	I	T	No	M	I	Working On-Site
Transaction Content	Provision and refinement of the control software, designed interactively with the inventor as requirements changed						
Component Supplier 1	I	F	T	Yes	M/C	C	Factory Visits
Transaction Content	Provision of the image processor), developed to the specification of the inventor and interactively						

Component Supplier 2	I	F	T	Yes	M/C	C	Factory Visits
Transaction Content		Provision of the scanner control electronics, developed to the specification of the inventor and interactively					
MRC Alum./ Scientists	A/M	I	T	No	C/M	U	Conferences/ Phone/Visit
Transaction Content		Feedback on early prototype performance and ideas for additional features. Later provision of add-on prototypes					
Nicam 728							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Technical Community	I/A/ M	I	T	No	C	M	Conferences/ Visit/Phone
Transaction Content		Relevant technical information concerning broadcasting electronics, with some feedback regarding Nicam project					
Receiver Supplier	I	F	O	No	M	U	Meetings
Transaction Content		Enchancement to receiver to specification of BBC development team					
On-line Tape Certification System							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Applied Mag (Supplier)	I	I	T	Yes	C/M	U	On-Site Visits
Transaction Content		Provision of basic information on computer storage medium and several versions of ceramic reader-head					
Control Data Eng. (Cust.)	I	F	T	Yes	C/M	U	On-Site Visits/Phone
Transaction Content		Input on features of product, some ideas on solutions to certain problems, and faulty tapes for testing prototype					
Friend at CEGB	A	I	O	No	M	U	Phone
Transaction Content		Loan of expensive high-speed scopes for testing of prototypes of innovation					

Technical Consultant	I/A	F	T	No	C	U	Personal Contact/Phone
Transaction Content		Technical input concerning the required electronics and some trouble-shooting of electronic problems					
Peboc Pharmaceutical Intermediate Process							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
ICI Pharm. (Customer)	I	F	T	No	C	M	Meetings/ Phone
Transaction Content		Constraints indirectly imposed on the process features by the various demands of the customer on the end-product					
Bangor Uni. Project Team	I/A	F	T	No	C/S	M	Phone/Visit Lab. or Uni.
Transaction Content		Results from a small number of minor chemical tests related to the process. Ideas to solve problems encountered					
Research Community	I/A/ M	I	T	No	C	M	Conferences/ Visit/Phone
Transaction Content		Various minor inputs to the direction of the project and ideas to solving various problems with the chemistry					
Polifold							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Plastics Supplier	I	F	T	Yes	M/C	M	On-Site Visits
Transaction Content		Provision of variety of plastic strips to provide support for the roof covering material					
Existing Customers	I/A	I	T	No	C	M	On-Site Visits
Transaction Content		Feedback of the problems of installing and using existing competitor soft-roof products gave initial ideas & impetus					
Sister Hire Firm Custs.	I	I	O	No	C/S	U	Questionnaire
Transaction Content		Feedback from tough usage of a series of pre-production prototypes on hire vehicles led to a series of refinements					

Pullman Series							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Existing Customers	I	I	O	No	C	M	Questionnaire
Transaction Content	Feedback concerning performance of existing range of products and suggestions for new features						
Materials Supplier	I	F	T	No	C/M	M	On-Site Visit/ Literature
Transaction Content	Information and samples of materials to meet Portakabin/ pan-European specification regulations						
Euro. Regul-ation Expert	I/A	I/F	T	No	C	U	Personal Con-tact/Phone
Transaction Content	Interpretation of existing European regulations						
Uni. Insul-ation Expert	I/A	F	O	No	C/S	U	On-Site Visits/Report
Transaction Content	Feedback from rigourous laboratory and stimulation tests of materials and overall product insulation performance						
Pyrethroid Insecticides							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Two Top Consultants	I/A	F	T	No	C	U	Personal Con-tact/Phone
Transaction Content	Expert advice concerning direction of chemical research and suggestions for problems encountered during project						
Research Community	I/A/ M	I	T	No	C	U	Conferences/ Phone/Journal
Transaction Content	Relevant findings from other research in field, feedback on project and many ideas on mass production of chemical						
US Uni. Agric. Dept.	I	F	O	No	C/S	U	US Visits/Fax Phone/Report
Transaction Content	Organisation of network of field-test stations in North & South America, field-test results & feedback from farmers						

