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TECHNOLOGY, KNOWLEDGE TRANSLATION AND POLICY: CONCEPTUAL FRAMEWORKS AND CASE-STUDIES

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ABSTRACT

The aim of this thesis is to develop, present and then demonstrate conceptual structures that link together an apparently heterogeneous range of research activity about technology in situations which are the subject of decision-making and policy formulation.

Technology is considered to be knowledge as applied in organisations, communities, policy contexts and so on. It thus takes in not only the physical processes and output of the engineering sciences but also the new forms of organisation which use that output, their impacts on, and interactions with, people at large and with the so-called natural systems in which those people are embedded and with which they also interact.

Methodologically many of the research publications which this thesis incorporates approach technology related issues and problems from the bottom up, from the most microscopic level of the individual human actor, the smallest feasible level of natural and engineered systems. It is an attempt to redress the top down perspectives which dominate technology and science policy formulation and decision making. This approach often requires research interaction at the level of the individual person or at the lowest level of physical and biological activity relevant to the issue at hand and the appropriate techniques for such interaction are debated and demonstrated.

The principles of "translation" or "mapping" which are capable of being applied to a range of interactions between different domains (physically engineered, diverse individuals and knowledge) are developed. The thesis then shows how the representation of responses of people to products and services has evolved and begins to focus on organisations as suppliers of those products and processes.

Technology is articulated as knowledge in the context of technology transfer into organisations and the thesis shows how those ideas evolved into the concept of knowledge dynamics in organisations. The problems of interactions which involve bio-physical systems as well as engineered systems and people and the issues of sustainability and policy relevant research are introduced. The nature of integrative interdisciplinary research about these issues is presented as a form of knowledge dynamics.

The thesis shows how the concepts above can be used to distinguish between policy and decision relevant issues, and how they help to provide a conceptual framework within which the similarities and differences between knowledge policy in organisations and science research policy can be compared. Thus it is a series of interdisciplinary explorations into complex decision and policy relevant situations in which technology, in the form of knowledge and as the study of interaction between the designed physical world, people, organisations and natural systems, is a constant theme.

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FIGURES

CHAPTER 1

1. SCOPE OF THESIS AND CONCEPTUAL TOOLS

1.1 Introduction

This thesis is about technology and how to position an understanding of it in relation to organisations, communities and the natural world. The focus is on the interactions and processes surrounding technology/organisation, technology/ community and technology/natural systems interactions which are the subject of decision-making and policy formulation. Here technology is considered to be applied knowledge; applied in organisations, communities, policy contexts and so on. This use of the word technology serves to distinguish knowledge related perspectives on technology from those which are concerned with engineering, which now more often means designs, mechanisms and infrastructure. This perspective would regard the latter as the physical manifestations of knowledge processes as embodying many different types of knowledge. Technology is thus taken to include interactions which involve that wider range of human knowledge activity which also develops organisations, systems of government, methods, procedures and so on.

Technology, as the study of the technos, thus takes in not only the output of the engineering sciences but also the new forms of organisation which use them, their impacts and interactions with people at large and with the so-called natural systems in which those people are embedded and with which they also interact. In as much as this perspective focuses on the roles and contributions of diverse and idiosyncratic individuals in the workplace it echoes the style of thinking to be found in the work of such writers and activists as Cooley (Architect or Bee?: The Human Price of Technology, 1987) which has influenced a number of our research projects and students.

Technology in these terms can be considered as the study of certain phenomena, the interactions between engineered or designed systems and the social and natural systems. It is concerned with the physical features of designed systems only in as much as they have performance characteristics which are relevant in the respective domains of organisation, community and the natural system environment. As will be seen later it is also helpful to consider some of these interactions as essentially knowledge interactions. The contribution developed in this work uses the conceptual devices, and sometimes the theory, that derives from systems disciplines and application since, as an epistemological device, the notion of systems allows us to examine situations which are essentially interactively complex and which involve social actors as well as physical features.

Since the intention of technology is broadly about generating social utility directly or indirectly for people in their various contexts, this emergent view of technology is about the extent to which knowledge about the performance of designed intervention is necessary, relevant and usable by the potential actors involved. Of course, the products of our industries and commerce, even if well intentioned, often have unintended consequences when used so that often issues of concern involve symptoms of "problems" rather than the design of new products and services. Seen from a complex systems perspective this is hardly surprising, and underlying this thesis is the view that our "designed" world, and the people and organisations which produce or use the output of that world continually interact in new ways to give unexpected outcomes.

The science and engineering worlds have a dynamic of their own which results in products and services which are new to the experiences of the user. They create new opportunities that enable people to reconfigure activities within their lives and to follow new pathways. This is seen within this thesis as an issue of co-evolution. Co-evolution between systems is often only considered at the macroscopic level i.e. at the level of society or community. Such perspectives often do not penetrate the internal world of invention and innovation sufficiently and leave an unbalanced view of the complexity of the interactions that are taking place. Much of the research which this thesis refers to approaches issues and problems from the bottom up, from the most microscopic level of the individual human actor, the smallest feasible level of natural systems and of engineered systems. This attempt to redress the top down perspectives which dominate much of policy formulation and decision making often requires research interaction at the level of the individual person or the lowest level of physical and biological activity relevant to the issue at hand.

The thesis is therefore also about research "method" as a process in which certain activities and associated techniques are brought to bear upon situations which are of concern to people in the world at large. The view that technology itself is about the acquisition of knowledge about certain types of interaction and that knowledge is uniquely associated with human beings forces us to think in terms of people as well as artefacts and machines and about the soft technos; organisations, processes and procedures which they bring to bear in daily life.

The main strands of the approach developed here derive from the exploration of interdisciplinarity and systemic thinking in the context of policy and decision relevant issues. It often involves an attempt to exploit knowledge already available or to identify specific new knowledge which may be needed to support the development of policy or to develop a framework in which decisions can be made. Interdisciplinarity is itself a complex area in that the knowledge agenda of different disciplines which may have a bearing on some situation is almost never the same as the agenda of knowledge required for that situation to be diagnosed, understood and managed by the actors within it and the agencies which operate (or should) on their behalf. The nature of disciplinarity (as it influences the way in which decision and policy relevant issues are addressed) is a significant component of the following debate. But disciplines also revolve around characteristic methods and techniques so that it is not only the conceptual devices and frameworks they offer which are useful but also their influence in obtaining information and data about different types of phenomena.

The systemic influence on this view of technology also introduces the idea that the diversity of individuals and constituencies and their behaviours is what gives rise to desirable and undesirable emergent properties and systems. So research techniques which facilitate interaction with people and about their perceptions are prominent in the research described below. Because this approach considers the processes by which events and changes take place to be at least as important and as complex as analysing configurations and states, it requires the exploration of a number of different perspectives in any policy or decision relevant situation and each exploration may use knowledge and techniques appropriate to that perspective and to a given constituency. This may seen as a multiple paradigm approach, widely used in soft systems methods and in a number of forms of failure and risk analysis. The problem has always been how to link together the insights from each perspective in a formal way and an attempt is made in the following chapters to demonstrate how this may be attempted.

The published papers which make up the substantive research activity for this thesis are multi-authored; indeed, given the points made above, it would be surprising if they were not so. They constitute the territory within which the ideas above are expanded and exemplified according to the rules applying to this thesis. They are papers published jointly by me and my colleagues in journals or at conferences largely between 1992 and 1997. They have been divided into a smaller set of main papers, central to this thesis, and a larger supporting set of papers which explore more detailed aspects of the main themes. The are authored by me either in collaboration with one or more of my colleagues or, on other occasions, with Ph.D. graduates whose work I have directed.

On other, sometimes formal occasions, the author sequence is alphabetic and thus, as in my schooldays, my name may appear later than the extent of my contribution. On other occasions I have helped colleagues, often former PhD students of mine, to extend ideas and concepts by integrating them with their ever increasing knowledge in their own specialist spheres. Reference is made to the substantial contributions made to collective reports (such as our work for DGXII on ARCHAEOMEDES I, 1994) and recent work on Environmental Perception and Policy Making (EPPM, 1997) some of which is not as yet formally published. Use has been made of jointly authored papers where possible to describe these contributions and they have also been placed in context in a more lengthy way in the text. Other research which cannot easily be formally presented but which is central to the arguments stems from research for commercial organisations which is confidential (at least for the present). Since that work is intimately linked to the main lines of thinking in this thesis it has been possible to rework it anonymously into the main body of the text.

What is presented in this thesis is not therefore the more orthodox repertoire of the single disciplinarian operating within a defined knowledge agenda of a discipline but a series of interdisciplinary explorations into complex decision and policy relevant situations in which technology, in the form of knowledge and as the study of interaction between the designed physical world, people, organisations and natural systems, is a constant element.

This body of work, as exemplified by the papers cannot be treated as self-contained. It has a history as well as a future trajectory. It was arrived at as the consequence, and with the influences, of early training and employment as an engineer, of interdisciplinary research and consultancy in the field of Transport Planning and

Technology Assessment over some fifteen years and ten years collaboration with Professor of Technology Policy, Martyn Cordey-Hayes, in developing the Innovation and Technology Assessment group at Cranfield, subsequently merged with the International Ecotechnology Research Centre (IERC).

During ten years of that fifteen I also worked as a teacher for the Open University in the UK as a tutor of systems thinking courses and summer schools. I was alerted to the work of Vickers, Stafford Beer and Checkland as well as the internal developments of the OU Systems Group for whom I also designed systems teaching activities. Current research extends into water recycling technologies and "Sustainable Cities", policy and water issues in Spain and Greece , Knowledge Dynamics in organisations, how owner/managers of small manufacturing companies use their knowledge, and, increasingly, the exploitation of environmental and biological science knowledge in the design of utility technologies, such as Land Fill as a Carbon Storage system, and the combining of small scale bio-ecologies with mechanical and biological processes in the treatment of water and effluent.

The aim of this thesis is to develop, present and then demonstrate a conceptual structure that links together an apparently heterogeneous range of research activity represented by the set of publications . Although the papers have a publication chronology of their own, they need to be grouped in a way which reflects the strands of thinking with which they are associated in the text. A number have been selected as principal papers while the remainder are used in support. The principle papers which need to be read in conjunction with the text are referenced in the text with a suffix A at the point when they should be read and numbered in that sequence. They will be found in the same volume as the text, in Appendix A. The supporting papers have the suffix B on the first occasion that they are referenced and will be found in Appendix B in a separate volume. Reference has necessarily been made to some fifteen Ph.D. theses by researchers in INTA and subsequently in IERC. Most of those noted in the text were supervised by me, though some were supervised in collaboration with or solely by Martyn Cordey-Hayes whose own research has overlapped and substantially influenced my own.

1.2 Interaction and Translation

1.2.1 Introduction

In this thesis the concept of mapping between two attribute domains is central to the development of a method which can be more widely applied than the physical modelling and supply-demand relationships from which it is derived. The family of phenomena to which it is applied have been noted in the introduction. The end result of the many research projects included in or alluded to in this thesis is an extension of this concept of mapping functions. The basic ideas can be applied to issues in which the use of knowledge and how it is translated and transferred between functions in organisations, between organisations, between citizens and organisations and between disciplinary knowledge domains in interdisciplinary issue driven research is central and common to both. While academic research is essentially divergent and driven by an independent agenda the needs of organisations are mainly for convergent knowledge. (This point was originally made by van de Leeuw in personal communication during the course of our interdisciplinary research on EPPM, 1997). The relationship between divergent and convergent knowledge acquisition and exploitation is of interest in the wider contexts of both academic research policy and organisational knowledge management. Research into knowledge dynamics in organisations (Gilbert, Seaton and Cordey-Hayes, 1997) suggests interesting analogies to knowledge dynamics in the research community; (Seaton, 1997).

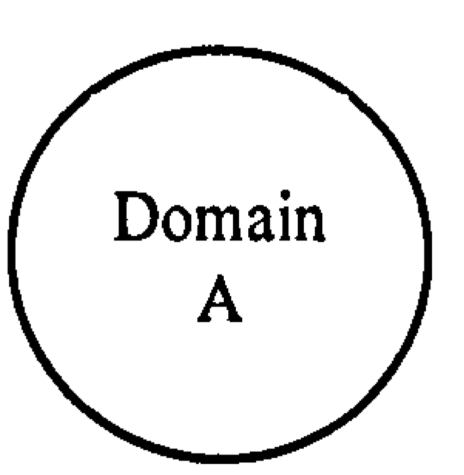
The main contribution of this thesis is to develop this conceptualisation through the demonstration of the contribution of key research as revealed in selected publications. However, to arrive at a conclusion without offering any sense of destination or route from the start would be frustrating for the reader. The intention of this chapter is to offer enough insight for the significance of the subsequent text to be appreciated.

The next section thus develops some of the building blocks about the characteristics of the nature of interactions and translation across and between different domains and extends them to interactions between knowledge domains. For this it uses the results of two parallel research projects which are so recent that they have not been published. One of these IERC projects (for the EU Directorate for Science Research DGXII) was on Environmental Perception and Policy Making (EPPM, 1997). A substantial part of the research involved experiments about interactions between disciplines. The reason for these experiments within the project is the increasing concern about the limited exploitation of science research knowledge in policy formulation and decision making. The second research project is specifically on the issue of "Knowledge Dynamics" in organisations and is based on field work inside operating businesses of a large telecommunication and information service company.

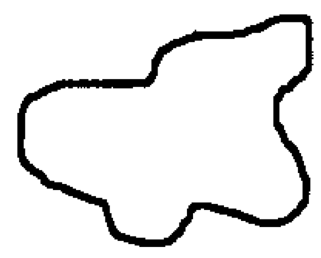
1.2.2 Notation

Where two, or more, domains address a common problem a mapping can be developed between the two. Often this means identifying how the characteristics or attributes of the situation as seen by one domain reveal themselves in the attribute space used by the other domain. Sometimes the mapping can be formalised in an explicit way; as in physical modelling or supply-demand relationships. In organisations and in the policy formulating process where knowledge is the currency it is often characterised by a process of searching for an appropriate mode of discourse (a set of ideas, metaphors, and stories that both domains can relate to and be informed by) and the learning consequent to that. The purpose of much team building is to facilitate this search for an appropriate mode of discourse and to explore the way other people think about an issue from the point of view of their job role.

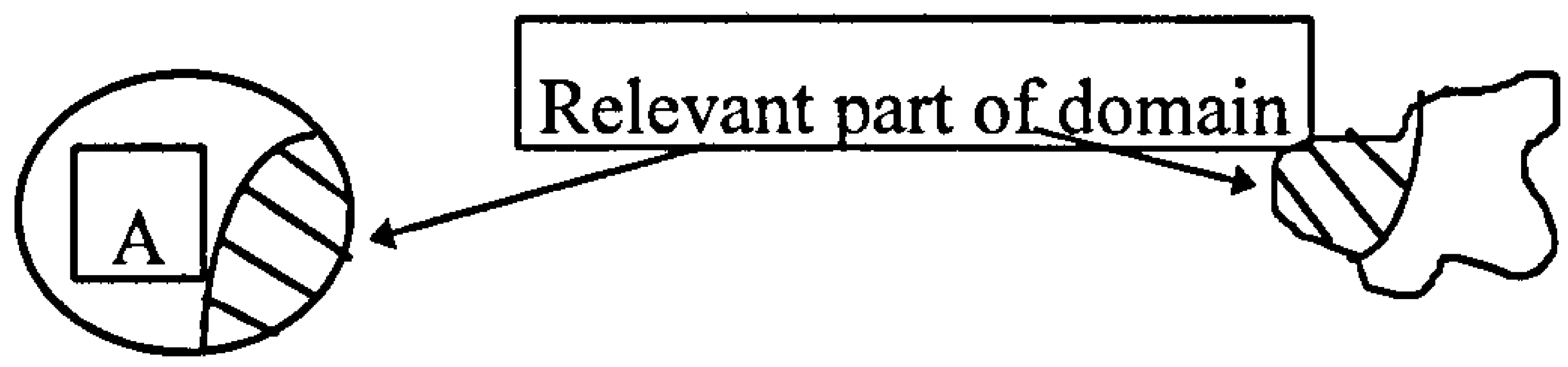
If the domain is in an organisational setting it might be noted as



Equally one of these domains may be outside an issue or an organisation and much more diffused and could be seen as more vaguely and poorly understood



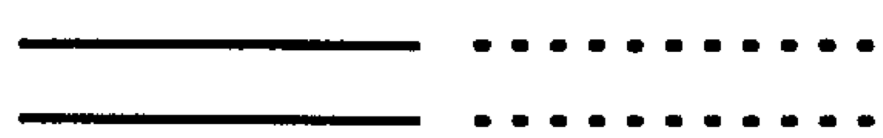
More generally only one part of the total domain whether internal or external will be relevant to a given issue



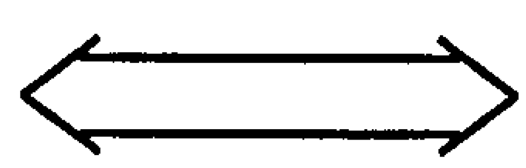
We also know that there is a need for some form of translation between domains which can be noted as:

Where this involves filtering from one to another rather than true interaction it can be modified to, depending on direction

A transfer channel can be shown as below depending on whether it is established or whether it has yet to be established or is inadequate



The transfer, as distinct from translation, can be shown as completed by the addition of arrows thus



1.2.3 Knowledge interactions in organisations

Knowledge translation can be considered as the ability to create a mapping function between one knowledge domain and another. Knowledge transfer is the complementary ability to extract pertinent knowledge from one domain and to apply or deliver the translated knowledge to a recipient. Understanding the "receptivity" (Seaton and Cordey-Hayes, 1993) of this recipient (be it an individual, group, community or organisation) is a precursor to successful knowledge transfer and research by Gilbert (1995), Trott, Cordey-Hayes and Seaton (1995, **B1**), Cordey-Hayes, Gilbert and Trott (1995) and Gilbert, Seaton and Cordey-Hayes (1997), has explored this issue. Successful knowledge translation and transfer requires prior understanding of the knowledge domains between which translation and transfer may take place (how the knowledge is located with respect to existing knowledge and how it might be applied) and the opening of channels between the two parties.

In some organisations, particularly those which do not use much in the way of physical equipment (so-called knowledge based organisations), knowledge translation between knowledge domains (externally and internally) and between individuals within those domains is the crucial issue in knowledge management. At a given level in the organisation common sources of problems in both instrumental and developmental knowledge translation are the failure to be able to identify recipients or to properly develop transfer channels. Translators thus have an imperfect understanding of the receiver's knowledge domain, or cannot properly locate them, or transfer to them within the organisation.

In other types of organisation, particularly those with a strong dependence on technical and physical equipment, in which the routine control function is a larger element in management, vertical knowledge translation is a more dominant problem. Technical competence is, in itself, seldom a source of concern but managing the action and decision spaces within which that knowledge is exploited appears to offer problems of both instrumental and developmental knowledge management as does the facilitation of new instrumental knowledge. The interdependency of functions, each with its own local objectives, performance measures and reward systems also presents problems of prior understanding of instrumental knowledge domains and the development of transfer channels. Often many of the effective operational and instrumental knowledge transfer channels may be informal.

1.2.4 Knowledge: Interdisciplinarity and Policy Relevant Research

The increasing pressure on research to provide immediate and appropriate knowledge for contemporary "problems" has caused many to reconsider the ways theoretically driven research contributes to the long term welfare of our societies. Since much of this research is interdisciplinary in nature, much thought has been given to the ways "disciplines" arise as entities (if indeed they do). We now have a modest body of literature that can be used to inform these considerations. Burrow (1966) drew attention to the social and intellectual processes which gave rise in the 19th Century to the then new disciplines of archaeology and social anthropology. During the 1970's and 80's there was considerable interest in planning for urban regional growth and the social and economic issues surrounding that growth which once again focused attention on the need for interdisciplinarity. More widely, task forces of the supposedly knowledgeable were to be assembled to solve "problems" and the effective management of these was discussed (Chubin et al, 1986 Peacocke, 1985). Also, particularly in the USA, the debate extended to such issues as the curriculum in schools. Interdisciplinarity in the pursuit of new knowledge in the academic world became in itself the subject of academic study. One of the more comprehensive academic treatments of can be found in the earlier writing of Klein (1983).

During the 1960s and 70s research resources were relatively plentiful in Western Europe and the USA and a sense of optimism, options and choice pervaded these societies. In these harder times, resources are more scarce and questions are being asked about the interaction of disciplines in the pursuit of new theoretical knowledge, the application of existing knowledge to newly identified "problems", and the role of interaction between disciplines jointly and individually with the symptoms of new "problems". There is growing evidence of a "gap" between those tasked with the management of these "problems" and the academic sources and processes they have traditionally exploited. While it is perfectly proper to ask penetrating questions about its utility and cost-effectiveness, a strategic understanding of the nature of interdisciplinary research and of the properties of emergent systems seems to be lacking.

There is a danger that financial constraints and political pressure will result in the domination of the intellectually driven research agenda by those who believe they understand the nature of a "problem" either because they have no resources to explore the symptoms or because they wish to impose their own view. People, as individuals and members of communities, institutions and governments may come to look upon academic research as increasingly marginal to their concerns if the need for a diverse knowledge base to deal with future surprises is not explained, when in practice it may have much to offer. Evidence of this breakdown of understanding can be seen in the vogue for an appeal to science after some policy has had unforeseen and undesirable consequences. This suggests a pervading failure of the policy formulating community to use the conceptual devices of emergence, hierarchy, scale etc. in policy and decision relevant situations. If surprise is a normal part of life then unforeseen consequences are to be expected and contingency plans must be made.

Research which is unconstrained by conventional perceptions of "the problem" and the related "policy instruments" provides a diversity of knowledge that can sometimes give prior warning of unforeseen consequences. Perhaps more importantly, this diverse knowledge base can be called upon to develop remedial strategies when "surprises" occur. An exploration of the concept of emergence, innovation and surprise has recently been the subject of research by Hadfield (1997) and in the current ARCHAEOMEDES II programme of research. Such research is part of a growing attempt to understand new phenomena in the field of environmental degradation which arise from the interactions between technological, natural and social systems.

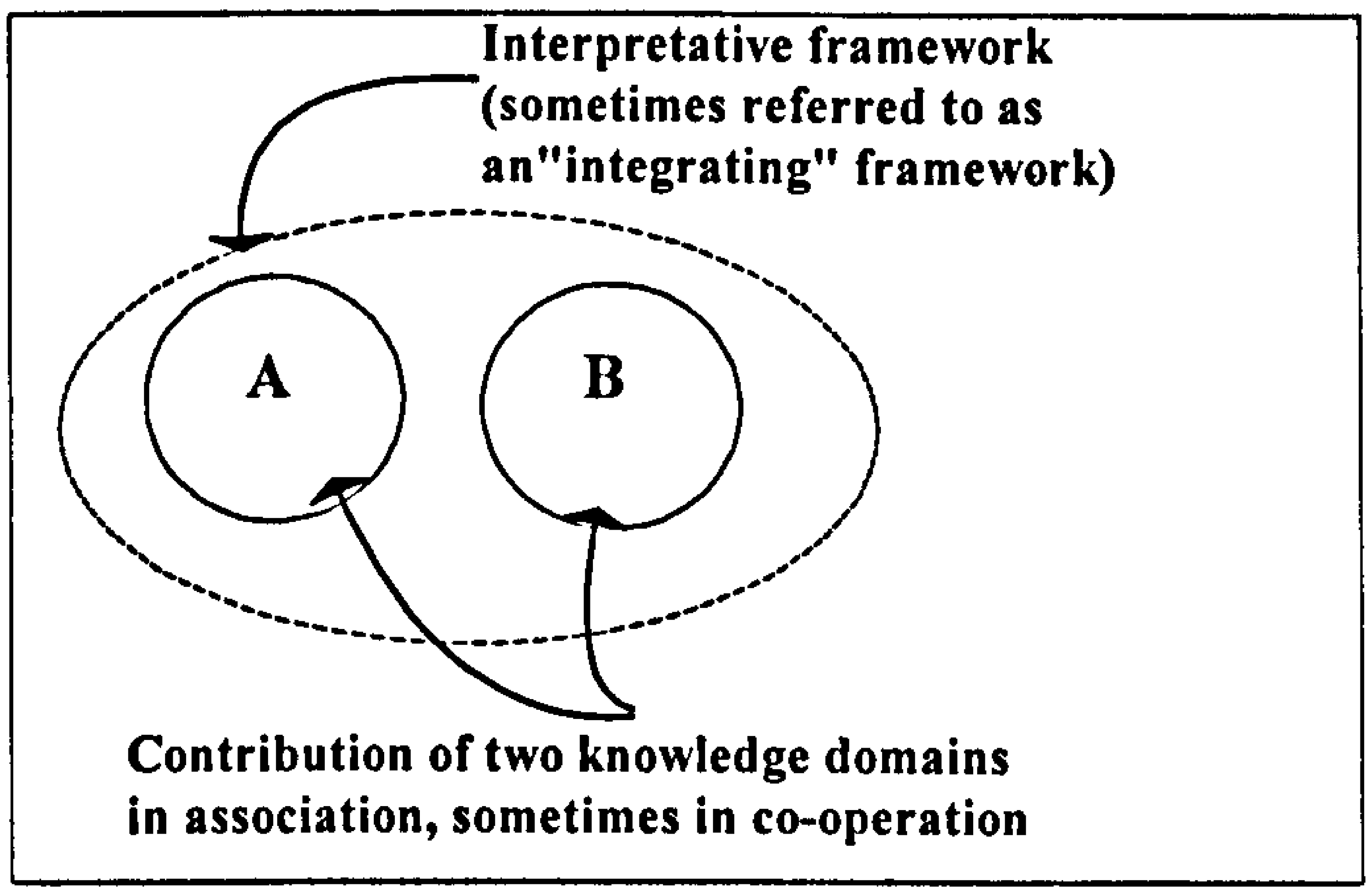
1.2.5 Representing knowledge dynamics as a mapping function

Knowledge Domains

There are close parallels between academic disciplines and business functions and job roles although, as discussed later, the need is for knowledge in organisations to be more convergent i.e. problem solving, while academic theory developing research is often divergent and opportunity creating. In formal organisations two or more people, groups or business *functions* with different knowledge domains may be required to take an interest in the same phenomenon or decision issue either by chance or because of a deliberate intention of a project. Some mechanism is needed to bring together the disparate contributions. Figure 1.1 shows this for a loose association of participants. The more types of knowledge domains involved and the greater the qualitative difference in their approaches, the harder will be the task of integrating their knowledge contributions.

In interdisciplinary research *disciplines* tend to have autonomous domains of knowledge, agendas for knowledge acquisition and internal modes of discourse, methods and techniques. Disciplines are driven by curiosity, discovery and competition for explanation of a class of phenomena. The agenda for new knowledge is set by the discipline's peer group, mostly by its senior members. Under conditions of sufficient stress groups may split off and form new agendas thus forming schools of thought within a discipline.

Figure 1.1 Disciplinary Association



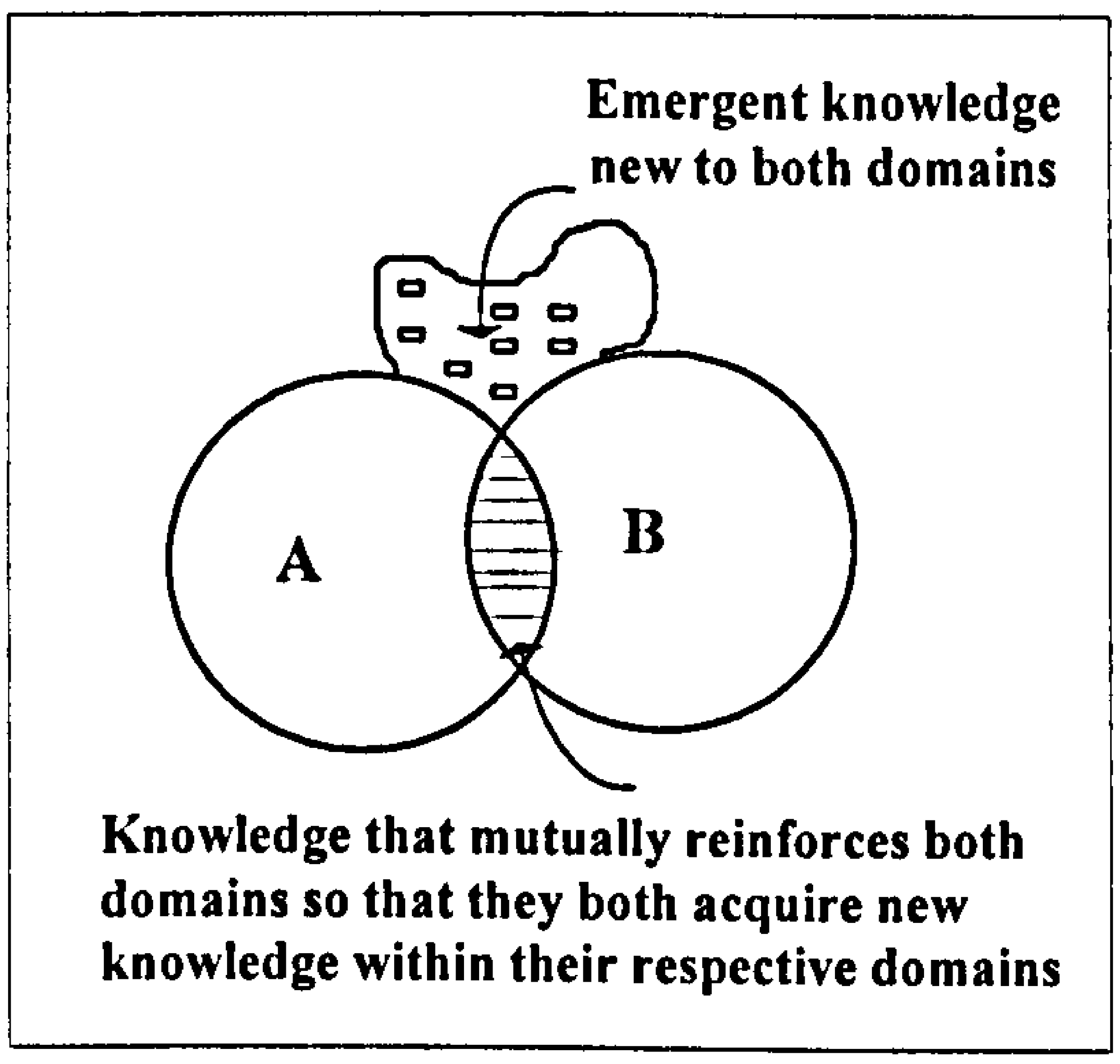
On occasions two or more disciplines may take an interest in the same phenomenon either by chance or because of a research project design. So Figure 1.1 can also be used to shows this loose association which is described as multidisciplinary. As in the organisational context the more disciplines involved and the greater the qualitative difference in their approaches, the harder will be the task of integrating their work. Since the participants seldom have a common corporate ethos and objectives the problem is one of synthesising rather than achieving a common understanding.

Synergy and Emergence

Occasionally there is an attempt to enable two or more domains (or individuals competent to operate within two domains) to operate on common territory. Where this involves interaction in an organisation that results in mutual benefits in acquisition of new knowledge to each of the domains, this approach can be described as *interdomain.* Figure 1.2 also shows the situation where this interaction generates new knowledge which lies outside the interacting domains and this is described as emergent knowledge since it arises from the co-evolution of the two knowledge domains. By analogy with academic research an activity which does this can be described as *transdomain.*

In the context of academic research members of two or more disciplines (or, as in an organisation, an individual competent to operate within two disciplines) may operate on a common phenomenon . Where this occurs the interaction results in mutual benefits in acquisition of new knowledge within the existing disciplines. This approach can be described as *interdisciplinary.* The generation of knowledge outside the interacting disciplines can again be described as emergent knowledge since it also arises from the co-evolution of the two knowledge domains. Some researchers describe this form of knowledge generation in interdisciplinary research as *transdisciplinary* (O'Rourke, 1995)

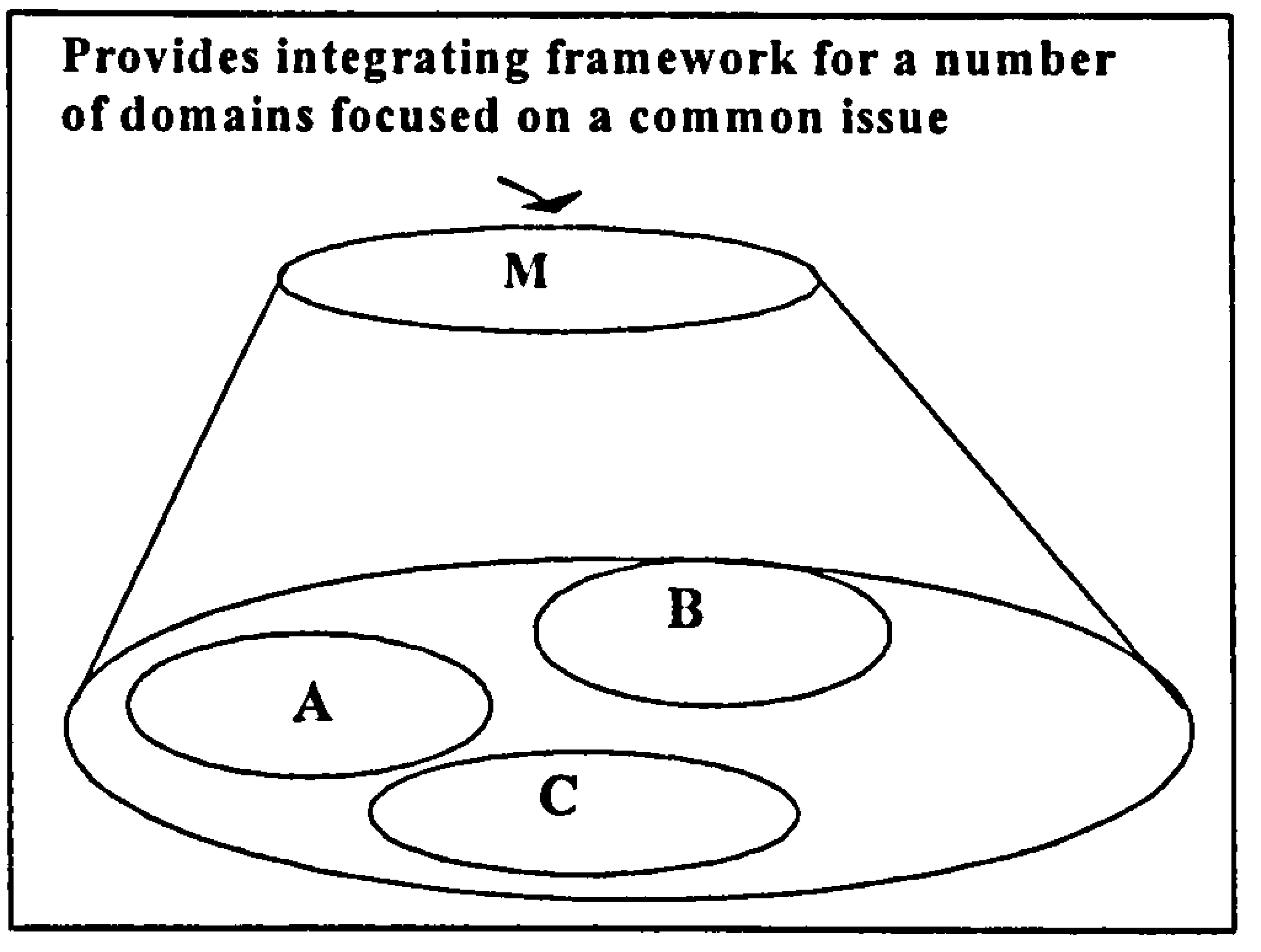
Figure 1.2 Interdisciplinary Association



Hierarchy and Management

More often in an organisational setting, rather than a need for an interactive project there is a need to collate routinely the knowledge of these interactions in a way that makes them useful. One model is that someone, a project leader, co-ordinator, perhaps a manager (M), Figure 1.3, is required to pull together these disparate areas of knowledge and, conversely, is able to disaggregate the knowledge needs at this level into knowledge activities a level below. It resembles the situation where a manager sees her/his role as the sole integrator and does not facilitate the interactions at the level below. This latter issue is one of the topics addressed in Chapter 6.

Figure 1.3 Managing Knowledge Domains

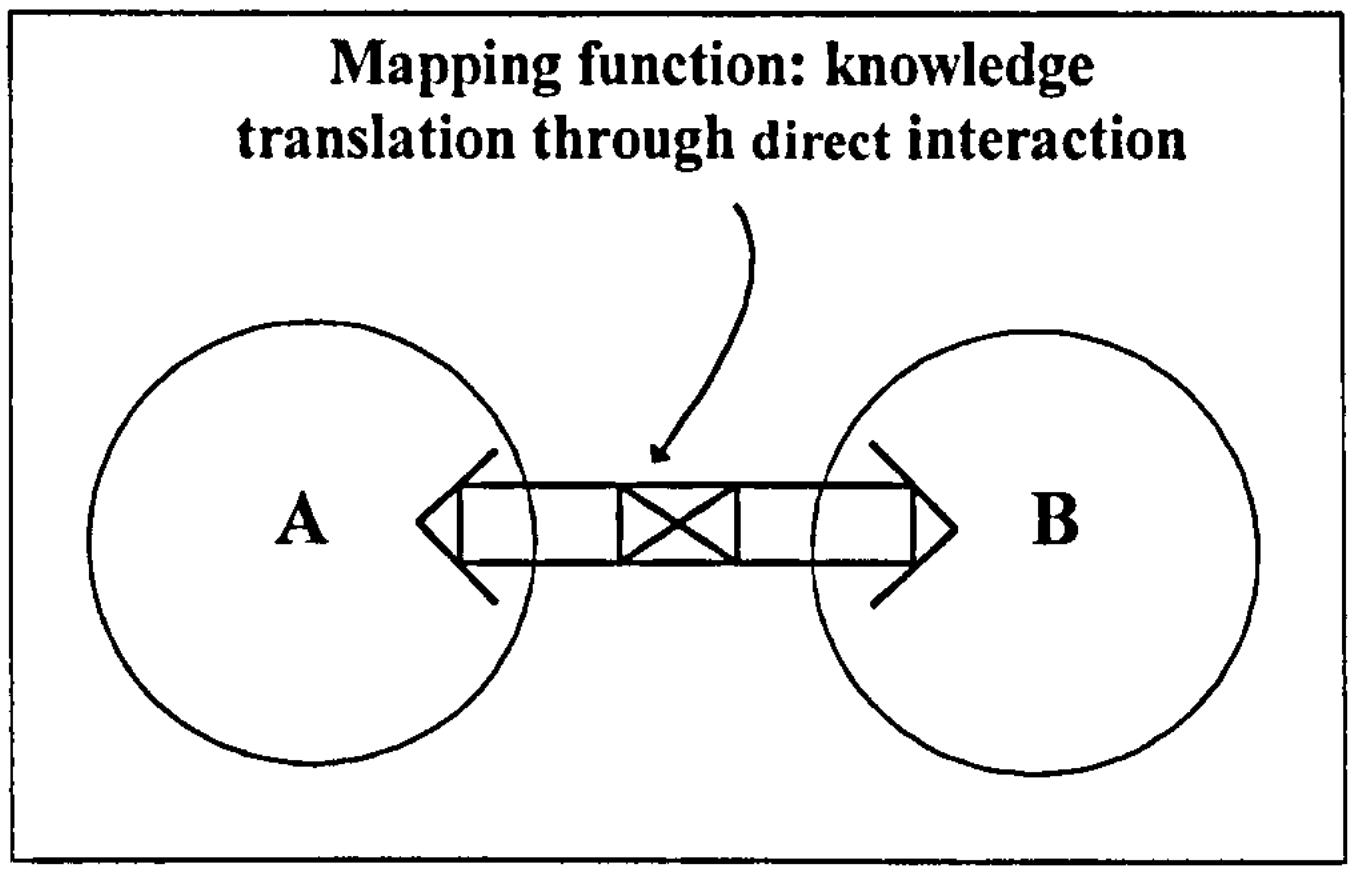


In interdisciplinary research there have been a number of attempts to promote the notion of a *meta-discipline*, Ackoff (1971) for instance. The idea is that an intellectual framework can be constructed that contains and explains that part of the knowledge domains of a number of interlinked disciplines concerned with a common phenomenon as in Figure 1.3. This is quite distinct from the integrating framework needed for multidisciplinary research whose function is essentially interpretative. There is a tendency for some systems disciplines to see themselves as the ultimate "explainers" and thus to englobe other disciplines. This is often countered very effectively, particularly by social scientists in interdisciplinary teams, so perhaps the resulting uncomfortable "dialogue" is beneficial in its own right.

1.3 Knowledge Translation

The simple set of symbols shown earlier and the discussion above enables Figure 1.4 to be constructed. At the end of this thesis the thinking behind this diagram will have been developed considerably further. At this stage, however, it is sufficient for use as an interpretative device for many of the pieces of research discussed later. This set of concepts and their synthesis have their roots, as noted earlier, in a history of the author's early study and research and have been formalised and made explicit through recent research into knowledge dynamics. The principles are capable of being applied to a range of interactions which involve translation or mapping from one domain to another.

Figure 1.4 Knowledge Translation



The next chapter show how these views were formed. Chapter 3 then shows, in the context of transport systems analysis the growing frustration with the limitations of the then contemporary thinking about the representation of people and their responses to products and services and how that was improved. It also begins to focus on organisations as suppliers of those products and processes and the organisational and engineering hierarchies involved. It begins also to identify such interactions as evolving over time. Chapter 4 then articulates the view of technology as knowledge in the context of technology transfer as an interactive process and shows how those ideas evolved into the concept of knowledge dynamics in organisations. In parallel, Chapter 5 approaches the problems of interactions which involve bio-physical systems as well as engineered systems and people. The issues of sustainability and of policy relevant research are introduced and the nature of integrative interdisciplinary research as a form of knowledge dynamics is developed. Chapter 6 returns to the themes above and shows how the concepts can be used to position a wide range of policy and decision relevant issues, and how they help to provide a conceptual framework within which the similarities and differences between knowledge policy in organisations and science research policy can be compared.

CHAPTER 2

2. MAPPING BETWEEN DOMAINS

2.1 Introduction

This chapter describes the historical influences on the style of thinking adopted in the thesis. Any experienced interdisciplinary researcher will know that his or her cumulative knowledge has been influenced by many schools of thought. It is appropriate to make this explicit in this thesis and to do so a number of key publications have been used to represent those schools of thought.

The chapter starts with the early influences of engineering design and in particular the earliest exposure of the author to the concept of modelling. In the engineering world of the 1960's modelling referred to the use of physical models whose attributes are scaled in such a way as to enable them to be used to explore particular phenomena in the full sized world. There are many books which deal with this but that by Massey (1971) is still in daily use. Material has been extracted from it to demonstrate the issue of how to translate phenomena in one set of circumstances to another set of circumstances.

We then move from the purely physical world to that of micro-economics and the representation of the interaction between "consumers" and "goods". This enables, at least in some elementary way, "people" to be introduced and some form of "mapping" to be demonstrated. The publication selected is by Lancaster (1970) who had, and still has, considerable influence on micro-economic thought. His work is complicated, mathematical and difficult for the non-economist but he writes in a way which enables the main lines of argument to be identified. His approach is relevant because he is one of the first to decouple the interaction between goods and consumer by focusing on the "characteristics" of the good rather than its engineering properties. As will be seen, his treatment of the consumer is, by today's standards, unsophisticated and in Chapter 3 ways of overcoming this problem are identified.

In order to move from goods to services, and in particular to transport services, where the publications which support this thesis start, use is made of the work by Quandt and Baumol (1966) who use an almost identical approach to that of Lancaster but applied to transport in the form of the "Abstract Mode" concept. Thus we can see the idea of decoupling and translation in the same field, transport, in which the first case-study, in Chapter 3, is presented.

2.2 Dimensional Analysis and Physical Similarity

The history behind an interest in "interaction" can be traced back to the author's early education as a civil engineer at the University of Manchester and the use of Osborne Reynolds original equipment to re enact the determination of Reynold's Number. This is a dimensionless number that is associated with the transition between turbulent and laminar flow regimes in water flows. Well before the advent of computational facilities, the main way of exploring the performance of the full scale design was to build a physical scale model. One in the Simon Engineering Laboratories at Manchester was probably a hundred metres long and of a segment of the River Mersey that was prone to silt up. While the water in such a physical model still behaves as at full scale it interacts with scaled down elements of width of channel and representations of silt, the foundations of bridges, quays and so on. There is a method in such circumstances for determining the correct ratios of the dimensions of the scaled elements that reduces every physical component to a limited number of primary or "fundamental" quantities such as Mass, Length and Time (MLT) and then manipulates combinations of these to reduce the complexity of experimentation or to identify the scalar ratios to be adjusted or accounted for in scale physical models. Through this method it is possible to find the appropriate MLT combinations of elements in a model which map, for the purposes of a specific investigation, onto the full sized world. Armed with this knowledge researchers were able to undertake experiments with some hope of translating the results back into effective design or of limiting the number of variables to be explored in experiments. It is apparent that such modelling is also selective about the aspects of that real world that they want to concentrate on and in this sense are formulating and testing a conceptual model. There are many much more complicated examples in aeronautical design where scale models are still used (for supersonic aerofoil analysis, for instance) and in many other branches of engineering and architecture, despite the improvement in computational processes.