Puraspec							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
New/Potent. Customers	I	I	O	Yes	C	U	Customer Visits
Transaction Content		Specifications of process arrived at by determining customer requirements. Early feedback from usage					
Research Community	I/A/M	I	T	No	C	M	Conferences/ Journals
Transaction Content		Minor input in relation to other research findings & contribution to approach but generally an unpopular field.					
Scimitar H							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Component Supplier 1	I	I	T	Yes	C/M	I	On-Site Visit/Phone
Transaction Content		Provision of key-pad to Marconi team specification and developed interactively with team					
Component Supplier 2	I	I	T	Yes	C/M	I	On-Site Visit/Phone
Transaction Content		Provision of electronic relays to Marconi team specification and developed interactively with team					
Component Supplier 3	I	I	T	Yes	C/M	I	On-Site Visit/Phone
Transaction Content		Provision of LCD frequency display to Marconi team specification and developed interactively with team					
Royal Signals (Brit. Army)	I	F	O	No	C	U	Visit to Army Establishment
Transaction Content		Feedback following demonstration of prototype by Marconi engineers and usage by RS engineers					
Technical Community	I/A/M	I	T	No	C	M	Conferences/ Journals
Transaction Content		Relevant technical findings and feedback concerning specific problems with specific components					

Shielded Magnet							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Technical Consultant	I/A	F/I	O	No	C	I	Phone/ On-Site Visits
Transaction Content		Highly technical input concerning problems related to product design and magnetic field distortions					
Magnet Community	I/A/ M	I	T	No	C	U	Conferences/ Journals
Transaction Content		Relevant findings of research and feedback concerning project direction and specific problems encountered					
Compet. Eng (Total of 4)	I/A	I	T	No	C	M	Conferences
Transaction Content		Information concerning parameters and specification of existing & forthcoming competitor products					
Supplier	I	I	O	No	C/M	M	Phone/ Literature
Transaction Content		Available material specifications					

Stripper-Head							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Silsoe Res. Institute	I	F/I	T	No	C/S	C	Meetings/ Reports
Transaction Content		Licensing of plastic teeth design developed by SRI and lab. performance testing of early prototypes					
Plastics Supplier	I	F	T	Yes	C/M	I	On-Site Visits
Transaction Content		Iterative refinement of the plastic material employed for the teeth following field-testing					
Small Group of Farmers	I/A	F/I	T	No	C/S	C	Farm Visits/Phone
Transaction Content		Series of prototype versions tested over a period of four years providing critical performance feedback					

European Distributor	I	F	O	Yes	C	U	On-Site Visits/Phone
Transaction Content		Acted as liaison with non-English speaking farmers to channel back specifications required for local conditions					
ADAS	I	F	O	No	C/S	U	Phone/ Report
Transaction Content		Feedback from benck-mark performance test of early production models by official agricultural body					
Studio 9000							
Actor	Tie-Type	Form -ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Existing Lead Customers	I/A	I	T	No	C	M	Customer Site Visits
Transaction Content		Requirements in terms of features and performance, which was input into early project specifications					
Symphony							
Actor	Tie-Type	Form -ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Materials Supplier	I	F	T	Yes	M/C	I	On-Site Visits/Phone
Transaction Content		Provision of series of film materials developed iteratively to properties specified by Simcare after each field-test					
Small No. of Stoma Nurses	A/M	I	T	No	C	U	Hospital Visits/Phone
Transaction Content		Input of professional experience in terms of required properties. Suggestion of particular patients for field-tests					
Selected Stoma Pats.	I/M	I	T	No	C/S	I	Hospital Visits/Forms
Transaction Content		Detailed feedback of product usage. Iterative field-testing/ product refinement with patients experiencing problems					