It is worth identifying the source of these ideas about mapping and translation in more detail since they were the ideas, subliminally adopted perhaps, which were the seminal influence on much of the subsequent thinking behind the research covered in this thesis. They also represent one of the ways in which the conceptual models used in the physical sciences and engineering can be exploited (in conjunction with other knowledge domains) to create a perspective on quite different classes of phenomena.

One particular book, much in daily use by engineers, scientists and technologists even now in British universities such as Cranfield is that by Massey on "Units, Dimensional Analysis and Physical Similarity" (Massey, 1971). He starts by reviewing the history of units and the confusion between units (as attributes) and magnitudes of those units and then proceeds to Dimensional Formulae.

He says, (p50):

> "Equations relating the magnitude of physical quantities are thus of two kinds: (a) those which define derived magnitudes ('defining' equations), and (b) those which express physical relations which have to be established by measurement. The equation $F = ma$ is of type (a) because it defines the magnitude of force in terms of those of mass and acceleration. The equation $F = Gm_1m_2/r^2$, however is of type (b) because measurements of F, m_1, m_2 and r are required to establish the value of G. Whether a particular equation is of one type or the other depends on which magnitudes have been chosen to be fundamental, and on how the derived magnitudes are defined from the fundamental ones."

"The magnitudes of physical quantities are expressed by the product of a numeric and a unit, and it is the unit which essentially distinguishes the magnitude of one type of quantity from another."

Thus MLT have been selected to be "fundamental" and the symbol [L] may be used to represent the unit of length (for brevity we use the letter L for the quantity length). Similarly [T] may represent a unit interval of time, [M] a unit mass and so on. The square bracket refers therefore to a unit of some physical quantity. Massey then goes on to show how many physical quantities can be expressed in terms of a given set of fundamental quantities. Velocity can be expressed as [L]/[T], the dimensional formula, and similarly acceleration as $[L]/[T]^2$. Whatever the units used this relationship will always be true:

"Dimensional formulae are characteristic of the *magnitudes* of physical quantities but not of the quantities themselves. It is often wrongly supposed that dimensional formulae in some way give information about the intrinsic nature of the quantities with which they are associated. However, a dimensional formula for the magnitude of a particular quantity is not unique: it depends on which magnitudes are regarded as fundamental and on how the derived magnitudes are defined."

and then:

"To say that the dimensional formula associated with viscosity, for example, is $[M][L]^{-1}[T]^{-1}$ tells us nothing at all about the intrinsic nature of viscosity - the 'lack of slipperiness', as Newton put it. This kind of information comes from the definition of the quantity, not from a dimensional formula....in other words it defines a possible unit of that quantity."

MLT are the most commonly used "fundamentals" in mechanics. Other fundamental quantities are used for situations involving heat, electricity, magnetism and light. Dimensional formulae represent in this thesis the first step in developing an abstraction of one domain to be used in another since they are the basis of physical modelling. A couple more elements are required to make this clear.

Dimensional Analysis uses the idea of Dimensional Homogeneity, (p53):

"The principle is simply that the dimensional formulae of magnitudes which are added, subtracted or equated must be identical. Once a particular set of fundamental quantities ([L], [M] and [T] for example), has been chosen, then if two quantities are of the same kind it is a necessary consequence that the dimensional formulae of their magnitudes are identical."

He then goes on to show that the converse may not be true when a small number of fundamental quantities are used. Thus the dimensional formula for torque and energy are each the product of force and distance and the dimensional formulae of each is $[F][L]$ or $[MLT^{-2}][L]$ thus $[ML^2T^{-2}]$. However the intrinsic nature of these quantities differ in that for torque the force is perpendicular to distance and for work they are in line. They cannot be added since they are intrinsically different. More generally these different "intrinsic natures" are referred to as "attributes" in this thesis, (p54):

> "Checking relations for dimensional homogeneity should become an automatic habit."

It is this principle on which Dimensional Analysis is based. He goes on:

> "The methods of dimensional analysis are of very wide application and are valuable in the study of phenomena which are too complex for complete theoretical treatment. Such complexity may result from a large number of independent variables affecting the phenomenon, or from a mathematically complicated form of the expressions relating these variables."

The process of analysis immediately has to face up to the issue of what quantities to abstract for the investigation of a phenomenon. All possible relevant quantities must be included even if they are ostensibly invariant with respect to that phenomenon, such as the gravitational constant or the velocity of light. He goes on to observe:

> "On the other hand, there is no virtue in bringing in quantities which have no bearing on the situation. For example, in a problem concerned with the equilibrium of a fluid, the viscosity of the fluid - which is in evidence only when there is relative motion between different particles of fluid - need not be considered."

So the first problem of modelling physical phenomena, the generation of appropriate equations to represent a phenomenon, is the selection of the things which affect or cause that phenomenon. There is nothing unusual in this view and it can be extended to many other styles of thinking than just that associated with mechanics and physical processes.

What is clever is the way in which dimensional formulae are used as an intermediate or translating device. One stage further in the application of dimensionality needs to be described. This method of analysis was initially expounded by Lord Rayleigh (1842-1919) and is often referred to as Rayleigh's (or the indical) method. A more elegant approach was first made explicit by Buckingham (1867-1940) although others had also already used it, and is known as Buckingham's Pi theorem in which Pi (or Π) is used as a symbol for 'product'. Massey introduces this thus, (p63):

> "The object of Buckingham's method is to assemble all the magnitudes entering the problem into a number of dimensionless products (Πs), and the desired relation connecting individual magnitudes is then an algebraic expression relating the Πs. A rigorous proof of the theorem requires the theory of simultaneous linear equations and this need not detain us."

The procedure is well established and most physical experimenters will have applied it in their training and work, (p64):

> "The Pi theorem now states that if *m* is the number of distinct fundamental magnitudes required to express the dimensional formulae of all the *n* magnitudes, then these *n* magnitudes may be grouped into *n-m* independent dimensionless Π terms,..."

and thus

> "...the advantage of dimensional analysis from the experimenter's point of view (is that) the number of variables needing separate consideration is reduced from *n* to *m.*"

This facility, of manipulating magnitudes as a way of handling the properties of attributes and understanding their relationships, underlies the issue of Physical Similarity. Massey is so economical in his writing that, again, it is more effective to quote from him rather than try to paraphrase. So he goes on (p89):

> Practical problems are seldom solved by theoretical analysis alone , and it is frequently necessary to turn to experimental results to complete the study. Even if a complete quantitative theory has been worked out, experiments are still necessary to verify it, because theories are invariably based on certain assumptions which may not be precisely satisfied in practice.
>
> Much of this experimental work is, of course, done either on the apparatus for which the results are required, or on an exact duplicate of it. But a large part of the progress made in many fields of study has come from experiments on scale models."

Massey then alludes to the use of scale models in the design of aircraft, ships, flood control of rivers and chemical plants and investigations into the performance characteristics of turbines, pumps, propellers and other machines. He goes on to consider the properties of materials:

> "In a number of instances tests are conducted with one working material, and the results applied to situations in which a different material is used."

and then, (p89):

> "In all these examples, results taken from tests performed under one set of conditions are applied to another set of conditions. This procedure is made possible by the laws of similarity. By these laws, what is observed in one set of circumstances may be related to phenomena occurring in other sets of circumstances."

The types of Physical Similarity that Massey identifies are: Geometric (similarity of shape) based on the ratios of length, Kinematic (similarity of motion), Dynamic (similarity of forces) thermal (ratio of temperature differences), chemical (ratio of concentrations), electrical (same connectivity, similarity of resistances, inductances and capacitances), electromagnetic (ratio of electric field strength and magnetic field strength for corresponding points in the two systems under comparison. For the two systems to be dimensionally similar the corresponding IIs must be the same and so on.

This is the origin from which some of the most useful ideas for this thesis originate, (p89):

> **"By these laws** (of physical similarity) **what is observed in one set of circumstances may be related to phenomena occurring in other sets of circumstances."**

Much of the following is concerned with how this same issue of relating attributes and phenomena across domains may be tackled for various classes of phenomena and how the intrinsic natures or attributes may be mapped between one domain and another by analogy to "fundamental and derived magnitudes". This basic idea of "mapping", and subsequently translation, extends to simple examples such as the business of generating isometric projections from two dimensional perspectives (geometric similarity) and most pupils at school will have come across other examples in geography for instance, of plane mapping. At its most sophisticated, when it involves concepts of dynamics and co-evolution for instance, it is an issue that preoccupies mathematicians and complex systems theorists. In sociology and environmental policy formulation a similar preoccupation is addressed, for example, by discourse analysis (Hajer, 1995). It is this basic issue of mapping and translating that underlies the following thesis. Starting with this simple notion it can be extended and developed in a range of contexts, although only within the range of phenomena bounded by the scope of this thesis as described in the Introduction. In some situations the interaction between the two (or more) domains is a social and intellectual process in its own right while in others it is a more formalised derivation of how behaviours in one domain reveal themselves in another.

In order to communicate the exploration of this basic idea in a systematic way it is necessary to use some essential concepts and explain some of the ideas that underlie them. The first set of useful notions has been derived from work with systems ideas in a wide variety of practical settings. It has been acquired largely as a result of teaching systems thinking for the Open University in the UK and research into policy relevant issues. The second set of these, which leads naturally into the development of these ideas in the first paper, is that of properties, characteristics and attributes.

2.3 Lancaster and "Consumer Demand: a New Approach"

One of the main influences on thinking in microeconomics in the mid 1960's to the early 1970's was the work of Kelvin J Lancaster who provided a new development of micro-economics which became the basis for much analysis of transport systems. Econometrics, along with civil engineering, some aspects of geography, regional science and a significant number of physicists, constituted the main intellectual resource in transport research in the USA and the UK with similar though not identical distributions of disciplines in Northern Europe. The field of transport research was thus, even early on, multidisciplinary and this is one of the main features that this thesis deals with.

The text used here is an extended version of his earlier work, some of which was included in a book edited by Quandt and Baumol in 1966, which also contains their specific paper on Abstract Modes that is relevant to this section. The demonstration and proof of Lancaster's theoretical approach is highly mathematical and deeply rooted in the detailed concepts and vocabulary of the then contemporary micro-economics. Since the reason for discussing his work is to extract the useful conceptual devices (and to identify their limitations in other contexts) and to transfer and translate them into other fields of enquiry, this sub-section uses quotations from his own commentary. It should be remembered that this was published in 1971 and some of those limitations are now considered obvious. It is also firmly set in the principle of scientific enquiry although the frequent allusions to prediction cross the boundary between falsification and validation into the territory of practical prediction for action. It is this latter tendency in economics which has become a cause for concern since in dynamic circumstances such as those surrounding innovation and rapid social change the assumptions that certain features represented in the theory will remain unchanged can be challenged. There is also the use of the idea of optimisation as an assumption about the motivation for behaviour by people which might now be challenged. However it must be placed in its historical context. Much of the economic thinking of this generation had been dominated by the need to use resources efficiently during the Second World War and, in Europe, by the need to allocate rationed resources for a long time after then. It is noticeable that a number of classic analyses he refers to are about nutrition and diet, (p10):

> "None of these approaches mentioned (*the traditional approaches of the 40's and 50's*) attempted, however, to integrate the characteristics approach into the central core of demand theory. The work on the diet problem, in which the basic elements for a complete analysis are present, concentrated only on subsistence and failed to take account of the divergence of preferences between individuals. With the war over, this specific approach was too narrow and the analytics of the problem were digested into the more technical developments associated with the growth of linear programming and activity analysis."

In his introduction, (p1,2), he outlines his intentions thus:

> "The accepted theory of consumer behaviour in economics is the result of a long process of eliminating excess input and making the theory efficient. The excess input was initially on the psychological side, and relatively strong assumptions about utility and the nature of human psychology were gradually shaved away until it was shown that the predictions of the theory required only weak assumptions about the consistent preference ordering by individuals.
>
> The long concentration on the preference side of consumer demand theory has diverted attention away from the simple fact that demand theory involves two types of input - information about things as well as about people."

Earlier work had been preoccupied with the effects of budgets, of value and so on but had treated products as goods. This insistence on the linkage between these two perspectives is immediately attractive. He goes on:

> "As it stands in the generally accepted form, demand theory makes no use of information about things. Whereas current theory enables us to trace the effects of different preferences (greater or lesser convexity of indifference curve for example) on demand, it provides no way at all of tracing the effect of changes in the physical properties of goods on demand.
>
> Someone with no economic background, studying the economist's theory of demand , might well find the concentrations on preferences, to the exclusion of other properties of goods, a strange one. After all, one would expect information on the properties of goods to be more easily obtainable, and to be more universal in character, than properties of individual's preference orderings. A theory that takes no account of information that is readily available, and depends entirely on information that may be available in principle (preference orderings) but not in practice, is surely a strange one."

He thus raises two points that are relevant subsequently in this thesis. He is clearly going to focus on a theory about the ways in which goods can be more effectively differentiated, which is the main purpose of the book. Secondly, and perhaps inadvertently, he draws attention to the limited practical knowledge available to the economist about the nature of the consumer's world.

After a brief summary of what he regards as "Traditional Demand Theory" he deals with "Giving Goods Their Due" (p6 - 8) which raises one of the most important issues of difference between his approach and the subsequent developments by non-economists. Rather than give the whole of this text short quotations have been extracted:

> "But there is surely some common element in how different people see the same good: a steak is seen, in this sense, as something to eat, with many properties that could be agreed upon by everyone, and not as something with which to make clothing......Those who do not like steak dislike it because of some of its properties, not because they see an entirely different set of properties from the steak-eaters."

This assertion of objectivity is developed a little later much in the manner that a physical scientist might:

> "Any good possesses an enormous number of physical properties: size, shape, color, smell, chemical composition, ability to perform any one of a variety of functions, and so on. Because not all properties will be relevant to choice, we shall henceforth use the term *characteristics* for those objective properties of things that are relevant to choice by people.

The fundamental propositions on which the analysis of this book is based are two:

(1) All goods possess objective characteristics relevant to the choices which people make among different collections of goods. The relationship between a given quantity of a good (or a collection of goods) and the characteristics which it possesses is essentially a technical relationship, depending on the objective properties of the goods and, sometimes, a context of technological "know-how" as to what the goods can do, and how.

(2) Individuals differ in their *reactions to* different characteristics, rather than in their assessment of the characteristics content of various goods collections [8]. It is the *characteristics* in which the consumers are interested. They possess preferences for collections of characteristics, and preferences for goods are indirect or derived in the sense that goods are only required in order to produce the characteristics."

He relates this to earlier work about goods being desired in order to satisfy "wants" and then says something which would today be disputed:

"Generally speaking, it seems better to avoid explicit psychologizing and simply note that it is the characteristics of goods, not the goods themselves, in which people are interested."

In Footnote 8 in the text of the quotation above, he moderates this view though still claiming his position:

[8] "This is the working hypothesis of this book. It is clearly not applicable in all cases. **People may sometimes appear to "see" properties of a good that are not seen by others and defy objective analysis.** Our interest here is in the addition to both analytical understanding and potential predictive power of cases in which the characteristics approach seem to fit. At worst, we fall back on the traditional analysis by assuming that the consumption technology is unknown in practice for some groups of goods."

In his chapter in Quandt (1970) he is a little more forthcoming about the need to understand the perceptions of consumers in a more direct manner. After some discussion about the "Operational and Predictive Characteristics of the Model" he observes, (p47):

"Last, but possibly not least simply asking consumers about the characteristics associated with various commodities may be much more productive than attempts to extract information concerning preferences within the context of conventional theory."

and a little later, referring to dispersed consumer preferences:

> "Some of the problems that arise are similar to those met by psychologists in measuring intelligence, personality, and other multidimensional traits, so that techniques similar to those used in psychology, such as factor analysis, might prove useful."

Lancaster's approach is not going to help us with understanding what people want, need or "see", but where it is helpful is in the decoupling of the engineering properties of a good from the characteristics which are relevant to the consumer. When we shift ground to situations which are not primarily about consumer goods but about services, technical and organisational innovation, emergent systems and policy instruments this part of his approach will still be useful. Not least he formalises the nature of decoupling by generating and demonstrating what he himself calls " a mapping" between characteristics and consumer preferences thus demonstrating the principle of mapping in a new way:

> **"Using these two basic propositions, we view the relationship between people and things as at least a two stage affair.** It is composed of the relationship between things and their characteristics (objective and technical) and the relationship between characteristics and people (personal, involving individual preferences)."

He goes on to declare the real focus of his theory:

> "A variety of models might be constructed on the basis of this two-stage division. The emphasis in this book is on the goods-characteristics relationship, and it is the various possibilities inherent in this that will be developed."

and in a comment which provides a link to the transport planning literature and a reference to Quandt and Baumol (1966):

> "When faced with such problems as estimating the demand for forms of transport which may not yet exist, the economist is forced into a characteristics approach, whereby estimates are attempted of the demand for various characteristics of travel, the demand for a hypothetical mode of transport being synthesized from these."

Finally, in Quandt (1970, p 50)) he envisages a future direction for such theories as his:

> "This paper is nothing more than a condensed presentation of some of the possible ways in which the model can be used. It is hoped that a door has been opened to a new, rich treasure house of ideas for future development of the most refined and least powerful branch of economic theory, the theory of the consumer himself."

This emphasises a distinction between "revealed preference" and "stated preference" techniques. The former deal with observation and measurement of behaviour while the latter focus on direct investigation with consumers which we will return to a little later.

2.4 Characteristics in Transport Supply and Demand

In a period from the early 1960's onwards to the mid/late 1970's the predominant concern in transport planning was for demand forecasting of movement in space and time and by mode of transport. Set against the unprecedented demand and growth it was almost irrelevant what accuracy was achieved except that underestimation of road capacity could result in premature congestion. At that time the policy imperatives for transport in the UK, as in many of the industrialised northern countries, were about creating road capacity for growth in car ownership. However, access to a car was still limited and the growth in demand for mobility (later articulated in terms of accessibility) meant that new public transport technologies were constantly being promoted. Over a six or seven year period we were involved at Cranfield in the technology assessment (the economic and consumer performance characteristics) of airships, amphibious hovercraft, tracked hovercraft, high speed magnetically levitated vehicles, supertrams, non-stop peristaltic people movers, as well as a range of variations on conventional modes of transport such as railway, bus, tram, cycling and walking.

One of the main preoccupations was how to predict which mode of transport people would use, particularly when investment in an innovative mode of transport was proposed. The rather tightly confined problem set of the car/bus split on the trip to work was quickly widened to include modal choice in many other situations such as non commuting trips, ferry versus hovercraft, turbo-prop versus jet aircraft, and so on.

Initially simple choice models of bus or car for the trip to work (which was the most likely time for congestion to occur) were derived from early work on consumer choice of products by economists and econometricians. They became the focus of interest more widely because transport presented some interesting differences with other "consumer products". For instance the temporalities are very prominent in both the supply and demand contexts in that transport capacity cannot be stored by the producer, while the consumer is subject to time budgets. There is a spatial dimension which gives rise to an interest in the way various trip end activities have differential utility with respect to location.

One approach to modal split which used similar ideas to those of Lancaster's was that of Quandt and Baumol who developed the idea of Abstract Modes. It will be helpful to make the link between the work of people like Lancaster and the transport planning and innovation issues in Chapter 3 through this contemporary work of Quandt and Baumol which was the more direct influence on our early work. The version of their paper in Quandt (1970) is a direct reprint of the earlier paper, Quandt and Baumol (1966).

They assert in their "Concluding Comments" that, (p99):

> "Apparently by coincidence, a number of other writings have recently taken the same view: one in which goods and services are specified as abstract bundles of characteristics [19]".([19] - Lancaster, 1970).

On p84 they offer "The Theory of Abstract Modes" which is essentially the application of Lancaster's characteristics approach:

> " Our analysis of transportation demand is not formulated in terms of the demand for travel by trains, airplanes, and other conventional means of transportation; it utilizes instead a number of abstract modal types, none of which may correspond entirely to any specific present or future mode of transportation. In a world of changing technology in which tomorrow's vehicles may differ radically from those of today such an approach offers obvious advantages if one seeks to produce an analysis pertinent to the future. Thus we will find it useful to define a mode in terms of the type of service it provides to the traveller and not in terms of the administrative entity that controls its operations or the sort of physical equipment it employs."

They are doing much the same as Lancaster proposes, decoupling the physical and administrative context of supply from the performance characteristics to which the consumer will respond. However the issue still remains as to what are these characteristics. They suggest objective variables as follows (p84):

> "An abstract mode is characterized by the values of the several variables that affect the desirability of the mode's service to the public: speed, frequency of service, comfort and cost. Thus one can define a continuum of abstract modes, most of them may have no current counterpart, although some of them will become realties in the future. More important, it should be recognized that an actual mode may in one type of service correspond to some abstract mode A, while in another usage it may be related to an entirely different abstract mode."

They then go on to give a worked example and later (p86) the following observation:

> "The present theory therefore presupposes that individuals are characterised by a modal neutrality which is substantially comparable to the neutrality towards risk exhibited by persons who have a von Neumann-Morgenstern utility index. In other words our modally neutral person chooses among modes purely on the basis of their characteristics and not on the basis of what they are called.
>
> In theory this assumption may be very desirable but, in practice, it may be difficult to characterise modes so completely that what would otherwise appear as modal neutrality is, in fact, encompassed by the characteristics of the various modes. It is well known that a substantial aversion to flying has characterised and perhaps still influences, some segments of the population."