Synon/2							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Lead User (CityBank)	I/A	F	T	Yes	S/C	I	
Transaction Content		Iterative beta-testing of software: fixing bugs as located & updating beta software. Input on performance & features					
Developers at IBM	A	I	T	Yes	C	U	Conferences/ Phone/Exhib.
Transaction Content		Input concerning technical specifications of existing and future IBM machines and operating systems					
Existing Users	I	I	T	Yes	C	U	Exhibitions/ Phone
Transaction Content		Post-commericalisation feedback on performance and ideas for new features in subesquent software versions					
Town & Country III							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Component Supplier	I	F	T	Yes	M/C	I	On-Site Visits
Transaction Content		Provision of specialised speed control system for downhill driving: an important product differentiator					
Design Consultant	I/A	F	T	Yes	C/S	U	On-Site Visits
Transaction Content		Iterative industrial product design as specification of product evolved through field-tests					
Dutch Distributor	I	F	T	Yes	C	I	Phone/ Literature
Transaction Content		Info. on strict Dutch govt. regulations dictating min. spec. Also feature ideas eg. lights, indicators, main. free battery					
Friends/Dis-abled Users	A/I	I/F	T	No	C/S	U	Home/Site Visits
Transaction Content		Early input into requirements and feedback from field-tests on early prototypes					

Local Disabled Orgns.	I/M	I	O	Yes	C	U	Group Visits
Transaction Content		Feedback on features and performance of late prototypes					
General Users	-	I	O	Yes	C	U	Exhibitions/ Phone/Site
Transaction Content		Feedback on difficulties of usage with specific disabilities. Ideas for features eg. puncture-free tyres & plug position					
Competitors	-	-	-	-	-	-	Exhibitions/ Literature
Transaction Content		Performance and feature specifications of competitor products as a bench-mark to exceed					
Water-Mains Refurbishment System							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Water Research Centre	I	F	O	No	S	C	Meetings/ Report
Transaction Content		Critical accelerated age testing of epoxy resin water-pipe coating to ensure to adverse toxicological effects					
Electronics Supplier	I	F	T	Yes	M/C	I	On-Site Visits
Transaction Content		Provision of electronic components to pipe-lining equipment developed in-house					
Material Supplier	I	I	O	Yes	C	M	Phone/ Literature
Transaction Content		Information concerning properties and performance of a range of materials and resins					
Toxicologist Consultant	I	F	O	No	S/C	U	On-Site Visit/ Report
Transaction Content		Preliminary toxicology test of short-listed materials for lining water-pipes					
3/4 Friends/ Water Engs.	A	I	T	No	M	M	In Situ/ Phone
Transaction Content		Usage of disused water-pipes of various water companies allowing initial prototype testing of lining equip. & resin					

Xenos							
Actor	Tie-Type	Form-ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Electronics Supplier	I	F	T	Yes	S/M	C	Meetings/ Phone
Transaction Content		Provision of the critical programmable chip component tof Xenos, designed to specification of Neen Pain					
Cambridge Consultants	I	F	T	Yes	S/M	U	Meetings/ Drawings
Transaction Content		Iterative industrial design of product, in particular to ensure compatiability with batteries world-wide					
Uni. Pain Consultant	I	F	T	No	C	U	Personal Con-tact/Phone
Transaction Content		Specialised tacit knowledge of application of electrical pulses to relieve pain					
Friends/Pain Specialists	I/A/ M	I	T	No	C	U	Pain-Clinics/ Phone
Transaction Content		Ideas for features from experience eg. tactile nature of buttons & self-setting. Suggestion of patients for field-tests					
Pain Clinic Community	I/M	I	T	No	C	M	Pain-Clinics/ Phone
Transaction Content		General feedback of post-commercial product of performance and features					
Friends/ Users	A/I	I	T	No	C/S	U	On-Site
Transaction Content		Field-tests of prototypes limited only to friends suffering pain in order to maintain secrecy and keep R&D costs low					
Competitors	-	-	-	-	-	M	Exhibitions/ Literature
Transaction Content		Performance and feature specifications of competitor products as a bench-mark to exceed					