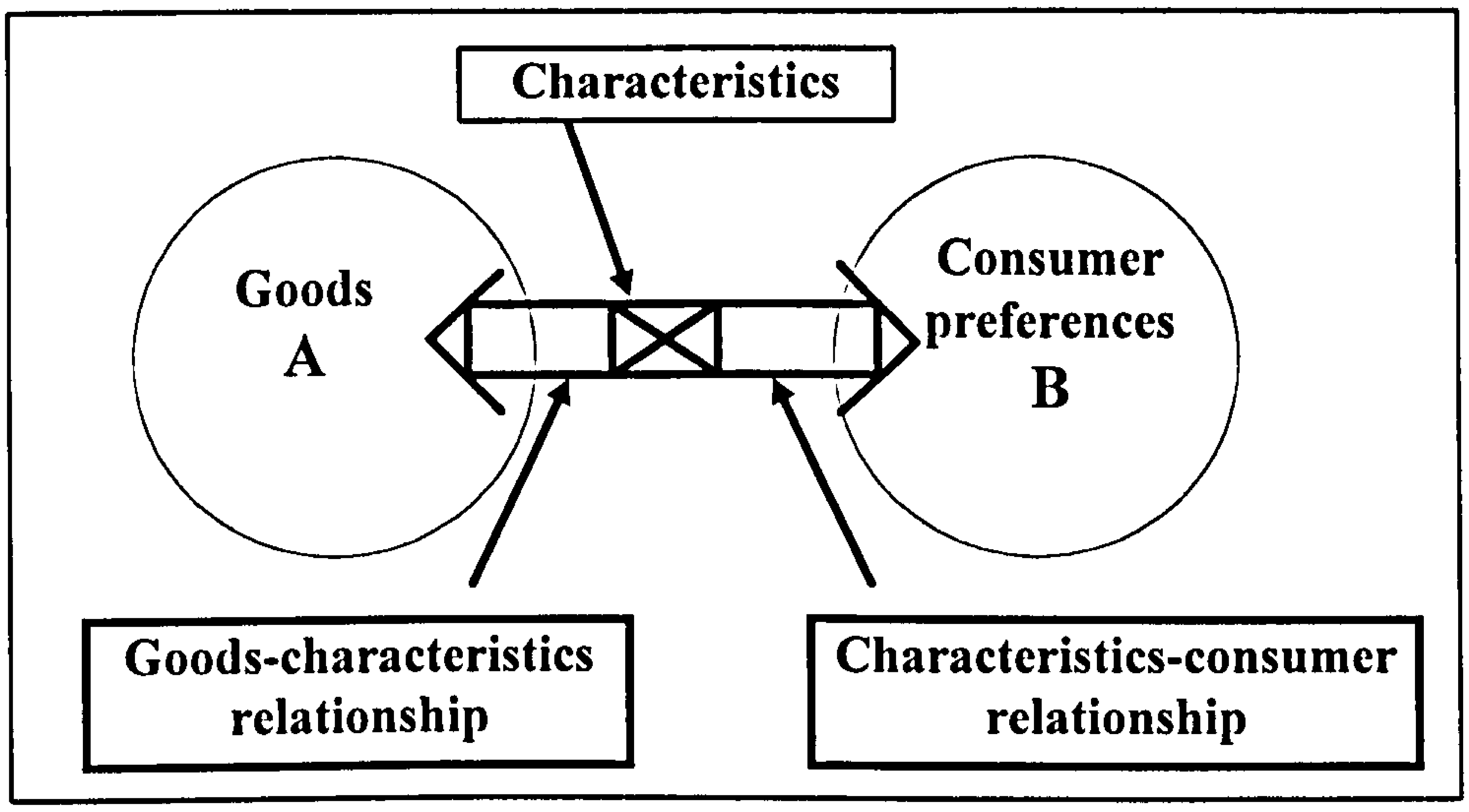
They then go on to discuss how to handle this technically within their model by splitting the abstract modes into two groups, air and non-air and continue in the main part of the paper to demonstrate the mathematical and statistical processes of the model on various types of data and in various contexts.

2.5 Discussion

These last two pieces of work, Lancaster and Quandt and Baumol, are now some 25 to 30 years old. They have been chosen because they were, in their day, pre-eminent examples of the influences on not only our research but on others in the field of transport planning who had an interest in innovation in transport. They also provide a platform for a discussion of how research in transport needed to develop.

Lancaster's approach is based on the increasing number of consumer products in a sophisticated society. It implicitly takes the position of the producer of goods who wishes to explore potential markets, although subsequent researchers have been interested in the implications of consumption in welfare economics. The main strength that was drawn from this work, as exemplified in the work of Quandt and Baumol, is the way in which it positions a set of characteristics between a good or service as an entity and the response of a consumer. In terms of the diagram developed in Chapter 1 Domain A is the set of goods or service attributes, Domain B the consumer preferences and the translation between the two domains are the mapping function between the physical properties of the goods and the characteristics and the mapping function between the characteristics and the consumer preferences.

Figure 2.1 Mapping functions between domains



The weakness which we had to address is the belief that there are objective and universally agreed characteristics about which people are concerned. In the context of innovation there can be no assurance that this is the case. While Lancaster restricts himself to the problem in the context of finely differentiated goods so that cumulative knowledge might just be sufficient to assert this assumption of objectivity it is not true of the Quandt and Baumol model where new characteristics might well occur. Indeed their rationale is precisely that new forms of technology (they mean physical engineering) are likely to occur. The problem is with the view that all goods and services can be described by a finite but perhaps large set of objective characteristics rather than in the terms of reference of the potential consumer. Lancaster mentions the possibility of what he calls "psychological" research but in such a way that he probably means direct enquiry about an agenda of characteristics already posited by market researchers and analysts. The possibility that a product carries with it a bundle of social or organisational attributes cannot be considered from this perspective. On the other hand we are offered a view of the disaggregate consumer and Lancaster in particular spends some effort on explaining the problems of non-additive and non-linear characteristics.

There are some further problems. The models referred to above are all static in that the consumption of goods does not influence the production of goods. Other economists are trying to rectify this limitation which is common to many branches of economics and our early attempts at modelling supply demand interactions suffer the same fault. The corresponding dynamic of innovation within Domain A is not really questioned although it is clear that what may be considered an innovation in physical terms may not change any of the characteristics perceived by degree or type.

The second problem is that if we want to import these ideas into contexts other than consumer preferences for goods and services (which we do), and which involve hierarchical relationships such an approach gives no guidance. In addition the decisions are assumed to be made by autonomous individuals and yet, even in the field of ordinary consumer products, this is seldom true. Even when more advanced techniques of social enquiry are used, such as a range of elicitation techniques, this limitation still occurs. How to get from an individual to a group or community in the context of technology, innovation or knowledge transfer is not yet well understood.

CHAPTER 3

3. TECHNOLOGY MANAGEMENT

3.1 Introduction

The first two sections in this chapter lead up to the foundation paper for the body of research activity and case studies in this thesis, "Decision-support Systems and the Strategic Management of Train Service Punctuality", Seaton & Black (1987).

The work of Manheim (1980) in the late 1970's had an engineering and microeconomics background and a direct influence on the style of research reported in the Seaton & Black paper. His work is about transport service design in a much more interactive manner than the earlier material of Quandt and Baumol and within a systemic framework. These ideas had a strong influence on our work at Cranfield and are worth examining more closely because of that despite the limitations which will become apparent.

It was this need for direct interaction with transport users (and later non-users and operating companies) and the contemporaneous developments in social psychology, market research in the 1960's, and somewhat later, applied sociology, which enabled a much wider range of issues than conventional supply demand relationships to be explored. The early work in attitudinal research of such researchers as Lewin (1936), Katz and Stotland, (1959), and Oppenheim (1962) and many others developed through the mid 1960's by Fishbein (1963) into concepts that had particular relevance to transport demand research, Fishbein and Ajzen (1975). In turn this prompted thoughts about the nature of innovation and response to it. Research which builds on a history of the work by Fishbein in this multidisicplinary (and increasingly interdisciplinary) transport research is that of Towriss whose Ph.D. was directed by Cordey-Hayes. It is convenient within this thesis to use Towriss (1984) on the further development of "expectancy value models" for application in a range of land-use, transport and product situations. His paper exemplifies the starting point of the opportunity that was created by certain schools of thought in the social sciences in order to investigate more directly the world of the consumer and ultimately the world of managers and employees in organisations and the many constituencies involved in emergent policy relevant situations.

3.2 Performance Functions

Manheim attempts to tackle some of the issues of service design problems specifically in the field of transport supply. He begins to develop an approach based more on systems thinking, (p119):

> "Transportation is usually achieved by quite complex processes in which man and machines interact, within institutions which are often large and complex, to

> deliver transportation services to the consumers of those services. The challenge facing the transportation systems analyst is to learn how to intervene effectively in these large complex systems. To accomplish this intervention, the analysts must be able to predict the consequences of alternate actions. Often, he does this by abstracting from the complexity of this reality a simplified representation - a "model" - which he can manipulate to analyse the alternative options open to him."

He thus establishes not only the notion of complexity but also of modelling as an abstraction. However he is also asserting a characteristic position of an engineer, the intention of all this activity is to "intervene". He goes on to disaggregate the "actors" (his word) into a number of what we will call constituencies, users, operators, physically-impacted, functionally impacted, governments etc.. This is essentially similar to the user, non-user and operator division used by Seaton and Clarke (1971) ten years earlier and for much the same reason, they all operate in different attribute domains. He discusses the nature of their interactions with a transport system and concludes that:

> "Thus, to understand transportation system performance, we must recognise that *two major aspects of transportation system performance are important - service and resources."*

He is making a distinction similar to that which Lancaster makes about the goods - characteristics relationship (although he uses Quandt as his reference). He goes on to discuss the nature of non-price attributes and defines those characteristics of a service, the "service attributes" which influence consumer demand as (S). He also notes that in many transport situations there is a feed-back on service quality as demand, for a given capacity, increases (congestion and overcrowding is the extreme of this process). A set of alternative actions which impinge on output and corresponding resource inputs he refers to as (T). They can be considered as a set of service design options and are analogous to the choice of alternative production processes, plant sizes and so on. This area was itself a fruitful source of systemic analysis techniques which in the UK gave rise to the work of Jenkins (1981) and Checkland (1981) at Lancaster University in the 1980's. The magnitude of the resources consumed by alternative configurations of the production system he denotes as (R), specific elements of the (transport system) environment as (E), and the volume of users as (V). He then sets up the "Performance function" $\varnothing$ of the system in the form:

$$\varnothing_E(R,S,T,V)$$

and then he splits this into two sub-functions, $\varnothing_S$ so that

$$S = \varnothing_S(V,T)$$

$$R = \varnothing_R(V,T)$$

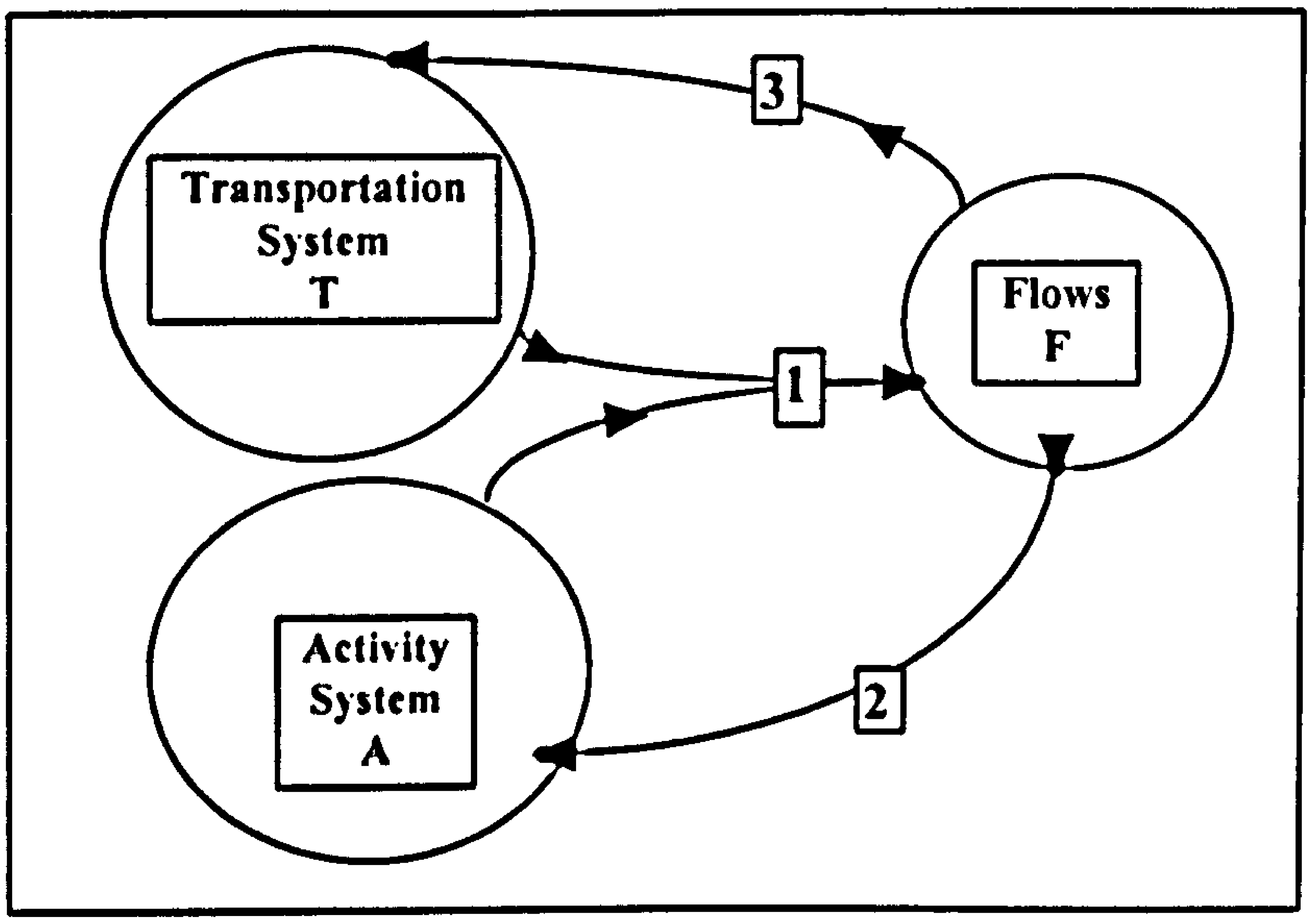
and "resources consumed" (R) and the "service provided" (S) are separated. It is a much clearer way of showing the translation between supply and demand attributes and neatly demonstrates the interdependent nature of the transport problem because any (S) will have implications for revenue (price is still one of the attributes) and any system design (T) will have both revenue and cost effects. Indeed he says (p122):

> "Finally we note that the actual implementation of ∅ may be a computer program, a set of mathematical relations, or any other style in which models are implemented....We will now outline the use of a performance function for analysis. The first step in using a performance function for analysis is to interface it with a demand model in order to predict travel market equilibrium."

Note, however, that he retreats to a position of searching for an equilibrium. He recognises later in the paper that the world is not quite as simple as that when he provides the following diagram about which he comments (p123):

> "In the most general case, where we take into account shifts in the activity system, the results of the travel market equilibration would enter into an activity system equilibration model (e.g. an urban land use or inter regional economic model) to predict shifts in the demand."

Figure 3.1 Manheim, 1980 Co-evolution of Transport and Activity systems



In the diagram he shows three aspects of the wider situation which involve recurrent equilibration, the Travel Market, Activity System and Operator. Contemporary thinking in complex dynamic systems would disapprove of this approach to a systemic problem. Although it is not clear that Manheim himself, and other writers at the time, did think about continuous dynamic interaction and change, there are good reasons why research into utilities finds the concept of change difficult to handle. Historically transport, water, communication and energy utilities (the "civil" as opposed to "military"), have involved "massive" infrastructure, usually in the pursuit of economies of production, throughput or connectivity, but sometimes, in the sense that Massey might apply, economies of scale. It actually takes an appreciable time to build such infrastructure, and once built, they tend to stay in use for decades and sometimes centuries. They are also very expensive to get rid of. Strategically, as will be discussed later in this thesis, it might be better to use smaller scale and spatially disaggregated technologies had they been available. Many of those now available use recent research into such areas as materials science, electronics (control systems) or, as in the case of hydrogen fuel cells for electricity storage and generation, knowledge from the leading edge of applied physics. Many of these systems deal with a technology that does not have nice monotonic and continuous cost and performance functions but rather difficult integer type effects and discontinuities in those functions.

Another limitation of his approach is that he only takes explicit account in his overall framework of the changes in the activities of the individual which are induced by changes in the transport service. In practice there will be many influences on the activity system of individuals and groups other than transport so that while they may be thought of as co-evolving their interdependency is, at best, only partial. This closing of the system boundary and treatment of the "environment" in this way avoids some of the inherent complexity surrounding such co-systems.

Manheim develop his ideas extensively, relating and comparing the more complicated aspects of his approach to classical theories of the firm. There is however another aspect of his approach which would now be thought of as deficient and it is much the same problem that Lancaster and Quandt and Baumol reveal. He says, (p133):

> "Demand is a function of a vector of service attributes S which can be partitioned into three subvectors $S = (S_1, S_2, S_3)$: S_1 = price (P) and any other money attributes which enter into the operator's revenue (or costs); S_2 = other attributes whose values are influenced directly by demand volume, within a range (or relationship) established by the operator's choice of options T: e.g. travel time which may be influenced by "congestion" effects, probability of finding a seat at a desired departure time, etc. (but *not* price which is set by T; frequency and its inverse, schedule headway are also set by T but irregularity or deviations from schedule frequency *are* influenced by demand); S_3 = all other attributes influencing demand."

Again we have the assumption of some neutral or common set of attributes to which the consumer responds but without any idea of whether these are the service attributes which are actually perceived and by whom. Earlier in the paper Manheim gives his own list of candidate attributes, (p119), as total trip time from origin to destination, total waiting time, total cost, total probability of loss or damage; these are much the same as used by Quandt and Baumol and are convenient since they can be measured objectively and elasticity's constructed which can be calibrated on the basis of observed changes in behaviour. It is not at all clear that these attributes and the magnitude of them in the units applied are those which consumers perceive; if not, then a major error can occur in the models. Since they are often used to forecast future demand in real investment situations, they will, compounded with the independent evolution of the human and activity systems, further induce unintended consequences.

3.3 The individual's perceptual world

It is one of the themes of this thesis that it is not possible to properly understand the response and behaviour of people to an artefact, situation or policy instrument without also understanding their perceptions. In this section we show how research in social psychology was developed in order to provide this insight. It is the basis of many investigation techniques which form an essential part of the research activity reported in the papers which are an integral part of the thesis. The theory and approach, with variations, can be used to investigate perceptually based response to a wide range of issues rather than the historical dependence on observation of reaction through behaviour.

As noted earlier, a convenient way into the body of research that deals with this problem is a paper by Towriss (1984), both a PhD student and subsequently researcher with Cordey-Hayes in the Cranfield team. It uses as a basis work by Thomas (1976), who had earlier worked with Fishbein, while in the Cranfield research team.

A short digression may help to locate this section with respect to the wider thesis. In the summer of 1971 I was awarded a "Vacation Consultancy" to the Transport Research Assessment Group (TRAG) of the then Road Research Laboratory (RRL). RRL (subsequently the Transport and Road Research Laboratory, TRRL) was then the authoritative research agency of the Government for transport, mostly road design, modal split and vehicle safety at the time but with a remit also for innovative transport technology.

The task I set myself was to explore ways of understanding "Latent Demand". This is concerned with the phenomenon of untapped demand (at that time from the viewpoint of the supplier) and was treated conventionally, in the style of Lancaster and Quandt and Baumol, as an extension to the elasticity function of the average consumer. The distinction, however, between the "willingness to pay" and "ability to pay" had become prominent in the economics of social welfare as issues of equity became relevant in policy formulation. In other words it had become apparent that the assumption about the "average consumer" presupposed that the only issue of choice about whether to travel and by which mode was that of consumer preference for a given set of "service characteristics", largely dominated by price. The possibility that some people were debarred from this choice, because of low income or because of the deterrence of non-price attributes began to be considered.

At that time psychologists were employed at RRL, mostly for the study of driver behaviour and vehicle ergonomics, but some in transport demand analysis. Using their research and library resources one chapter of my manuscript was on "Attitude Measurement". The titles of a few influential papers and books give an indication of the type of work then in vogue.

"Principles of Topological Psychology" Lewin K., (1936) "A preliminary statement to a theory of Attitude structure and change" Katz D. and Stotland R. S., (1959)

"Communication" Oppenheim A. N., (1962)

"Attitude techniques in action" Schaffer M. T., from whose work I quoted in 1971 thus:

> "Factual data regarding the actual social and economic situations are relatively easily obtained. By utilizing direct questions, asked in an appropriate manner, an agency can do an excellent job of drawing a social and economic profile at both the individual and aggregate level. However, factual data, no matter how complete and valid, can only provide a one-sided picture of the "people-problem". The subjective view of the social situation, as seen through the eyes of the people themselves, is extremely important."

The next link in this progression so far as this thesis is concerned is represented by the work of Fishbein and his colleagues in such publications as Fishbein, (1963), "An investigation of the relationship between beliefs about an object and attitude towards that object" and Fishbein and Ajze, (1975), "Belief, attitude, intention and behaviour: an introduction to theory and research".

The crucial contribution of this work lies in the title of the second paper; they make a set of distinctions, ending in behaviour, not previously made in the contemporary literature in the USA and UK. In my own words of 1971:

> "Attitude studies are frequently criticised as being of questionable validity because they fail to demonstrate the relationship between attitude responses and actual behaviour of respondents. Since transport policy makers are interested in understanding, predicting and, if possible, influencing behaviour of transport users they too should be interested in the association between attitudes and behaviour"

The paper by Towriss follows on from this sequence of attitude research. He focuses on a weakness within the Fishbein model in that it assumes a "common set of characteristics". He eloquently critiques and then responds to this idea that there are common sets of characteristics and deals with precisely what Lancaster calls "psychologising". However he does this not from a micro-economic perspective but in the field of applied social psychology and is thus another demonstration of the development of interdisciplinarity in research. Towriss's paper also touches on other issues, particularly aspects of learning, which are relevant to other avenues of the research, technology transfer and knowledge dynamics in organisations, which this thesis encompasses.

The theme of the Towriss' paper is that there is a major discrepancy between the theory of expectancy value models and the manner in which they are used. Towriss reports on Fishbein, a significant researcher in the 1960's and comments (p63):

> "Attitudes are viewed as being affective or evaluative in nature. Thus Fishbein (1967) defined attitudes as "learned predispositions to respond to an object, or

class of objects, in a favourable or unfavourable way." Beliefs, on the other hand, are defined in terms of the probability that a particular relationship exists between the object and the belief (i.e. the attitude object) and any other object, goal etc. For example a person may believe that 'high tar' cigarettes cause lung cancer. The object of the belief is 'high tar' cigarettes and the related concept is lung cancer. The two are linked by a probabilistic relationship. The person may be highly certain that the relationship exists or alternatively he may be relatively unsure that high tar cigarettes bring about lung cancer.

Belief formation, it is theorised, follows the principle of learning. Whenever a belief is learned, some of the implicit evaluation (i.e. the feeling of favourablness/unfavourableness) associated with the related object or goal etc. becomes associated with the attitude object."

He goes on to present the standard formulation of this rationale in algebraic terms (p64):

"Thus an individual's attitude towards an object is a function of his or her beliefs about that object and the implicit evaluative responses associated with those beliefs. Algebraically the relationship is given by:

$$A_o = \sum_{i=1}^{n} b_i a_i$$

where:
A_o = The attitude towards the object
b_i = the subjective probability that *o* is related to some other object, goal etc: *i*
a_i = the evaluation of (i.e. the attitude towards) object, goal etc.: *i*
n = the number of beliefs about *o* "

He then discusses the research which suggests that only five to nine items of information can considered by a person at one time and that fact limits the number of beliefs that act as determinants of attitude at any given moment. In passing he notes that:

"...many theorists irrespective of their conception of attitude, acknowledge that attitudes are not the sole determinant of behaviour, and that external influences need to be considered"

This is relevant in that much of the research that forms the basis of this thesis, and the research programmes with which some of that work is associated, normally deals with individuals as decision agents since that is the most disaggregated level from which to work. We recognise that the behaviour of individuals is influenced by their relationship to other people (and other things) and there has been a significant attempt in some of our research to identify the way in which appropriate aspects of sociology, social anthropology and theories of group dynamics can be formally integrated in the research process.

Attitudes by themselves are not a complete indication of how people will actually behave and Towriss reports on the models which link behaviour to behavioural intention and thence to attitudes towards a specific behaviour and "subjective norms". He observes (p65):

> "In essence the 'attitude to the act' incorporates the outcomes of the performance of the behaviour in a particular situation, and is thus more likely to be a better predictor of that behaviour than a measure of attitude to the object."
>
> "The normative component is determined by the perceived expectations of specific individuals or groups, and the person's motivation to comply with those expectations. An example of a normative belief might be that "My wife thinks that I should buy a Mini Metro as my next new car"

The main point of Towriss's research, and the reason for discussing it here, is his assertion that the models to which he refers contain a discrepancy between theory and practice. The nature of that discrepancy and the way he resolves it shed a great deal of light on the limitations of Lancaster's "characteristics", Quandt and Baumol's version of the Abstract Mode and Manheim's vagueness about the performance/demand relationship. It also leads to a general style of enquiry in much of the research reported in the papers for this thesis.

Towriss comments on the use of a free response format with a small group of people as the first stage in conventional research and offers an example of the questioning style (p66).

> " 'What are the things that come to mind about buying a Ford Fiesta as your new car?' The individual's responses are recorded, item by item; the beliefs most frequently elicited from the sample are abstracted and are termed 'modal salient beliefs'. Fishbein and Ajzen (1975), for example suggest that the ten or twelve most commonly occurring beliefs are used for this purpose. These beliefs are then employed in a second survey, over a larger sample and their evaluative aspects are recorded."

The procedure and analysis are slightly more complicated but need not be debated here since the main point made by Towriss next is (p67):

> "...the use of a common belief set not only results in severe limitations on the researcher's ability to test the theory underlying the model, but also the usefulness of the results.
>
> The derivation of a modal salient belief set presupposes homogeneity of beliefs across a given population (i.e. each person is assumed to possess the same set of beliefs). Since, in theoretical terms, this implies that each person has a similar conditioning history, such an assumption is unlikely to be valid. A consequence of the use of modal salient beliefs, therefore, is that individuals will be asked to respond to belief items which to them are not personally salient."

After a short discussion of the way in which this impinges on the validity of the normal analysis procedure and models he goes on to suggest an alternative form of model (p68).

> "The alternative form of expectancy value model which is presented in this paper is one which dispenses with the common belief set, and which instead employs individual salient beliefs (i.e. those beliefs which are idiosyncratic to the individual). The procedure for using this form of model is very simple. For each of the behaviours that are to be investigated, the individual's beliefs about the performance of that behaviour are elicited in free response format (e.g. what are the things that come easily to mind about using Brent Cross for your main weekly shopping?). The individual's responses are recorded item by item. These belief items are then read back to the individual whereupon they are scaled for their evaluative aspects and belief strength, using simple bi-polar scales. Attitudes to the behaviours are measured together with subjective normative beliefs, and intentions to perform the specific behaviours."

Towriss claims three significant advantages in this approach of which the second and third are the most relevant to this argument (p69).

> "(ii) Secondly, when using individual salient beliefs no *a priori* assumption of belief homogeneity is involved; thus compared with the use of modal salient beliefs, the chances of the presentation of non-salient beliefs is minimised. Because respondent's own beliefs are employed, tests regarding the model's validity can be made more rigorous. To take an example in the previous section, it is a relatively simple task when using individual salient beliefs, to test if an averaging procedure yields better estimates of attitude than using the simple summative model.
>
> (iii) Perhaps the most attractive aspect of using individual salient beliefs is that their use facilitates an examination of how, for example, beliefs about buying a particular product, or using a particular service, vary across a given population. ..."

The approach involves much data handling and analysis so that it too carries some disadvantages but the important point is that it demonstrates a point in time when it became possible to explore the "idiosyncratic beliefs" of people about potential decisions. It is not the only way of doing this and a number of semi-structured interview processes and corresponding analyses have been developed, some owing more to sociology than social psychology. It is, however, this potential to confront the economist's dependence on revealed behaviour, the assumption of common characteristics as pertinent to the individual, and the loss therefore of insight into diversity, that is of value. It suggests that where the interaction between two domains involves individuals (and as members of groups, communities and organisations) direct enquiry techniques should be used. It is that which characterises much of the research reported in this thesis.

What the scientists, economists and engineers contribute is the ability to separate out the internal interactions in the technical and production or supply systems. It is the bringing together of these with the ability to penetrate the perceptual world of the individual in a wide range of settings which constitutes one of the contributions of this thesis. In the next part of the thesis the way in which the internal worlds of technology, natural systems and individuals can be connected are explored. The range of case-studies is not systematic since the possibilities for investigation are seldom in the hands of the researchers but driven by events and issues. This research always has in mind the potential for intervention in organisations and society in the form of engineering design, policy instruments, structural features of organisations, and so on.

There is use of the terms such as *intrinsic nature, characteristics* and *attributes* in the fields of study discussed above. Within this thesis it is proposed that they be differentiated as follows.

Characteristics arise from the systemic behaviour of particular configurations of physical and engineering properties (and in other settings as organisational configurations and so on) and can be more generally described as *performance characteristics* when they are the interface with people.

Attributes are those properties of the good or service in use and in the context of the user which they (not anyone else) regard as relevant, described in their terms and values. (corresponding broadly to beliefs). Instead of Domain B being associated with consumer preferences this view implies that it is the domain of an individual's salient attributes with respect to some product, service and so on. What counts is their perception as individuals (in their social context). On occasion these perceptions of characteristics may be collectively shared; often they will not be. These attributes arise from underlying values and attitudes towards activities themselves so that the priorities of activities, relationships, well-being come before any consideration and perception of the performance characteristics which are of interest to the researcher. So there is also a question of relevance in that a set of responses to questions about an object, activity and so on will offer poor guidance if nothing is known about where in the person's agenda of concerns it lies.

What counts as an innovation to the individual is not whether some change in Domain A gives rise to new performance characteristics per se but whether any change in performance characteristics at all is interpreted by an individual as an innovation because it creates the opportunity for structural change in their activity set. Much the same is possible when someone who knows nothing of a product or service first becomes aware of it, what Hadfield (1997) describes in a somewhat different context as "perceptual emergence".

3.4 Technology as Supply and Demand Interaction

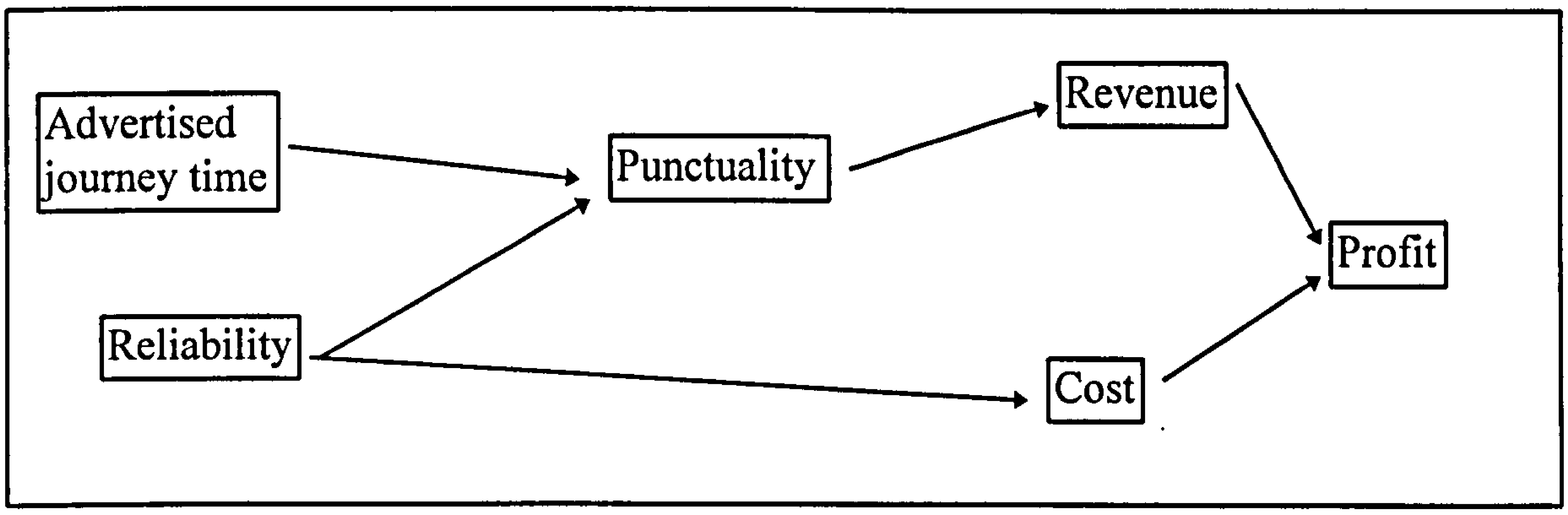
3.4.1 Introduction

One paper from earlier than the window of 1992-97 is included here because it provides a crucial platform for later debate and because in a sense it summarises a substantial part of the author's experiences up to that point. The particular paper, Seaton and Black, (1987, A1), is the distillation of a three year project undertaken for British Rail in the period 1984-87. The paper itself is selective of material from that project report for an audience of mainly specialist engineers at a conference on "Computers in Railways" (1987) where it found a niche at the softer end of the agenda on the economics of railway operation but focuses on the core rationale of the project itself. The paper should be read at this stage and will be expanded upon below.

The research project was co-sponsored by BR Derby (the Research Laboratory of BR) and InterCity (the then operating arm of BR responsible for all long distance passenger train services and newly constituted as a quasi-commercial business. At the point of privatisation InterCity had actually made a real operating profit over the two previous years). In the early 1960's the first long distance routes between London and Manchester, and subsequently across the western routes of the country to Scotland were electrified using the 25k volt overhead system. By the 1980's the original generation of electric locomotives were still in use (and still are!) and were becoming unreliable both in terms of availability and in the course of operation.

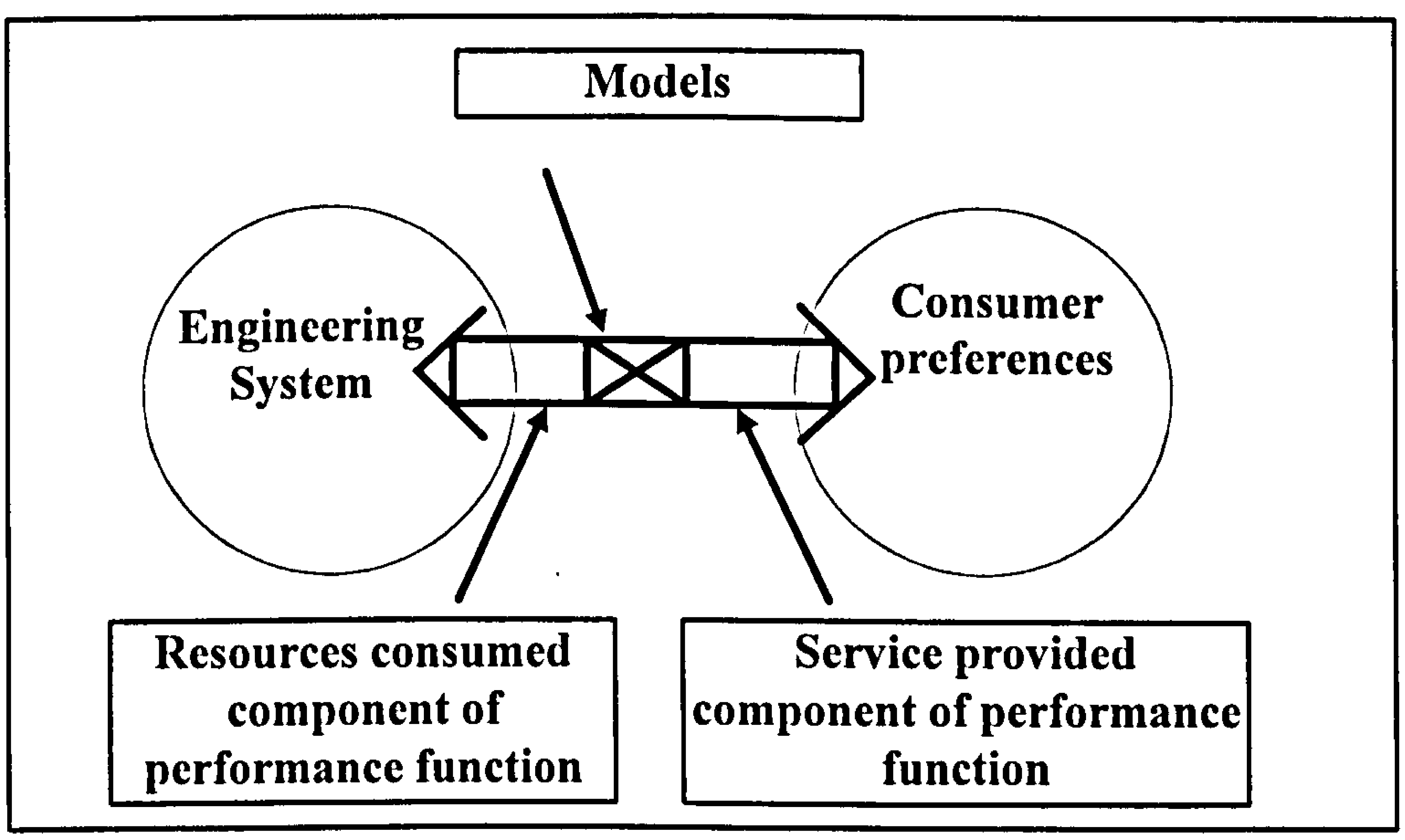
The original specification of the contract was to study reliability in terms of train availability at the start of a journey, but later encompassed components and sub-systems of the routes and trains run by InterCity. Within a very short time these reliability issues were re-articulated as a problem of train punctuality on arrival at stations (somewhat more relevant to passengers) and eventually to the relationship between costs of reliability (an engineering and operations design) and the costs of revenue lost in terms of passenger response to unpunctuality. In keeping with much of our earlier work we were attempting to find out from the point of view of profitable operation what the relationship between these two was. Profit per se was not as crucial a concept as generating some mapping function by which to evaluate this relationship which could equally have been concerned with subsidy. What was clear from the outset was that BR and InterCity in particular were unable to link cost and revenue functions. In fact their knowledge of costs and how they vary with engineering performance (speed, reliability, ride quality etc.) at a systems level was virtually non-existent. The problem we set ourselves was to find the mapping function between the costs of changing engineering performance attributes and the effects of them on train punctuality and in turn on passenger response as revealed in changes in revenue and as shown in the figure below from the paper.

Figure 3.2 Reliability/Punctuality and Profit



This strategy owes a great deal to basic systems thinking developed in Transport Studies in the previous decade. It also calls upon a number of disciplines, engineering knowledge (supplied by BR), reliability engineering principles (the systemic exploration of emergent performance at a systemic level of lower level sub-systems and components), econometrics as applicable to the cost functions of engineered systems and their engineering performance, railway management and operations (a research officer from BR who subsequently returned to them) and the elicitation and analysis of passengers perceptions and likely response to delay and unpunctual arrival (Black and Benwell, co-authors of the report to BR). The main diagram in the paper (Figure 2, p39) summarises the whole story of the work and is summarised below in terms of the standard diagram of translation described earlier and in terms of Manheim's approach.

Figure 3.3 Mapping between Engineering systems and Consumer Preferences



It was found possible to formally integrate engineering data with a model of train operation and thence with a model of passenger response. Until then BR had operated purely on guess work as to how a change in an engineering parameter would finally affect passenger revenue. They were not alone since we found over a number of years that few transport operating companies ever formed even a strategic systemic view of this type.

There were a number of features of the study which were of particular interest. The first concerns the hierarchical arrangement of components and sub-systems which go to make up an operating system such as a locomotive, a section of track, signalling and operations management. It was apparent that there were many non-linear relationships (and many discontinuities as well). Failure of components and systems specified in probability terms and the relationship between distributions was a foreign concept to the staff. A second interest was the extraordinary separation between the main sub-systems noted above. There was no notion of any trade-off between, say, locomotive performance, staff availability, points failure and signalling strategies under a particular type of failure condition. Another interest was that while engineers perceived performance in terms of specifications handed to them or negotiated, about speed, reliability and so on they operated in a knowledge domain which does not translate these into journey time, punctuality etc. which is the domain of experience of the passenger as elicited from passengers themselves.

The final output of this project included a "model" which, with planned timetable information and given type of failure by duration and location, could work out the short and medium term effects of such a failure. The task of the engineer is to design equipment, maintain it and provide the human resources needed to provide the system and of the operations management the staff to operate it. This created the opportunity to give individuals, sometimes very low in the organisation, the revenue effects of their decisions about their own little world and furthermore different specialisms could examine trade-offs rather than defend arbitrary fixed budgets and "could do better" pronouncements. The same approach also enabled engineering innovations to be evaluated and new needs of passengers and potential passengers to be translated into performance specifications for systems and sub-systems. The research, though predicated on the mitigation of failure can be used for the opposite, the promotion of new "profitable" services. (By proxy pricing the value of time of passengers "profit" can be translated into a wide range of social variables and thence policies). When we undertook a number of practical activities with maintenance engineers it was found possible to use this translation model to evaluate specific options almost at the level of individual pieces of track and points.

However it took some time for the "operators" to catch on to the same principle. Organisationally BR were attempting to mimic the behaviour of a profit making company while retaining the organisational structure of a bureaucracy. In this type of organisation the issue of safety is itself of fundamental importance and the maintenance of a safety culture in personnel is important. At a strategic level, of course, only so much safety can be afforded and some sort of evaluation of premature loss of life and injury has to be made whether explicitly or implicitly. Railways in Europe have also inherited the staff and command structure of the armed forces (The Inspector of Railways for accident investigation is still also a senior serving officer in the armed forces). In essence this gives a human control structure over successive hierarchies. Feed down processes are geared to strategy as determined by the executive and successively translated into action spaces at each lower level. The feed up loop is a reporting by exception process in which data is more a more aggregated. The discipline of the organisation is focused on blame and blame accountability and there are none of the organisational learning processes that can be seen in our later research into knowledge dynamics. The system is primarily data driven and that data is control data rather than decision-making information at the level of the strategy of the organisation. During this project BR actually eliminated a complete level of Divisional management of operations because communication and control technologies had so much improved. Under these circumstances the operators, who manage train staff , station staff, shunters and so on found it very difficult to come to terms which the implications that they could alter say, staff attendance, in such a way that it improved profitability. In other words money spent on effective training, industrial relations etc. could lead to a reduction in train delays and cancellations and subsequent loss of revenue.

3.4.2 Discussion

Eventually the lessons from this research were adopted widely within BR and extended to many other issues, including safety. The tendency was to enable a formal vertical integration within engineering and operating departments and lateral integration between supply and demand. This could have been an alternative model, suitably developed, to the privatisation of BR as enacted by the current UK government. As will be seen in later sections in this thesis this translation process, by formal models or by other types of management of knowledge transfer and translation processes is not generally evident in many large private sector organisations in the service sectors and little understood in industry at large. The promotion of formal modelling in the 1960's to 1980's may have generated a great deal of misunderstanding between analyst and modellers (hence the rise of more qualitative and softer systems techniques in management science) and some of these reservations have been tracked down in the survey of OR practitioners that forms the basis of the paper by Jeffrey and Seaton (1995, **B2**).

The way in which the environment in this study was treated as static gave rise to further thoughts. In reality engineering science throws up innovations in materials, electronics, and operations new ways of training or different conditions of employment. On the other hand while the demand for attributes of the rail service affect the response of potential passengers they in their wider roles are also changing their locations, relative preferences for employment and leisure and so on for many reasons which have nothing to do with the quality of rail services. This is the message that Manheim conveys in the diagram in the introduction. This can be seen as a co-evolutionary situation as between rail and passengers each of which is a system set within a wider set of co-evolving systems. Co-evolution of two interrelated systems is a convenient reduction in some cases for this complex situation because we can think of no real decision or policy context in which the systems in the primary co-evolution of interest are not also co-evolving with other systems. Each of our primary pair is also co-evolving with systems which are at different levels (scales, hierarchical location) in other co-evolutionary pairings. This can be seen as one way of interpreting the notion of nested hierarchies and will be discussed later with reference to emergent systems. It also suggests that one limitation of current evolutionary thinking is this element of reductionism (something which Allen addresses in his most recent work). This co-evolution has been formally explored in a PhD thesis by Qu (1995) which placed an exploration of the communication properties of organisations and employees within the context of the co-evolution of telecommunications and organisations. She showed that there were genuine innovations in telecommunications (in as much as they present new attributes to potential users or created new opportunities for action). These enable organisations to enhance other initiatives arising from the wider environment within which they operate; changes as such as distance working in order to retain particularly valuable personnel, new spatial distributions of offices in response to service demand and so on.

A further issue arises in that of vertical processes in the organisation. Towards the end of the BR research the case-studies, particularly with the operators, merged into consultancy (although this had to be limited by the resources and deadlines of the project proper). The management issues raised in this project gave rise to another research project in the form of a PhD by Paradissoupolous (1991). Paradissopoulos was a senior railway manager in the Greek National Railways with a qualification in civil engineering but with interests in the principles of management of nationalised utilities and services. His research into systems ideas had thrown up not only the early work of Ashby (1956), Bertalanffey (1981), Shannon and Weaver (1962)and their contemporaries but also the Viable Systems Model of Stafford Beer. Beer's view of organisations is based on what he calls a Cybernetic perspective, the science of communication and control. He developed his ideas intellectually through a series of books, culminating in a Managers Guide to the VSM (Beer, 1985), and through consultancy to many large organisations.

The principles are that organisations can be seen as hierarchically structured systems, each with different agendas with respect to other levels in the hierarchy, which are connected by channels of communication and variety reduction or amplification mechanisms. These fulfil, in the ideas of complex and evolutionary systems, the process of aggregation and disaggregation of action spaces (and by implication decision spaces and knowledge domains) of successive levels. The variety management uses Ashby's ideas and the communication processes owe something to Shannon and Weaver and something to the early work of Forrester (1981).