Yeoman							
Actor	Tie-Type	Form -ality	Sym-metry	New Link	Trans. Type	Trans. Value	Exchange Mechanism/s
Supplier	I	I	T	Yes	M/C	C	Factory Visits/Phone
Transaction Content	Design of digitising table to Yeoman specification						
Design Consultant	I	F	T	Yes	C/S	U	Meetings/ Phone
Transaction Content	Industrial design drawings of product						
Lead User/ Friend	A/I	I	T	No	C/S	I	Meetings at Club/Pub
Transaction Content	Extensive testing of prototype including obscure features in planning race routes for the Royal Thames Yacht Assoc						
Yachting Friends	A	I	T	No	C/S	I	On Board Yachts!
Transaction Content	Good feedback on user-interface. Able to modify software interactively on-board. Used friends to maintain secrecy						
Boating Journalists	I/A	F/I	T	No	C	M	Phone
Transaction Content	Feedback on features and performance of pre-production models of Yeoman						

KEY:

Tie-Type	I = Instrumental A = Affective M = Moral	Transaction -Type	C = Cognitive M = Material S = Service
Formality	I = Informal F = Formal	Transaction -Value	C = Critical I = Important U = Useful M = Minor
Symmetry	O = One-way T = Two-wayy		

TABLE A.6: The Stimuli of the Innovation Projects in the Study

Need-Stimuli			
Explicit Market-Need	Perceived Market-Need	Internal Technical-Need	Internal Business-Need
E70A LCD Mixture	Backlite	ARM RISC Microprocessor	Condor Rucksack
Flexilink	Canned Draught Guinness	MRC-500	Scimitar H
Isoview 3	Diflucan	Nicam 728	Shielded Magnet
Linear Actuator	Fastrac	Peboc Process	
On-line Tape Cert. System	Pullman Series		
Polifold	Synon/2		
Symphony	Xenos		
Town & Country III	Yeoman		
Water-Mains Refurb. System			
Means-Stimuli			
Science-Push	Internal Technology-Push	External Technology-Push	Technology Application
Carboplatin	Elektra	MotorMonitor	Amethyst
Pyrethroid Insecticides	Hydro-Probe	Stripper-Head	DVA-4000
	Puraspec		First-Sense
	Studio 9000		

TABLE A.7: The Exchange Value of External Inputs and their Role in the Innovation Process by Locus-Type

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Amethyst								
Features	U				C			C
Solutions			U					U
Field-Tests	U				C			C
Overall	U		U		C			C
ARM RISC Microprocessor								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			M					M
Solutions			U					U
Field-Tests			M					M
Overall			U					U
Backlite								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions	U		U					U
Field-Tests	I		I					I
Overall	I		I					I
Canned Draught Guinness								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions				U				U
Field-Tests				M				M
Overall				U				M
Carboplatin								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features						U		U
Solutions			I					I
Field-Tests						I		I
Overall			I			I		I

Condor Rucksack

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions		I	U	U				I
Field-Tests	I		U					I
Overall	I	I	U	U				I

Diflucan

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			U			U	M	U
Solutions			U					U
Field-Tests						I		I
Overall			U			I	M	I

DVA-4000

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions				M				M
Field-Tests								
Overall				M				M

E70A LCD Mixture

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests			U					U
Overall	U		U					U

Elektra

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U	U				U
Field-Tests	I							I
Overall	I		U	U				I

Fastrac

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions		M		U				U
Field-Tests	I							I
Overall	I	M		U				I

First-Sense

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U					U		U
Solutions		I		U				I
Field-Tests	U					U		U
Overall	U	I		U		U		I

Flexilink

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions		M						M
Field-Tests	M							M
Overall	M	M						M

Hydro-Probe

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		C	U	U				C
Field-Tests	I							I
Overall	I	C	U	U				C

Isoview 3

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I						M	I
Solutions								
Field-Tests	U							U
Overall	I						M	U

Linear Actuator

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		M						M
Field-Tests	M							M
Overall	U	M						U

MotorMonitor

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions	U		C		C			C
Field-Tests	I							I
Overall	I		C		C			C