Forrester's early work in the late 1930's was on the then new hydraulic control systems for the moveable aerodynamic surfaces of aircraft. Inspection of the notation of Systems Dynamics shows its dependence on logistical control systems, i.e. where stocks and flows are of the hydraulic fluid. Positive and negative feedback is crucial to performance depending on circumstances and transition times and relative spatial distributions of demand for fluid at variable pressures (depending on movement and resilience to feedback) are some of the parameters of concern. Some of the communication and control in Beers model is about production and production control and successively higher levels are concerned with co-ordination of these to achieve what can be seen as emergent properties.

Although Beer, as a consultant, was able to achieve exceptional insights into organisational design, many others have queried his approach. Because of his association with the Alliende government of Chile some objections have been ideological. Others have argued that he took no account of learning and of learning as a human activity. Others feel that he fails to explain the evolution of organisations and takes what may be seen as a purposive view of organisations. Our research within Greek National railways aimed to demonstrate that what Gilbert, Seaton and Cordey-Hayes (1997) call Instrumental knowledge is well represented in his work but that Developmental knowledge is unappreciated. The fact is that he, and also Checkland, can achieve successful consultancy with organisations which few others who follow the intellectual line of reasoning seem able to. They may well underrate the implicit or tacit knowledge about people and management which they have and others do not. The research on the Greek railway management showed the limitations of the VSM model as well as its strengths (thus supporting the view that a number of perspectives are needed when situations are complex). The limitations concern the cohesiveness of people in the organisation as revealed by their common understanding of the relative contributions of different functions and levels to overall performance of the organisation

3.5 Conclusions

This phase of research activity in Transport Studies provided the basis for subsequent strands of research into Technology Transfer and Knowledge Dynamics on the one hand and to Technology Policy and Sustainability on the other hand.

The "supply" side can be seen as composed of organisations and people as well as engineering systems (soft or hard). Organisations may produce products, physical services, personal services and so on. How they obtain and handle innovation in the production systems, and how they evolve overall is the main focus of Chapter 4. So this strand of research enters that world and investigates their capacity for innovation and change and the policies that such organisations could adopt. It is a complex world in its own right and dependent on the knowledge, perceptions and behaviour of its inhabitants, and how they interact with the wider world outside. Much the same family of methods can be used in this world to understand the individuals and groups as can be applied to understanding the diversity of salient attributes of their customers or clients. From this human centred point of view the physical systems they manipulate can be seen as the physical manifestation of various types of knowledge interactions. At the scale above the individual organisation there are also a set of interactions that evolve over time. Much effort has been spent by Governments in designing and delivering policies to promote this capacity for innovation in profit making organisations, particularly in those that use physically engineered equipment, and in influencing the interactions at the next level.

The other strand arises from the application of similar thinking in a wider setting in which the use of designed physical systems in production or consumption, mechanical or bio-physical, impinges on natural systems. In this context the inner workings of any given organisation or agency are only one small part of the wider set of relevant interactions. The individual's perceptual world is just as relevant but now they may be in any one of their many roles. Central to this work is the expectation that many designed physical systems could be better designed if the design attribute space were to be extended to more accurately reflect the wider impact on natural and social systems. At the level above the individual's interaction with physical engineering and natural systems are also a set of interactions which are of concern to Governments. Often this is because the net effect of the many interactions below is unexpected and often unpleasant.

Methodologically an approach to this class of issues can be developed which uses the notion of mapping between physical/physical and physical/economic phenomena at one level and knowledge interaction at another. This method depends in itself on how issue relevant knowledge is translated and transferred. As will be seen in Chapter 6 it is possible to begin to find a common set of conceptual devices to encompass this whole area of interest.

CHAPTER 4

4. TECHNOLOGY TRANSFER AS KNOWLEDGE TRANSLATION

4.1 Introduction

This chapter focuses on four main publications, all based on case-studies and extensive interactive field work in companies. The research touched upon is, however, of greater scope and reference is made both to other research projects and publications. It demonstrate the evolution of thinking about technology from the research inside BR in the last chapter. The particular way that the word "technology" is used in much of the industrial and policy worlds makes it difficult to avoid using it in its common usage sense in this chapter.

The line of development is from the articulation of technology transfer from outside into manufacturing companies as an interactive process. Instead of the traditional view of companies buying new equipment, or inventing their own, the issue is seen in terms of knowledge. The failures and limitations of many policies aimed at promoting more vigorous technical innovation can be seen as a failure to understand the knowledge dynamics involved. Given such a knowledge perspective then it is clear that the technical attributes promoted by suppliers of knowledge map in a very imperfect way onto the attributes of many companies. One remedy is to better understand the attribute space of the recipient company and the exploration of this in terms of knowledge flows, different constituencies and so on is termed "receptivity". The idea of receptivity is used in an almost identical form when investigating the response of people to various policies, products and services. It is, in part, an extension of the perspective that Towriss developed.

These ideas have been developed in quite a practical way to help formulate policy towards manufacturing in an industrialising country in which there is no internal Research and Development (R&D). If the innovative capacity of manufacturing companies is considered in terms of knowledge then one employment aim of government in such a country might be to enable its indigenous population to be located in the paths of critical knowledge flows and their exploitation within companies. This research considers that the innovative capacity of companies is a function of the effort they put into people as well as organisation, and people as well as technical equipment. In many ways it has strong analogies to certain views about sustainability and sustainable productions systems in utilities and agriculture.

The third paper in this development shifts up a scale and considers the dynamics by which technical knowledge is translated and transferred between companies. It does this by tracking technical innovations in the Aerospace sector in Britain and how they are combined with prior knowledge of some other type to reveal themselves as innovations of another type. The key processes involve the abilities of certain people to place themselves in the way of the knowledge about such initial technical innovations and then to translate or map them into the technical knowledge of their own company and its innovative capacity.

The fourth paper is representative of a number of more recent research activities which make a more direct attempt to deal with knowledge processes in organisations. It involves identifying distinctions in the contribution of knowledge types to existing performance and to innovative capacity in both technical and organisational attributes. The research subsequent to that reported in this paper forms the basis of the concluding discussion and an important contribution to the final part of the thesis in Chapter 6.

4.2 Technology Transfer

This section moves the focus from an organisational decision context about service design in Chapter 3 to a broader policy context. A change in the UK government in 1979, to whom the idea of integrated transport planning and transport and land-use planning was anathema, and a shift in focus in transport to efficiency and profitability and away from accessibility, mobility and utility resulted in transport studies becoming preoccupied with physical distribution logistics, road pricing and so on. The opportunity was taken to apply the cumulative knowledge and interdisciplinary research experience from transport to the field of technical innovation in manufacturing and utility industry.

For much of the last ten to fifteen years or so in the UK, a strongly non-interventionist stance has been taken in government support for industry (by which we mean primarily manufacturing industry). The attempts by government to slim down and make more efficient this industry focused in two main areas. One was support for small and medium sized companies (SME's, defined by arbitrary numbers of employees). By promoting good practice and innovation the hope was that this scale of company would take on more staff and bite into unemployment. In larger companies again the message was about innovation but with more emphasis on leading edge technologies, high level technology and so on.

There was considerable emphasis on technology transfer between inventors, invention companies, universities and "innovating for use" companies and between the Defence sector and civil sector (in an attempt to justify Defence expenditure as a risk reducing front end for less risk capable companies). A whole range of mechanisms were introduced to enhance the generation of innovatory technology and the transfer of both this and existing technology. In general these policies were translated into detailed policy instruments, sometimes awards for clever inventions, but more usually into information dissemination about available technologies. One focus of this dissemination was the formation of Regional Technology Centres initially sponsored by the Department of Trade and Industry (DTI) around England and Wales as a sort of clearing house for various types of information. The initial sponsorship tapered off over a number of years with the intention that they would, in some way, become self-sufficient. Many did not survive and the remainder survived by becoming proficient in types of work other than those originally intended. They did not actually change much in the way of rates and types of technical innovation.

It was against this background that the paper by Seaton and Cordey-Hayes (1993, **A2**) was written. The paper uses the experience of four PhD research projects directed by these authors. Since the content of those projects, over a five year period, are adequately exposed in the paper there is no need here to cover them in detail. The paper itself contains some important conceptual elements that have gone on to guide a large number of more diverse research activities and it should be read now in order to give the basis for subsequent discussion in this section.

The idea that the issue of concern in technology transfer is actually about the transfer of knowledge rather than of physical equipment is central to the development of much of our subsequent research. The second key idea is that the idea of transfer is more tractable if it seen as an interactive process which has three components. Until then the tendency had been to see technology transfer as a one way process. The labels Accessibility, Mobility and Receptivity, first articulated by Cordey-Hayes in our discussions, owe something to our experiences in transport planning but also act as a simple taxonomic device which by asserting distinctions draws attention to the focus of much of the contemporary research and policy initiatives. It was possible then not only to locate the then current policies as being concerned with Accessibility and Mobility but to focus attention on Receptivity. A similar mechanism has subsequently been particularly useful in developing a taxonomy of knowledge types in organisations. Some of the research activity noted in the paper was about how Receptivity actually reveals itself within organisations, how it can be identified and what properties it has. The notion of Receptivity has also been extended into our research into Environmental Perception and Environmental. However it needs careful elucidation if it can be translated into guidelines for action and change by companies themselves. It is, within this thesis, clearly analogous to the rail service model discussed above in that the contemporary policy focus was on "demand" as revealed by requests for new technologies while Receptivity is much more about understanding the "needs" of an organisation from the point of view of the organisation itself.

As soon as the dynamics of the two co-evolving systems are considered the other interactions experienced by each of the systems have to be considered and that is what is being asserted in adopting the notion of Receptivity. It should also be noted that already it has been assumed that it is necessary to understand the perceptual worlds of the actors, their agendas, option and decision spaces and the attributes that are pertinent to them. So Receptivity suggests that we need to get inside the minds of these actors if we are to understand how to map available technology onto their attribute space. Ideally it might be suggested that organisations should have this capability themselves and, indeed, some large organisations do, but many smaller companies do not and this in itself suggests alternative policy foci to do with capabilities rather than configurations of supply (of innovatory ideas) and demand. We will return to this later in the context of organisations as evolving and co-evolving systems and in the context of Receptivity to policy and policy instruments in the fields of agriculture and environment.

It is also apparent that what is an innovation for one party may not be for another. There is a rich research literature on technical innovation in the USA and the UK (in the English language) and increasingly in Germany and Scandinavia in Europe. It has been a major preoccupation of the Japanese and Pacific Rim industrialised countries. Regardless of whether an innovation is technical or not it is possible to develop an idea of innovation in a more abstract way. This was hinted at in the discussion in Chapter 3.4 about railways and punctuality in that an engineering innovation for the supply engineering function might only result in a change in the scale of existing attributes of the recipient. So a really clever bit of engineering might reduce journey time, a clever piece of scheduling might reduce costs and so on. From the passenger's point of view nothing innovatory has happened; no radical changes in possibility have occurred and no change in the structure of behaviour is available. On the other hand what is conventional for one person or organisation may be innovative for another in that it introduces a new attribute into the arena.

In the case of manufacturing companies these new attributes may reveal themselves at various levels. Not least is the fact that many innovations carry with them a bundle of people (e.g. skill sets)and organisational attributes (distance working and performance measures which are not based on attendance) that may not have been encountered before. Towriss developed the social psychology techniques of Fishbein in his PhD and subsequently applied them to the issue of the determinants of new car buying as discussed in Chapter 3. Not all potential car buyers had the same set of salient attributes in mind and available new attributes do not appear on the agenda for some people. The same is likely to be the case for manufacturing companies.

Further research projects by Craig (1993), Longhurst (1994) and Gilbert (1995) focused on what we can now see as knowledge translation. The articulation of technology transfer as knowledge transfer is not in itself sufficient since it becomes apparent that specific knowledge in one domain may not be usable in another. It requires some form of transformation or adaptation before it can be integrated in a usable fashion with prior knowledge in another domain. It is not just a question of mapping in the way that the rail example deals with attribute mapping. Knowing how to do something, other than trivial routinised tasks, in one setting does not guarantee that it can be undertaken in another which has different routines and procedures or in which the imported knowledge has to be added to existing knowledge for some change to take place.

Craig takes the case of holistic fault-finding in manufacturing, designs the curriculum to professional training standards and then negotiates with a range of companies for its use in training programmes. With the exception of organisations which he found had little capacity to learn at all, he found considerable acceptance of the concept by both managers and operational level employees. In no case, however, was it actually instituted except where the essential elements of holistic thinking were dropped. The reasons for this are of interest. Often they lie in the problems of organisational boundaries which, with accountabilities and performance measures presented virtually immovable barriers to the capacity of change for managers. Indeed such limitations suggest that the primary role of management, to adjust decision and action spaces of employees, was denied to these managers. Other barriers occurred because of the lack of key actors in the process of change.

Longhurst tackles the issue at the point of interface between the employee and the manager and shows that there are range of difficulties that the manager and the organisation as a whole face when managers try to exploit the knowledge base of individuals. This problem is exacerbated when organisations train and educate employees without regard to the knowledge base that managers need to be able to exploit. Partly this is due to mis-specified knowledge needs by the organisation but there are also symptoms of translation problem as well. That knowledge is embedded in people rather than in artefacts further complicates the situation because of the idiosyncratic nature of people as personalities with values and perceptual systems of their own.

4.3 Innovative Effort

The previous research has lead to attempts to see organisations in much more people centred ways, particularly those organisations whose production functions are not based on conventional machinery and we shall return to these in the work of Gilbert, Seaton and Cordey-Hayes (1997). In the work of Al-Ghailani (1996), whose PhD I supervised and which is the basis of the paper by Seaton and Al-Ghailani (1997, **A3**), there are two main imperatives for the research. It would be helpful to read this paper now.

The policy context is quite different to the UK since all the considerable field work took place in the Gulf state of Oman. The Oman economy is only just at the point of substantial industrialisation. Most of the companies involved are strongly dependent on non-Omani nationalities for senior management and specialist skills. The companies are not generally very large nor are they at the forefront of technology internationally. The country is well supported by oil income but nowhere on the scale of Kuwait and Saudi-Arabia. On the other hand it is much more diverse in natural resources with a sound fishing industry, extensive agriculture and a very diverse landscape. It looks towards the Pacific countries, and India in particular for some of its technical skill base. The intention has been for some time to use oil income to create a long term industrial sector and to increase the employment role of Omanis in that sector. The other factor is that it would be sensible for that growth in industry to provide a base for the sustainable exploitation of the renewable resource systems while in a wider geo-political setting it would be better also to develop a limited number of technologies to a specialist level within the Gulf region.

The characteristics of the industry is that it is largely composed of companies which resemble SME's in the UK. They are not capable of supporting R&D functions internally so as to develop new technical knowledge and have to depend on external sources for new ideas, equipment and so on. Since they are managed by foreigners or are subsidiaries of foreign based companies the main sources of new knowledge are from outside the country. This presents a dilemma since not all Omanis can expect to study abroad for qualifications and many of those who do so in technical subjects end up working for the Government where pay is considerably higher than in the private sector. This situation is reminiscent of some types of tourist economy. Capital from abroad is used to develop hotels and tourist facilities. The tourists arrive and consume mostly imported goods. The profit from the hotels and facilities is retained by the foreign investors and local people at best end up in relatively low paid employment in the service sector or in local agriculture (since this is often the basis of the original economy). The benefits of this tourism by-pass the local economy (perhaps with the exception of notable locals). Much the same view can be taken of industrialisation in Oman where instead of capital, which in the short term is not a major problem, knowledge is in short supply internally. This view of accumulated knowledge as the equivalent to capital or at least to some set of capital assets is now finding wider acceptance in many countries and in many companies, particularly in knowledge based companies and organisations which operate no technical machinery and have no conventional engineering skills (e.g. service sector such as banks, consultancies, non-governmental organisations, media etc.).

In order to become part of the longer term knowledge economy it is necessary to find some strategy by which Omanis can be fully integrated into knowledge processes in industry. Straight employment subsidies are not thought to be effective since a sort of attendance or payroll subsidy does not guarantee that the employee takes part in the key knowledge processes in the company. The research considered two basic sources of concepts about knowledge in companies. One arises from work by Cohen and Levinthal (1990), widely used in the research described earlier in this chapter. They produce a conceptual model of "cumulative knowledge in a company which has an R&D function. The work was conceived of as a contribution to the debate in the USA about the returns to companies of R&D investment.

The other main strand of conceptual models arise from such researchers in the UK as Rothwell, (1990) at the Science Policy Research Unit, (SPRU) and Bessant and others at Brighton University and our own research in INTA. The limitation of this body of research is that it focuses on the transfer of technology from outside an organisation and thus is suitable for the types of non-R&D companies in Oman but does not deal with the cumulative knowledge processes.

What was also needed was a conceptualisation that dealt as much with the development of capacities to innovate as with technical innovation itself. In other words the capacity to use information in production and sales management, to adapt organisational boundaries and most of all to recognise that knowledge for the organisation is held in the minds (and hands) of its staff. Our work in Oman was undertaken by Al-Ghailani along these lines by reducing the relevant existing conceptual models to a set of necessary resource consuming activities that an organisation of this type would have to be under-taking if it was able to evolve itself as well as technically innovate. These activities were split into two dimensions, people versus technology centred and people versus organisation focused.

In a limited number but diverse range of companies it was possible to identify such activities and to estimate the amount of finance and time actually spent in such organisations on the various elements. In turn the activities can be assembled into a conceptual model more appropriate to this policy context and type of company. From the policy position it is now much clearer how technical innovation and growth is linked to both investment in people and organisational as well as technical capacities for change. By tracking the job functions of Omanis in these companies it is also possible to identify what policy instruments, types of industry and industrial and training support would best enhance the inclusion of Omanis in significant roles while developing an industrial base capable of long term development.

This and other current work represent the most recent developments in the substantive field of technology and organisational evolution using this bottom up approach. Again breaking down the problem to the level of knowledge processes and real world activity that they are associated with aids an understanding of the role of knowledge translation and receptivity. It lends weight to the benefits of considering situations from as microscopic level as possible if the emergent properties that are desired are to be understood. We are left with a number of useful conceptual devices which have use elsewhere. Receptivity has been progressively broken down by Craig and Trott, knowledge translation can be seen as a more advanced way of understanding technical features, the capacity of organisations to adapt and change is much more clearly mapped, the employees are seen as the agents of knowledge processes. Strategies that focus on the role of individuals in this capacity are now increasingly widespread.

4.4 Knowledge Diffusion between companies

So far the focus has been on organisations involved in technical processes for the production of physical products and how they respond to new knowledge (to them) not only about those processes and products but also about forms of organisation by which they can combine this externally derived knowledge and their prior knowledge in an innovative way. This suggests that innovation is a much about organisational forms, processes and structures of accountability and performance as it is about the physical elements and sub-systems which have to be managed. However organisations do not operate in isolation and there is a great deal of interest in how knowledge moves between different companies and different sectors of industry.

Cordey-Hayes, Craig and Seaton (1995, A4) report on a project for the Aerospace Division of the Department of Trade and Industry (DTI). The context is that the Aerospace industry in the UK is to some extent dependent on the demand for aerospace products by the military and thus indirectly on public funds. In addition there had been a long history of R&D subsidy for civil aviation products. Politically this had been questioned and the overt task was to identify and value the contribution to the British economy of the spill-over benefits of Aerospace R&D. There was a widespread view that the leading edge characteristics of Aerospace technology would generate knowledge that would be of more widespread use in other industries. No-one had tried to identify and evaluate this in the UK. The paper could usefully be read at this stage.

The report as published emphasises this evaluative aspect. Seaton & Cordey-Hayes subsequently gave a presentation at the Royal Aeronautical Society to a wider industrial audience in which the automotive and off-shore industries were well represented and in which the process nature and knowledge translation aspects of the project were considerable more emphasised. This is not available in the format of the presentation but was reported in two articles in 1996, one of them an occasional paper from the Royal Aeronautical Society and another in the magazine, "Supply Management", August, 1996. The key aspects of this work are less to do with the notional economic benefits than with the processes of knowledge transfer at a macroscopic level. What becomes clear is that technical and scientific knowledge from Aerospace is almost never directly transferable to other industries. There is seldom a need to meet the same stringent requirements that Aerospace imposes so that there is often a trade off between one or more process or product attributes and cost or the enhancement of another useful attribute in a different setting and use. However, most notably what often happens is that knowledge from aerospace is combined with prior but as yet unusable knowledge from some other sphere. This seems to be highly dependent on the ability of individuals to identify in what they seen elsewhere something than can be transformed or translated and also combined with this existing knowledge.

Particular situations and particular types of people seem to be associated with this process. In general it may be enhanced by the amount of scanning undertaken by potential host organisations (as in the case-study in ICI by Trott) but at the end of the day it also needs someone who can imagine the transformation of the knowledge and make formal connections with existing knowledge or can see two external pieces of knowledge and make a new connection between them They also need to be in a position for this connection to be credible to the host organisation and also for that host organisation to be able to adapt its staff, processes and structure as needed to take advantage of it.

It was apparent that this technical knowledge translation and transfer occurred in loosely associated groups with some other domains bereft of any symptoms of transfer. This was not a welcome message for those who would like to be able to find simple recipes for enhancing knowledge exploitation from R&D intensive sectors more widely. It does, however reinforce the view that the exploitation of knowledge is highly dependent on the quality and circumstances in which individuals find themselves and encourages a much more human centred view of technology transfer as a human based knowledge process.

4.5 Knowledge dynamics in organisations

The final section in this sequence takes another direction. So far we have been concerned with organisations that depend on physical engineering for their products and production functions in which the main problem was originally articulated in terms of innovation rates. By considering the internal processes by which innovation in its widest sense takes place the idea of knowledge processes, centred around people and involving knowledge translation gives a somewhat new perspective. There are many organisations, commercial or otherwise, in which the management of technology and technical knowledge is not central to their activities. Is there any way in which the ideas developed so far can be applied to them?

One of the pre-occupations of many organisations over the last decade or so has been with Information Technology (IT), and computers. Gradually over time the purely technical element (IT) has been seen as only one part of the wider issue of the design and management of Information Systems. In turn this field of study has focused more and more on the functions that use IS and more and more on the individual as users of IS. In our work which has involved IS we have seen it in terms of a "soft" technology with all the same implications as other forms of change. It would be possible to develop an interesting comparison between the IS community and its research and that of ourselves and similar researchers. One main difference stems from the pre-occupation of the IS community with technical design and functional use and so much the same mistakes have been made as in the example of BR. The way in which the technical attributes map into the attribute domain of the potential user is not well understood. The main difference in our own work is the idea of receptivity as a set of linked stages in a complex process by which the organisation can assimilate an innovation whether it be technical or organisational. In turn the application of these ideas involves an interdisciplinary approach.