MRC-500								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U		U					U
Solutions	U	C	I					C
Field-Tests	U		U					U
Solutions	U	C	I					C
Nicam 728								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			M					M
Solutions		U	M					U
Field-Tests								
Overall		U	M					U
On-line Tape Certification System								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions	U	U		U				U
Field-Tests	M							M
Overall	U	U		U				U
Peboc Pharmaceutical Intermediate Process								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions			M					M
Field-Tests			M					M
Overall	M		M					M
Polifold								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions		M						M
Field-Tests	U							U
Overall	U	M						U
Pullman Series								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M			U				U
Solutions		M	M					M
Field-Tests			U					U
Overall	M	M	U					U

Pyrethroid Insecticides

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions			U	U				U
Field-Tests	U							U
Overall	U		U	U				U

Puraspec

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			M					M
Field-Tests	M							M
Overall	U		M					U

Scimitar H

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		I	M					I
Field-Tests	M							M
Overall	U	I	M					I

Shielded Magnet

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			U				M	U
Solutions		M	U	I				I
Field-Tests								
Overall		M	U	I			M	I

Stripper-Head

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I		U		U			I
Solutions		I	C	U				C
Field-Tests	C		I					C
Overall	C	I	C	U	U			C

Studio 9000

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions								
Field-Tests								
Overall	M							M

Symphony								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U					U		U
Solutions		I						I
Field-Tests	I							I
Overall	I	I				U		I

Synon/2								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests	I							I
Overall	I		U					I

Town & Country III								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I				I		U	I
Solutions		I		U				I
Field-Tests	U							U
Overall	I	I		U	I		U	I

Water-Mains Refurbishment System								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								I
Solutions		I						I
Field-Tests	M		C	U				C
Overall	M	I	C	U				C

Xenos								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features						U	M	U
Solutions		C	U	U				C
Field-Tests	U							U
Overall	U	C	U	U		U	M	C

Yeoman								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		C		U				C
Field-Tests	I							I
Overall	I	C		U				C

KEY: C = Critical Input to Innovation
I = Important Input to Innovation
U = Useful Input to Innovation
M = Minor Input to Innovation
= No Input to Innovation

TABLE A.8: The Exchange Value of Informal Boundary-Spanning Dyads and their Role in the Innovation Process by Locus-Type

Amethyst

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests	M							M
Overall	U		U					U

ARM RISC Microprocessor

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			M					M
Solutions			U					U
Field-Tests			M					M
Overall			U					U

Backlite

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions	U							U
Field-Tests	I							I
Overall	I							I

Canned Draught Guinness

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions								
Field-Tests								
Overall								

Carboplatin

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features						U		U
Solutions			U					U
Field-Tests						U		U
Overall			U			U		U

Condor Rucksack

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions								
Field-Tests	U							U
Overall	U							U

Diflucan

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			U					U
Solutions			U					U
Field-Tests						M		M
Overall			U			M		U

DVA-4000

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions								
Field-Tests								
Overall								

E70A LCD Mixture

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests								
Overall	U		U					U

Elektra

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests	I							I
Overall	I		U					U

Fastrac

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions		M						M
Field-Tests	I							I
Overall	I	M						I

First-Sense

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U					U		U
Solutions								
Field-Tests	U					U		U
Overall	U					U		U

Flexilink

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions		M						M
Field-Tests	M							M
Overall	M	M						M

Hydro-Probe

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		U						U
Field-Tests	I							I
Overall	I	U						I

Isoview 3

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I						M	I
Solutions								
Field-Tests	U							U
Overall	I						M	U

Linear Actuator

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions		M						M
Field-Tests								
Overall		M						M

MotorMonitor

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions	U		C					C
Field-Tests	I							I
Overall	I		C					C

MRC-500

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U		U					U
	U		I					I
Field-Tests	U		U					U
Solutions	U		I					I

Nicam 728

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			M					M
Solutions			M					M
Field-Tests								
Overall			M					M

On-line Tape Certification System

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions		U						U
Field-Tests								
Overall		U						U

Peboc Pharmaceutical Intermediate Process

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions			M					M
Field-Tests								
Overall			M					M

Polifold

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions								
Field-Tests	M							M
Overall	M							M

Pullman Series

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions								
Field-Tests								M
Overall	M							

Pyrethroid Insecticides								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions			U					U
Field-Tests								
Overall			U					U

Puraspec								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			M					M
Field-Tests	M							M
Overall	U		M					M

Scimitar H								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions		I	M					I
Field-Tests								
Overall		I	M					I

Shielded Magnet								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features			U				M	U
Solutions		M	U	M				U
Field-Tests								
Overall		M	U	M			M	U

Stripper-Head								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	I							I
Solutions			U					U
Field-Tests	I							I
Overall	I		U					I

Studio 9000								
Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	M							M
Solutions								
Field-Tests								
Overall	M							M

Symphony

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U					U		U
Solutions								
Field-Tests	I							I
Overall	I					U		U

Synon/2

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions			U					U
Field-Tests								
Overall	U		U					U

Town & Country III

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions								
Field-Tests	U							U
Overall	U							U

Water-Mains Refurbishment System

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features								
Solutions		M						M
Field-Tests	M							M
Overall	M	M						M

Xenos

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features						U		U
Solutions								
Field-Tests	U							U
Overall	U					U		U

Yeoman

Role	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.	Total
Features	U							U
Solutions		C						C
Field-Tests	I							I
Overall	I	C						C

KEY: C = Critical Input to Innovation
I = Important Input to Innovation
U = Useful Input to Innovation
M = Minor Input to Innovation
= No Input to Innovation

TABLE A.9: A Summary of the Diversity of Actors in each Innovation Action-Set and the Exchange Value of their Inputs

Innovation	User	Supp.	Res.	Cons.	Dist.	Prof.	Comp.
Amethyst	U		U		C		
ARM RISC Microprocessor			U				
Backlite	I		I				
Canned Draught Guinness				U			
Carboplatin			I			I	
Condor Rucksack	I	I	U	U			
Diflucan			U			I	
DVA-4000				M			
E70A LCD Mixture	U		U				
Elektra	I		U	U			
Fastrac	I	M		U			
First-Sense	U	I		U		U	
Flexilink	M	M					
Hydro-Probe	I	C	U	U			
Isoview 3	I						M
Linear Actuator	U	M					
MotorMonitor	I		C		C		
MRC-500	U	C	I				
Nicam 728		U	M				
On-line Tape Certification System	U	U		U			
Peboc Process	M		M				
Polifold	U	M					
Pullman Series	M	M	U				
Pyrethroid Insecticides	U		U	U			
Puraspec	U		M				
Scimitar H	U	I	M				
Shielded Magnet		M	U	I			M
Stripper-Head	C	I	C	U	U		
Studio 9000	M						

Symphony	I	I				U	
Synon/2	I		U				
Town & Country lll	I	I		U	I		
Water-Mains Refurb -ishment System	M	I	C	U			
Xenos	U	C	U	U		U	
Yeoman	I	C		U			

KEY: C = Critical Input to Innovation
I = Important Input to Innovation
U = Useful Input to Innovation
M = Minor Input to Innovation
= No Input to Innovation

TABLE A.10: The Attribute Network Types and Strategic Link-Types Employed in the Development Projects in Study

Innovation	Attribute Network Type				
	R&D	Profession	User	Recreation	Friendship
Amethyst	P		L (S)	P	
ARM RISC Microprocessor	O/P				
Backlite	B				P
Canned Draught Guinness					
Carboplatin	O/B	O/B	L (S)		
Condor Rucksack	B			B	
Diflucan	O	B	L (S)		
DVA-4000					
E70A LCD Mixture	O				
Elektra	O		P		
Fastrac			B		
First-Sense		B	B		
Flexilink					
Hydro-Probe					P
Isoview 3					
Linear Actuator					
MotorMonitor	B		P		
MRC-500	O		O		
Nicam 728	O				
On-line Tape Certification System					
Peboc Process	P				
Polifold					
Pullman Series	B				
Pyrethroid Insecticides	O		L (S)		
Puraspec	P				
Scimitar H					
Shielded Magnet	P				
Stripper-Head			L		

Studio 9000					
Symphony		B	L (S)		
Synon/2	P				
Town & Country lll			L (S)	B	
Water-Mains Refurb -ishment System					
Xenos		B	L (S)		
Yeoman				O	

KEY: L = Liaison
B = Bridge
P = Link-pin
O = Overlap
S = Star