The origins of the formalisation of ideas about knowledge translation and dynamics lie in part with the PhD research of Gilbert (1995) supervised by Cordey-Hayes who researched issues of change management in organisations, particularly the implications associated with new IS. This was combined with the research reported in Trott, Cordey-Hayes and Seaton (on inward technology transfer as a knowledge translation process) in the form of a double loop learning model in Cordey-Hayes, Gilbert and Trott (1995). This provides the basis of much of the subsequent development in innovative effort and knowledge dynamics. The original work of Gilbert distinguished between instrumental knowledge and developmental knowledge as described in Gilbert, Seaton and Cordey-Hayes (1997, A5) where these two knowledge types are also embedded in a double loop learning model. This is the key paper for this section which it would be helpful to read now.

The distinction between these two types of knowledge recognises that an organisation can go on improving its performance through better application of instrumental knowledge as well as investing in its capacity to change (adaptivity). The conceptual model in Gilbert, Seaton and Cordey-Hayes shows something like a double loop learning model for the organisation which depends on both instrumental and developmental knowledge being present at each level of the organisational hierarchy and interactive between them. In other words developmental knowledge is not the monopoly of managers nor instrumental knowledge the sole speciality of the employee. Cordey-Hayes and Gilbert, (1995) have published on the similarities and differences between Trott's work on inward technology transfer in ICI and Gilbert's original conceptual model.

There has been an opportunity to develop these ideas further more recently and the results of that research are highly relevant to the conclusions in Chapter 6. There is at the moment an interest in what is called Virtual Organisations. These are supposed to be the potential forms of knowledge based organisations in which the functions do not need to be physically in the same place and which depend on specialist companies to contribute appropriate skills. These trends of interest in "Virtual" have much to do with the interest in how communication technologies may alter the form of society and organisations. However, the idea of Virtual Organisations does beg the fundamental question of why we have organisations as we currently know them and that has forced us to rethink the raison d'être of organisations yet again.

Telecommunication companies are interested in the idea of Virtual Organisations as part of a strategic wish to understand the demand dynamics which are likely to affect them as a company. In order to do this and extend it to possible future scenarios of organisations as potential customers as well as of the telecommunication companies themselves they need knowledge about the interior world of these customer organisations and a taxonomy of knowledge and knowledge processes they use. A project along these lines has been undertaken recently. It has two main components, a taxonomy of knowledge as relevant to organisations based on all the research mentioned in the text above, and case-studies within the telecommunication company itself on how managers and staff actually perceive knowledge and knowledge processes.

The two items' components are brought together through the further development of the research described in Gilbert, Seaton and Cordey-Hayes (1997). What people in real organisations actually think of as "knowledge" and "knowledge processes" is not well understood, though Trott's work comes near it and Longhurst had no problems in using the term "knowledge" as distinct from "information" with people in organisations. In the spirit of bottom-up investigation of the perceptual world of the key actors two case studies have been undertaken. Essentially employees were presented with Gilbert's conceptual model to create an agenda for discussion and then how knowledge is transferred, translated and inhibited is explored in the context of their working world.

Two other features of this work are worth noting. The strategy of the research is an example of interdisciplinarity as between business systems modellers in the host organisation and a technologist and a management researcher in the University research team. The second feature is that the interaction leaves the respondents with further insights, a vocabulary and an extended conceptual repertoire within their current jobs and to take with them elsewhere in due course. A final comment; when working with companies the activities can often be seen as case studies which support some theoretical or conceptual enquiry by the academic. In the UK the preoccupation with commercial confidentiality is such a constraint on publication and knowledge transfer between academic researchers that we have sought to build in as a deliverable to the contract provision for joint publication in the academic press. Such is the situation with the project noted, so that the intellectual insights overall from the project will be presented in publications soon after the completion of the research. Thus two of our ethical problems can be satisfied. We cannot assume that respondents to interviews and interaction will necessarily be better off by assuming that in due course some higher level decision-maker will make beneficial use of the knowledge. We also believe that the respondents should themselves be better off, with respect to their agenda and concerns.

There are a number of detailed points arising from this and the Gilbert, Seaton and Cordey-Hayes paper which can then brought together in the form of some main observations about knowledge dynamics..

- It is not sufficient just to discriminate between one knowledge type and another. The processes and interactions to which they relate must also be identified.
- Knowledge processes underlie the effective exploitation of knowledge
- They arise from interactions between people
- These interactions are influenced by organisational and management structures and are based, at the most basic level, on trust, reliability and clarity.
- Knowledge interactions are an interpersonal and cognitive process and are part of the general class of human learning
- Knowledge interactions can be seen as composed of two components, "transfer" and "translation" which need:
- Prior established channels of interaction which have been developed by mutual consent and personal acquaintance. Often this will need face to face contact and shared experiences
- Knowledge processes may use various types of communication and information technologies but cannot be substituted by them. Inappropriate design or use may actually inhibit knowledge processes
- Knowledge domains, at least in an organisation, are associated with job functions of individuals and groups so that action and decision spaces of the individual are intimately related with knowledge processes
- Managers have not only to handle lateral knowledge interactions but also to deal with (organisationally) vertical knowledge interactions
- While instrumental knowledge may reside with the individual, group or organisation developmental knowledge is associated with individuals. Organisation developmental knowledge is effectively the distributed developmental capacity of the individuals rather than an "organisational" property.
- Individuals each have unique histories of experience and knowledge acquisition. Diversity resides in this distributed developmental knowledge base. The attributes of organisational adaptability and flexibility arise from the inculcation and management of this developmental knowledge.

4.6 Conclusions

Knowledge translation can be considered as the ability to create a mapping function between one knowledge domain and another. Knowledge transfer is the complementary ability to extract pertinent knowledge from one domain and to apply or deliver the translated knowledge to a recipient. It requires prior understanding of the knowledge domains between which translation and transfer may take place and the opening of channels between them. When all of these processes are well tuned (the action, decision spaces and interactions at one level map well onto the requirements at another level of another domain) and are properly supported by appropriate education, training and information systems the organisation will have enhanced its ability to adapt and innovate.

Knowledge processes and failures within them are more useful contributions to understanding knowledge management than the earlier simple classifications of "knowledge" types. Developing distinctions between knowledge processes and contexts is likely to be a fruitful way of developing both investigative and educational models of organisations and of increasing the range of conceptual devices available to managers for knowledge management.

Further development is needed of the ideas of knowledge dynamics, the further development of a taxonomy of knowledge processes, particularly in the context of tacit knowledge and rules and hierarchical features of the organisation

There are interesting issues about the relationship between knowledge processes and organisational evolution. The extent to which business units really derive synergetic and emergent knowledge by being part of the corporate enterprise is central to understanding potentially new forms of organisations. However, many of the signs are that that knowledge processes are a subtle and social aspect of human relationships at work and cannot readily be substituted by information systems. The understanding of the relationship between information and communication systems and knowledge dynamics and management is to some extent dominated still by a pre-occupation with the technical attribute space.

A clearer identification is needed of what the actual knowledge management issues are. In our policy relevant environmental research, discussed in the next chapter, the ideas of option, action and decision spaces have already been proposed in the context of understanding receptivity to policy instruments. Quite how these reveal themselves in the organisational world with different accountabilities and performance measures needs to be considered.

CHAPTER 5

5. POLICY RELEVANT RESEARCH AND TECHNOLOGY

5.1 Introduction

This chapter builds partly on the previous chapters but also includes some additional perspectives. Methodologically it introduces the ideas of policy and decision relevant research. The additional influences stem from a more explicit inclusion of conceptual devices from complex dynamic systems theory. The phenomena of interest here are those that involve the interactions between engineering and production systems, individuals, communities and agencies and the natural systems which are generally and loosely described as "the environment".

The linkages to previous chapters are through the ideas about knowledge dynamics and mapping functions. In the earlier research knowledge processes inside organisations are the topic of research. In this chapter they are also part of the methodological issues. Researchers in this interdisciplinary and policy relevant research field are knowledge agents and cease to be anonymous and virtually hidden and become identities in their own right since the knowledge interactions between researchers and research disciplines (and the researched) are a necessary contribution to policy relevant research. Interdisciplinarity itself is thus part of the research agenda.

The research on technology transfer and knowledge dynamics in organisations arises from what some have described as a post-modernist and process perspective. It deals with the world from a point of view in which structure and configuration are no longer the dominant concern but work in conjunction with the patterns of actions, behaviour, and activities which constitute the dynamic of the "system of concern". Carried to extremes a process theoretic approach suggests that physical entities are the ephemeral manifestation of complex social and perceptual interactions and transformations.

This thesis takes the middle ground and merely observes that a historical preoccupation with structure, command and control, formalisation of hierarchy (and so on) needs to be countered by a concern also for the processes (often involving people as individuals or in groups, communities and organisations) which that structure facilitates. In this it complements the conceptual domain of complex dynamic systems theory as applied to the interactions between social, physically engineered and natural systems.

The distinction is that much of complex systems theory, derived as it is from associations with the chemistry and physics disciplines, tends to use mathematical representations of phenomena while the process theoretic approach, as identified in the earlier chapters, starts with the perceptual world of the individual. As will be shown the combination and interaction between these different positions offers a significant opportunity for the generation of synergetic and emergent theoretical knowledge as well as creating a powerful platform for informing policy makers about effective intervention in complex situations. These two complementary positions can be distinguished (as in other branches of systems theory and application) as "hard" and "soft" approaches each with theory building and theory testing strengths and weaknesses.

A further distinction that was implied above is between policy relevant and decision relevant research. The reason for making this distinction is that there is a body of research about decision making and a separate one about policy relevant research and yet another about the policy making process. Much of the research into decision making uses developments from the micro-economics in the style of Lancaster and the investigation techniques that Fishbein developed and which Towriss's work represents. It is about the decisions of individual actors (in their social context), often about products or services but also about lines of action or behaviour. It is exemplified in the research into farmers' evaluation of agro-forestry by Park (in Section 5.2) and the model of farmers' decision making incorporated into the complex systems model of the Argolid region of Greece discussed in Section 5.3 below.

Policy research requires an intimate understanding of the political process, the constitutional infrastructure and legal resources as well as of relevant science. We have just obtained funding from the EU DGXII at the time of writing for a joint Swedish-British-French project on science research and environmental policy and comments about this field of policy research are made in Chapter 6.

Policy relevant research is an attempt to integrate and exploit knowledge from multiple and interdisciplinary research for situations in which there are symptoms of problems which will almost certainly require policy intervention. It is essentially a diagnostic lead approach to problem formulation and was first defined and enacted in our ARCHAEOMEDES I (1994) research and further developed methodologically in the research project on Environmental Perception and Policy Making (EPPM, 1997). These reports for the EU, DGXII, are in the public domain but too lengthy for inclusion in this thesis. Both these and the current ARCHAEOMEDES II project were co-ordinated by van der Leeuw whose joint paper with Lemon and Seaton, (Lemon, Seaton and van der Leeuw, 1995) is a more accessible vehicle for communication about policy relevant research than the project report and is deployed in Section 5.3. A companion paper in the same publication is van der Leeuw (1995), "Social and natural aspects of degradation", which is a particularly helpful and comprehensive treatment of the linkages between historical and contemporary physical and social science research, policy relevance and research method in the field of degradation of socio-natural systems.

Section 5.4 of this chapter returns to the central issue of technology. Where, as in the Argolid, the use of engineered artefacts and systems leads to degradation of the bio-physical system and potentially to threats to the social system, there is often a tendency to try to remediate that degradation by the use of yet more engineered systems, the so-called "technological fix". Given that it is possible to offer a definition of "sustainability" which is related to resilience and survival (Sections 5.2 and 5.4) it ought, in principle, be possible to reconsider the design space of these artefacts and production systems. That is the aim of a number of our current research projects and one on water recycling technology is used here to demonstrate the approach. This returns us to the themes of the Seaton and Black paper in Chapter 3 and the underlying arguments in Chapter 2.

5.2 Integrative research and sustainability

This section addresses the issue of how productive activities (which involve intimate interactions between bio-physical, social and technological systems) can be seen in terms of the nature of both vertical functional and lateral knowledge interactions. One of the main activities which has been considered is that of agriculture although more recently research has been initiated in the field of water supply and disposal in the context of sustainable cities, and in the use of land-fill sites as carbon storage systems.

Agriculture can be seen as a food and energy production system which can create both social and physical environmental problems. In these social/bio-physical systems situations it is possible to develop notions of sustainability which derive from complexity theory and the more modern branches of ecology and evolutionary theory. In turn these notions can be applied to another family of technologies, those often referred to as utilities such as water, energy and communications. These are discussed in Section 5.4 below with respect to integrative design of utility systems and their contribution to sustainability.

The PhD research of Park, reported in Park and Seaton (1996, **A6**) approaches sustainable agriculture, in the context of particular options for crop and cultivation, as though it were a production technology and it would be appropriate to read this paper at this point so that the following discussion can be placed in context.

There is an interesting tension between a perspective on agriculture as a food and energy production system and a perspective on an agricultural system as "farming" and therefore inclusive of farmers as people living and working to a particular life-style. The knowledge domain of agriculture as a production system is dominated by bio-physical processes at the technical level and by engineering and economic systems in the cultivation process and choice of crops. The "farming" view of agriculture extends its boundaries to include the farmer as a decision maker operating within decision spaces determined by the agricultural policy environment of the time but embedded in a socio-political systems as well. The former view is taken in this section while the next section extends the boundaries towards the second view.

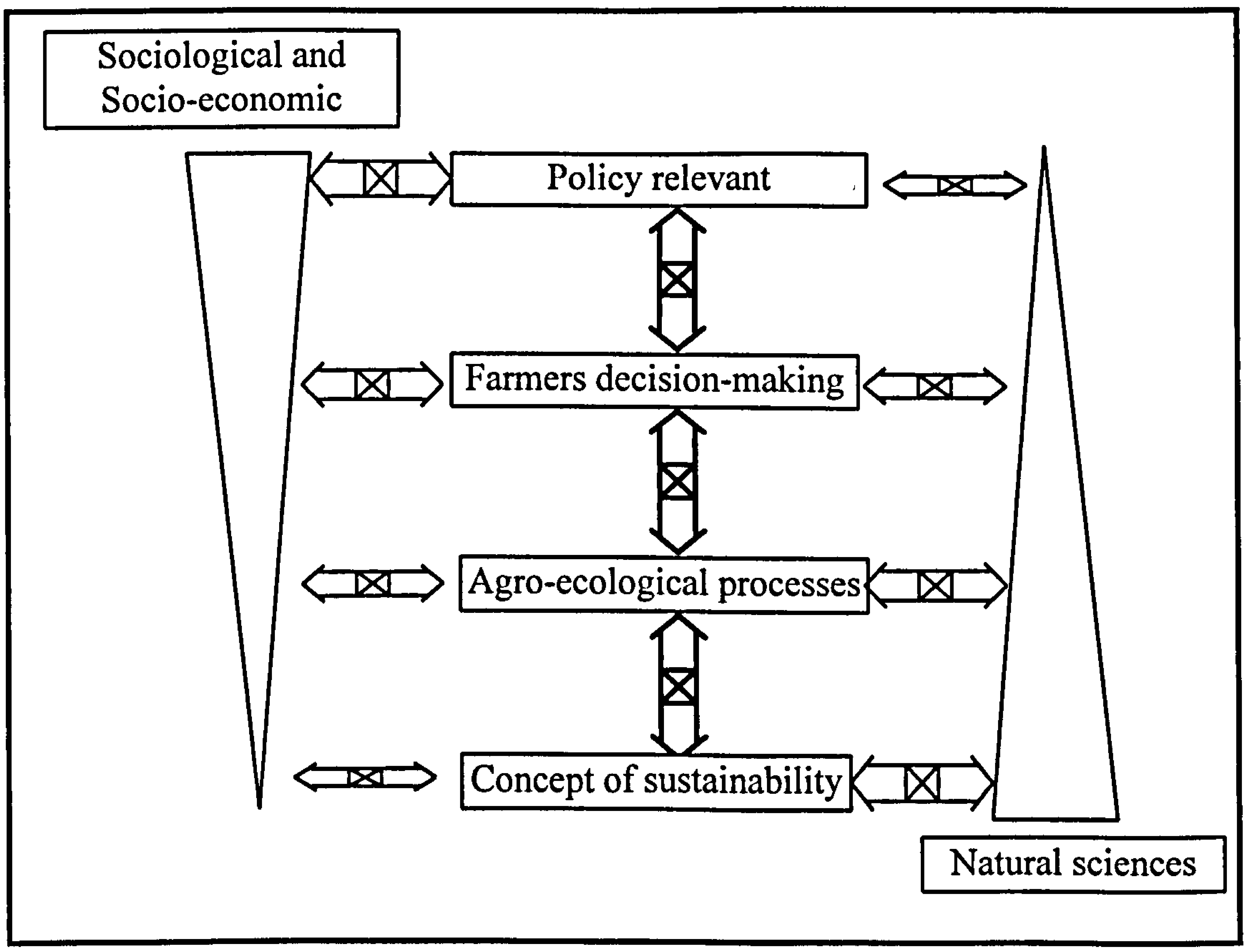
The research shows that if agriculture is considered as a production system it can be analysed as a set of mapping functions of a physical and physical/economic nature between hierarchical levels in one vertical plane and as a set of knowledge transfer and translation activities in the other plane. At each level of the hierarchy lateral translation depends on knowledge transfer from appropriate research disciplines and associated practitioners.

The paper by Park and Seaton explores that agricultural research with particular emphasis on integrative method and shows the framework within which such knowledge integration may take place and then proceeds to tackle the practicalities of that process. The particular agricultural technology considered is silvo-arable cultivation, the joint cultivation of trees suitably interspersed among other conventional arable crops. The effect of this introduction of trees is to reduce the depletion of crucial bio-physical processes in the soil system. In turn the effect of this is to increase the possibilities for growing some other crops at some time in the further. The long term benefit is in the ability to adapt to future, but unknown, circumstances while the potential costs, if any, are the economics of this technology in the short to medium term.

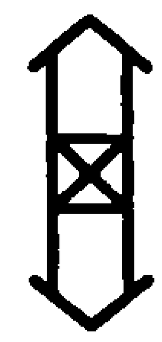
Before discussing the wider implications of this framework it is helpful to highlight some of the key issues addressed in that research. There are three levels of hierarchy which interact in this work. The bio-physics (ecology) of the soil system, the act of cultivation and the economic parameters that guide farmers towards different crops (and crop combinations) and alternative cultivations of those crops. An understanding of the relevant dynamics in the soil was aided by access to an ecologist, to the particular silvo-arable cultivation systems via a specialist company with the help also of the agricultural departments of Cranfield University, to cultivation and farming practice and knowledge of farmers by Park and to integrative method, systems (including modelling) and decision-making by this author.

The figure below is adapted from Figure 3 (p91) in the paper and Figure 2.2 from the subsequent research report on the Argolid in ARCHAEOMEDES I (1994). It thus provides also a convenient link between this work and a much larger body of subsequent research.

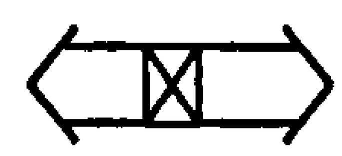
Figure 5.1 Knowledge Translation: ecological-agrosystem-policy interfaces



Interactions vertically which require some form of formal mapping function are denoted in bold thus:



Lateral interactions which require knowledge translation and transfer are in lighter print and denoted thus:



The width of these arrows is intended to convey the strength of the dependency on the two broad disciplinary fields of the social sciences and the natural sciences. This crude distinction is made to emphasise the traditional separations which can occur and which this style of integrative research attempts to tackle. The key to the work lies as much in the compromises made in the use of existing disciplinary knowledge in order to achieve some form of functional holism of the work as in the sophistication of the components.

The best models of organic content dynamics and of invertebrates in soil have no parameters which adequately represent the act of cultivation and crop type. They stand alone as insights rather than integratable knowledge. In order to make integration possible (that is, "what is observed in one set of circumstances may be related to phenomena occurring in other sets of circumstances", Massey, op cit.) a change in at least one variable in one domain has to be capable of being mapped as a change in another related domain. In fact it was necessary to undertake further field work and experiments to enable this. Although that fieldwork was greatly aided by access to controlled agricultural sites with centuries of history at Rothampstead (a national agricultural research facility), it was relatively crude compared to the contemporary specialist scientific research. None the less it focused on the relevant issue while other research did not.

Similarly, while there are many econometric crop choice models in the style of Lancaster (certainly since the 1960's and even earlier in some cases) these cannot consider an innovation of the type in the case-study nor are they based on the perceptions of farmers as production decision-makers about the situation. Yet again it was necessary to undertake an original investigation to penetrate this aspect of the situation. One of the objectives of the work was to investigate the reasons why options such as this are not taken up by farmers and how much change (through policy changes or just over time) would be required for them to exploit this type of sustainable agriculture. This is another example of where, without direct investigation and interaction with the decision agent, there is inadequate knowledge of the option and decision spaces within which decisions, if they are to be made, take place. This greatly influenced the work in the Argolid discussed in the next section, where the farming context was a main feature and echoes the issue of alternative perspectives as to agriculture as primarily about food and energy production (techno-econometric) or whether it carries with it many more social and cultural attributes.

What the research in Park and Seaton does not tackle, although this was realised towards the end of their investigations, are the scale effects and aggregation problems if policy were to shift towards supporting this type of crop. It is not clear whether it would be better to go for some agroforestry on many farms or selectively on a limited number. The problem is that if it is one of a number of crops the additional joint cultivation it increases the complications at the farm level while it is sufficiently uncertain (at the time of the research), not to be a good option for a small farm (always assuming that soil type, climate and economics at that scale are suitable). What was also found was that the marked trend to monocropping, or at least very limited ranges of crop and cultivation types, have resulted in a loss of knowledge about how to cope with alternatives and may in due course lead to loss of the ability, at the farm level, to learn about how to do this. In practice we may be seeing the loss of cumulative and diverse knowledge at the level of the farm. This may considered to be a feature of intensive farming in Northern Europe and in the UK in particular but the monocropping by some farmers in the Argolid presents similar problems.

A knowledge perspective would suggest that if farming is likely to be effective only in larger scale units (which is the apparent policy of the EU) then one of the balancing needs is to ensure that the cumulative knowledge at the farm level, or in regionally specialised areas, is itself maintained and developed. The reasoning for this lies in the particular concept of sustainability that this research has proposed. This, as mentioned earlier, is derived from the ideas in complexity and evolutionary theory that loss of access to options in the future reduces adaptability and flexibility and therefore the resilience of any system in question. Unlike the Bruntland (1987) definition of sustainability the view taken here about sustainability is not about continuity of the same thing but continuity of option spaces. This does not mean the same options over time but sets of options which have equivalent utility at the future point in time that those decision agents need them. As Jeffrey and Seaton argue in another paper, it is not the configuration of current structures, transformations and processes which is crucial but the capacity of the system of interest to adapt to any change over time and to form, in due course, new types of subsystems. This begs the question of at what scale any system should be considered as defining internalised resilient properties since at lower scales at least some failures and successes in terms of survival would be expected. It is not clear that attempting to develop long term survival properties in every subsystem is necessarily a survival strategy at the scale above. Much depends on how emergent properties and systems are a function of the individual sub-system and how much a function of the interactions between them.

One feature of the research reported in Park and Seaton that was not specifically addressed is that of policy relevance. The research really only considers one innovative technology (with some technical variations) and the response of farmers to that. It does detect that costs, uncertainty about markets and lack of appropriate production and product knowledge may be factors in the reluctance of farmers to opt, at least in part and at the time of the research, for this type of agriculture but does not formalise potential response to policy instruments. In the terminology of this thesis it is more about decision relevance than policy relevance because it only operates at the level of the individual farmer. The interactions that would occur between farmers, farmers and markets, and so on would create emergent phenomena, perhaps beneficial, at a higher hierarchical level. It is this emergence as a function of the interactions between people, their actions, organisations and so on which is the rationale for policy relevant research.

5.3 Policy relevant integrative research

The research in the agricultural region of Argolid in Greece is part of the wider ARCHAEOMEDES I research project (1994) involving many branches of the natural sciences, social sciences and sociology and social anthropology, and in many different sites in the European Union, presents a problem of how best to communicate about it. Overall it is a major exercise in multidisciplinary research in the context of the implications of climate change for the countries bounding the northern Mediterranean Sea. The idea was to investigate and to collate research across the largest time span, from archaeological time to contemporary time about physical, social and economic vulnerability to changes potentially associated with climate change.

The role of the Cranfield team was to research a "vulnerable" situation involving agricultural production in the Argolid region of the Peleponnese some 200 kilometres south-west of Athens. Here the individual actions of farmers in choice of crop (citrus fruit) and the concomitant need for irrigation, coupled with the availability of suitable technology, and encouraged by EU price guarantees has lead to a situation of environmental degradation. The level of water in the acquifers on which they depend has dropped letting in sea water and salinating the supply which in turn potentially affects the quality and yield of the crops. This situation is periodically exacerbated by periods of low rainfall (whether cyclical or due to climate change). No one farmer can affect the collective situation by his own actions although he can opt for some other crop or economic activity. These are the typical characteristics of an emergent system giving rise to a policy relevant issue.

The initial reason for the inclusion of IERC in the programme was the work by Allen on complex dynamic systems modelling but was enacted by a technologist (Seaton), sociologist (Lemon), and an econometrician (Black) with the collaboration of two local agronomists, (Blatsou and Calamaras) as well as contact with specialist hydrologists at the Agricultural University of Athens and a Greek-speaking social anthropologist. One of the main challenges was to find out how these different disciplines might be enabled to work in an interdisciplinary fashion so as to enable the integrative process to be applied in a policy relevant setting. The work discussed above and in Park and Seaton (1996) was a helpful starting point. It is also noticeable that the ideas developed in Seaton and Cordey-Hayes (1993) permeated the research and that paper is referenced and quoted in the paper by Lemon, Seaton and van der Leeuw (1995) that is used to support this section.

The formal report of the Cranfield research team on this project is well over two hundred pages long and quite unsuitable for formal inclusion here. However the content of that research has been the topic of a considerable number of papers by the research team. Some of these have overlapped in content because they have been aimed at different disciplinary audiences and need not be considered in detail unless for general interest. Indeed two were deliberately authored and published in order to discharge part of our obligation to transfer knowledge from policy relevant research back to the actors embedded in the situation of concern; Lemon, Seaton, Blatsou and Calamaras, (1995, **B3**) and Lemon, Blatsou and Seaton, (1995, **B4**). A further paper was really an attempt to report back to the Mediterranean agricultural research community, Lemon and Seaton, (1996, **B5**).

The reader is asked to read the paper by Lemon, Seaton and van de Leeuw (1995, **A7**) next. It was written a little time (1993) before the end of the project, for presentation, discussion and publication at the European School of Climatology and Natural Hazards, run by senior officers of DGXII (Science Research Directorate) and subsequently published in 1995. Although it makes no reference to the complex dynamic systems computer model which integrated much of the research, it offers the most comprehensive treatment of the project in terms that are the most relevant to this thesis. Reference to Figure 5.1 above derived from both Park and Seaton and the Argolid research might also be helpful. The attention of the reader is particularly directed to page 199 of the Lemon, Seaton and van de Leeuw paper where there is a useful linkage between the technology transfer research discussed in Chapter 4 and this policy relevant research under the heading "The implications of the study for policy relevant research".

With that paper in mind there are a number of issues that can be developed. This thesis concerns the relationship between a particular view of technology, knowledge translation and policy. Although there are many interesting features in the substantive policy relevant issues, in this thesis they exist primarily to demonstrate these issues. It is with that aim in mind that the following discussion is developed since disciplinarity is one of the research issues of concern. The discussion of disciplinary interaction is greatly facilitated by the use of named (but not personalised) co-researchers who are also co-authors of the papers referenced in support of this thesis.

Interdisciplinary research may produce sufficient synergy as to promote the development of new knowledge in the disciplinary knowledge domains that would not be acquired within the discipline alone. It may also produce emergent knowledge, that which is novel and normally outside each of the interacting knowledge domains. The relationship of researchers to a disciplinary domain forces them to play their role in these situations as though, in some way, they were independent. The author was responsible for the promotion of the idea of integrative research and of policy relevant research, a phrase first used in the report of the Argolid project. Since he had experience of working with econometricians he also collaborated with Black (see also Seaton and Black earlier) on the development of a farmer decision-making model (see also Park and Seaton) and with Lemon on the survey designs to acquire data for this and which also produced data for a physical model of the aquifer system. There had been an expectation that research by the specialist hydrologists would provide information and data about the water dynamics in the region suitable for inclusion in a dynamic model. This did not materialise and alternative ways using data from the survey of farmers and developing a model were found by Seaton.

The reason for this difficulty was, as Park found in his research, that the agenda of a discipline may be such that there is an absence of suitable knowledge for translation to the decision or policy relevant issue, or, as in this case, suitable hydrological models from which to translate or map. This was the situation in the Argolid research where the preoccupation of the scientists had, for many years, been the solution of the region's problems by water management in the form of infrastructure and artificial recharge of the aquifers. This tendency of disciplines to translate a phenomenon into a "problem" of a form amenable to their knowledge domains without regard to the wider complexity was itself an issue that the author followed up by interviewing most of the scientists involved. Faced with absence of a suitable hydrological model in the time period of the project Seaton used the data obtained from farmers about their own boreholes and, coupled with local knowledge from Calamaras, was able to construct a simple seven zone model of the aquifer dynamics. This was then coupled with the econometric decision-making model about farmers crop choice (disaggregated by social typology of farmers and crop choice developed by Lemon).

Allen, with the collaboration of the research team, then developed and integrated both of these models into a dynamic computer programme. Such an integrated computer model has the potential to enable the exploration of the researchers boundaries of knowledge (or ignorance). It is an important demonstration of the way in which formal models can collate and operate upon a greater number of conceptual components than the five or six that psychologists tell us we can manipulate in the brain. Its role in this thesis is to also demonstrate a way of managing formal mapping functions between a number of domains of dynamic phenomena. A short paper on this computer model (Allen, Lemon and Seaton, 1996, **B6**) was presented as part of an international meeting on desertification research and policy in Crete and should, by now, be part of the published proceedings. A version of this is included because it is the most economical way of conveying the mapping and modelling component of the research.

One further theme needs to be raised. Much of the ability to undertake this style of policy relevant research depends on the ability to undertake a range of activities which may be called in general terms social enquiry. In this research project they are the equivalent of the role that Towriss's methods provide for more focused issues and, indeed, borrow something from those. This family of methods enables the perceptions of actors as people, whether they be farmers, agencies, government, or scientists to be discovered. Without this we would be reduced to the position of Lancaster, Quandt and Baumol and Manheim and, more seriously, would be constrained only to issue types and problems which originate with suppliers, manufactures, and politicians rather than with the needs and desires of the population they serve.

In this project the role of the sociologist (Lemon) and his collaboration with social anthropologists and other social scientists was important because it extended the scope of issues (hierarchically and by type) that can be included in policy relevant and integrative research. To some extent they provide, in Towriss's terms, an insight into the normative belief component for models of decision agents and add to the range of attributes that describe peoples' diversity. Further, such approaches create a complementary qualitative model of the social and political dynamics surrounding emergent issues which reduces our sole dependency on mapping and translation which can only be handled in terms of physical quantities and mathematical functions; Ultimately they may provide the basis for knowledge translation and transfer to the population of a community in their own terms and about their own agendas of concern. Such issues are the subject of the paper by Lemon, Hart and Seaton (1992, **B7**) which may of some interest in that context.

The pursuit of perceptions and attributes of concern to people embedded in emergent situations involving technology (in its widest sense) and natural systems also generates additional types of knowledge. The semi-structured and structured interviews in the Argolid provided a great deal of data and information about physical processes as well as about the economic and knowledge aspects of options that farmers might consider. This was, as noted earlier, information and data which was not available from any other source. The reason for this, as in many other such emergent situations, is that, in their hierarchical and complex form, they are "surprise" phenomena and thus have not necessarily been on the agenda of relevant disciplinary research. One potential role for social enquiry may well be to supply knowledge derived from people which would otherwise be delayed (and possibly late) and at a level of experience not detectable until much later by agencies and governments. This is an interesting area of research which is currently being addressed in a number of research projects. The paper by Lemon, Seaton and Park, (1994, **B8**) explores the issues in the Argolid in these terms and is later developed in a shorter paper, mentioned earlier in this section, Lemon and Seaton, (1996)

5.4 The design of resilient engineering systems

In the context of this thesis the contribution of this section is somewhat more limited than those earlier for two reasons. It reports on the early stages of another branch of research which stems from as far back as the paper by Seaton and Black (1987) but in which the issue of technology design, Manheim's set of (T), is developed. Firstly, it does not at this stage involve anywhere near as much interaction and social enquiry with the population and organisations as earlier integrative research, though that is planned in imminent research activities and also it is limited to the class of "utilities" engineering and science. (That is such systems as water (and effluent) and energy production and management and their spatial linkage, transport and communication). The utilities present particular distinctive problems of spatiality in that they have spatial distribution properties similar to those of the transport systems this author research in the 1970's and 80's. Secondly, although some of the conceptual structures can be presented, the research is only just being operationalised and little by way of results are yet available.

This area of work is in turn related to the notions of sustainability touched upon earlier though in a rather more specific area and largely in the context of the Engineering, Physics and Science Research Council (EPSRC) research programme in the UK on Sustainable Cities. In Chapter 3 Manheim's diagram of co-evolving relationships between Activity and Transportation Systems is shown. The work discussed here is can be considered as an extension to his perception and anticipation of the need to consider the idea of co-evolution. It also owes a great deal to the theoretical and conceptual work of Allen on complex systems theory and its application to a wide range of issues. Pertinent to this current discussion are two very recent papers of his, "Modelling the Coevolution of Communications and Socio-economic Structure", (Allen, 1997a) in which a diagram of "The hierarchy of modelling" is shown (Figure 2, p87). This a useful summary of the difficulties we face in trying to capture complexity in our research and the fundamental problems of representing evolutionary processes within formal mathematical frameworks. The second paper, "Cities and Regions as Evolutionary Complex Systems" (Allen, 1997b) has a direct bearing on how we formulate our approach to engineered systems and also touches upon the research in the Argolid thus making a useful link between strands of work in IERC.

There is a reciprocal relationship between the research approach described in this section and the theoretical research of Allen. On the one hand research which directly enquires of the social and engineering worlds provides insights and a testing ground for ideas and genuine information and data on interactions in complex situations. The reciprocation is what has been referred to earlier as the "permeation of ideas". What is meant by this is that the theoretical structures in a field, such as complex systems theory, involve a number of interrelated conceptual devices, a sort of conceptual technology. It is these which form the accessible knowledge which can be transferred and translated into other knowledge domains. If it were always necessary to take on board every aspect of another discipline then we should need a large number of polymaths in order to exploit knowledge across more than one knowledge domain. The research design reported here has benefited from the use of some of the conceptual devices from complex systems theory as well as from the work on innovation and resilient organisations covered in Chapter 3.

The principal paper for this section is Jeffrey, P, Seaton R, Parsons S, Stephenson T ""Evaluation Methods for the Design of Adaptive Water Supply Systems in Urban Environments", 1997, A8) and the reader is asked to read that at this point.

Parsons, Stephenson and another colleague (Judd) are water treatment scientists with an interest in the application of biological and bio-chemical science to "small footprint" (physically small) water recycling technologies. The paper is based upon a research proposal for which EPSRC funding has been awarded. Jeffrey is a specialist in theories and modelling of interactions between society and technology. His Ph.D. (which I supervised) laid some of the foundations for this research design. It is also influenced by the spatial and hierarchical issues that came to light in ARCHAEOMEDES I and, as noted above by the work on complex dynamic systems by Allen.

The principal paper is supplemented by two others. Jeffrey, Seaton and Stephenson (1997, **B9**) articulates these ideas but more suitably for an engineering audience. Again it is an attempt to translate knowledge form one domain into another. The other paper, Jeffrey, Seaton and Lemon, (1997, **B10**) is a more speculative contribution to the systems thinking community and is intended to provide an initial platform for a wider development of this technology focused work into the more general issue of sustainable communities and technology, a more needs and desires driven perspective.

Some brief comments about Jeffrey (1993) will help the reader to bridge the gap between our earlier work and this paper. His research was contemporaneous with that reported in Trott, Cordey-Hayes and Seaton and in Park and Seaton and shows signs of the interactions between the fields of knowledge transfer and innovation, and the design of resilient production technologies.

The thesis itself essentially attempts to tackle the question:

> 'How can the characteristics of resilient technological systems be identified, engendered and effectively managed?'

He adopts three perspectives on this issue. He uses a progressively more complicated sequence of computer simulations of the costs functions of two scenarios. These are based notionally on electricity production technologies and consist of a single technology and that plus another. The effect of this turbulence is that in the second case there is some element of technological redundancy in that switching (subject to rules) can take place between the two technologies; the system has some element of variety. Note that the modelling does not deal with the issue of transition between the two scenarios. Effectively this would be a change in configuration (one, two, three technologies) and constitutes a more advanced problem since the timing and costs of transition themselves would then have to be included as an intrinsic part of the analysis. The equivalent in organisation research is the distinction between the "management of change" (the transition between structural configurations) and the management of the resilient attributes which give rise to such situations.

Conventionally the tendency in the design of utility systems has been to optimise a system by choosing the technology which appears to perform at minimum cost over a given time period under estimates of future conditions (classical cost-benefit analysis). Under such conditions it is usually only one particular technology which is identified. As circumstances change in an unpredictable way we accumulate a stock of technologies which are not the best now but which are too expensive to replace so that we may arrive at a situation of unintended variety. It is probable that this stock of technologies would also consist of large scale infrastructures and equipment itself difficult to map onto changing small scale and diverse demand attributes.

In his simulations Jeffrey adds more and more noise to the various costs under which the two scenarios operate. The noise is a quantified attempt to reproduce uncertainty into the scenarios. The analysis uses dynamic (non-linear and non-cyclic) cost functions, the representation of flexibility in the form of variety, and decision algorithms. These algorithms simulate plant investment and operational management decisions in terms of formal quantifiable options and criteria. The modelling shows that there is a gradual trend in preference over the long term from one to two technologies as uncertainty increases and begins to demonstrate some of the features of adaptability and flexibility in this technological context.

Since "surprise" cannot really be represented adequately in this way it is something of a compromise. A similar problem occurs with evolutionary models in that they need to represent innovation as an adaptive response which requires that new attributes hitherto unforeseen must come into play. In a calculating model the best that can be done is to have arrays of latent but pre-identified attributes available as the model performs. Whether this an issue of physical, knowledge or perceptual emergence is something that Hadfield (1997) distinguishes in her work. From the decision making point of view this distinction is relevant in that the decision agents are people and thus have perceptual landscapes of their own which include how they perceive the ways in which they can cope with uncertainty and turbulence.

The second perspective in this research was pursued through a survey of management under such conditions amongst decision makers and decision support practitioners in Israel, a country where political, economic and social change make for a decidedly turbulent business operating environment. While the work is of interest it serves largely to support the view that organisations which are capable of adapting are a key adjunct to sustaining utility services over the long term. Jeffrey does not actually connect the two points but it is probable that having resilient organisations (in the sense identified earlier in this thesis) is itself insufficient and they also need to have access to technologies, or technology combinations that are also resilient. In practice this may favour smaller scale technologies which can be moved spatially or adapted and changed in other ways and which can be much more specifically matched to small scale demand attributes. It favours to a lesser extent large scale physical infrastructure which lock suppliers (and therefore consumers) into given engineering system configurations for longer periods.

Indeed it can be argued that such locking in itself constrains the evolution of its co-systems since such a technology system is often only able to change over many decades. Recent observations have suggested that the rate of social change in urban areas may be substantially constrained by the relatively fixed nature of utility technologies. This line of reasoning begins to supply a testable basis for the concepts that Spedding (1991) has put forward and also those of Schumacher (1993).

Finally in this PhD research thesis Jeffrey studied the attitudes of modelling practitioners towards their modelling and analysis tools and their application. A group of Operational Research professionals in the UK constitute the focus of this study which provides the content of Jeffrey and Seaton (1995), noted in Chapter 4.

A number of the key conclusions from that paper are very similar to other of our research findings in quite different settings. The first is:

- The relative importance of system level behaviour over the behaviour of constituent elements of the system. The possibility of reformulating technology design criteria to promote characteristics which might enhance the performance of the system as a whole (Hierarchical aspects of system performance are particularly important here.)

This is a similar finding to that of Seaton and Black about the component, sub-system, system performance relationships in railway engineering design and can also be seen in the context of appropriate technologies as discussed in Chapter 4. A further conclusion suggests:

- Altered criteria for system aims such as survival and the continuation of minimum performance levels.

This is consistent with Park and Seaton and with the more recent work on knowledge dynamics and organisational evolution. It is the adaptability and flexibility that must be designed into technologies that is central to the research described in Jeffrey, Seaton, Parsons and Stephenson. A final conclusion is:

- The relative importance of human centred factors in achieving resilience by way of flexibility and adaptivity.

The research described in this section is complemented by similar research into such science and engineering based issues as landfill sites as a way of storing carbon (which at the most micro level can be seen as managing bacteria in a heterogeneous medium) and the use of small scale bio-ecologies in water treatment (which requires a mapping function between parts of the Linnaean taxonomy and a taxonomy of water quality). Parallel to this is research, nearly completed, on the relationship between the management of locations that produce unpleasant odours and the response of people in communities which requires the technical activities at the source to be mapped through a sequence of interfaces to the perception of recipients at some distance away.

These all follow a line of investigation which derives from the paper by Seaton and Black; the development and management of technology within a wider complexity and under conditions of uncertainty and surprise. They all require two activities. The first is the mapping or translation between one domain and another. This may be a spatial interaction, hierarchical or between technology and the social or biophysical domains. For this to be undertaken the second activity is also required, the translation from one or more knowledge domains to a policy, decision or design relevant domain.

The basic issue is how to map between domains of system configurations and their resource demands and between system configurations performance characteristics and demand when they are both evolving. The innovatory capabilities in science and engineering may produce useful innovations at a frequency and time scale that cannot be assimilated within conventional "massive" infrastructurally based systems or into organisations that are committed only to them. The aim is to find design configurations (or more properly, trajectories of configurations) of engineered systems which are resilient (offer adaptivity and flexibility) in the face of changes in the nature (e.g. non price attributes), scale and location of demand.

5.5 Concluding Comments

The structure of this chapter has followed the more or less evolutionary sequence of the research upon which it reports. It expands the ideas of integrative research as the exploitation of disciplinary knowledge for decision relevant research to policy relevant research about emergent issues. It then returns to the design of resilient engineering systems for utilities which aims to reduce the propensity of engineered systems to induce unwanted and unintended consequences when they interact fully with social and natural systems.

Resilience is conceptualised as a way of contributing to sustainability by facilitating evolution but how does it actually reveal itself in the real world? The function of the research described is to explore that real world from that conceptual position and it shows that it has similar properties in this work to that described in Chapter 4. Resilience in organisations (these days described as more or less "agile") is associated with innovation not only in technical terms but also in the innovative capacity of the organisation in terms of its developmental management knowledge which was shown in Gilbert, Seaton and Cordey-Hayes (1997) to be embedded in its employees. A potentially useful analogy can be seen between knowledge diversity in organisations and technical diversity (as the embodiment of knowledge) in resilient engineering design.

The development from Section 5.2 to 5.3 also moves us from a preoccupation with the individuals response to their own options to an interest in situations in which it is the interactions between individuals which gives rise to unintended or emergent issues. This serves to distinguish between decision relevant research and its historical dependence on the micro-economics and social psychology of the individual actor and policy relevant research which concerns the potential collective management of these systems.

Whichever way we approach these situations in the real world we return to the central role of individuals and groups in the creation (by individual action) and management (by collective management) of new phenomena that arise from the interaction of our purposeful and physically designed systems with our co-evolving social and bio-physical systems. This brings together two of the main points that Chapter 4 and 5 have in common. It is all very well to describe engineered systems as flexible and adaptive but it is in the hands of the human actors to exploit those properties. Unless they have perceptions and knowledge about resilience, and are embedded in resilient organisations and communities, then clever engineering designs for sustainability are irrelevant.

CHAPTER 6

6. CONCLUSIONS

6.1 Introduction

In this last chapter an attempt is made to identify some key issues about technology and science policy. In order to provide a basis for this in the final section the chapter takes the following form. Within Section 6.2 below there is a recapitulation of the main features of the thesis so far. This is intended to function as a reminder of the substantive research activity reported in the eight main publications and ten supplementary publications and the relevance of the conceptual frameworks in interpreting and collating them into a single body of work.

We then return in Section 6.3 to the distinctions and similarities between decision and policy relevant research and the role of knowledge in organisations and in the exploration of environmental issues. What has been learned from the research on knowledge translation and processes in organisations parallels problems of knowledge management of interdisciplinarity in policy relevant and integrative research. In order to make this clear it is necessary in Section 6.4 to develop the issues of knowledge management and disciplinarity somewhat further.

This then leads to Section 6.5 which proposes a set of analogies, instrumental and developmental knowledge, convergent and divergent knowledge and, from the work of Allen, Cartesian and Stochasts behaviour. From these it is possible to pose general policy questions about technology and science policy in terms of knowledge.

6.2 Recapitulation of the thesis

This thesis started by offering, in Chapter 2, the idea of mapping and translation as a way of thinking about a family of issues involving technology and policy in organisations and the wider impacts of physical engineered systems. It traces a history of mapping between circumstances and domains from the physical to physical to mapping between the attributes of the technical domain (of goods and services) and the users of those goods and services. It shows how earlier work on the interaction between goods and people was thought to depend on some common set of relevant characteristics and how this can be decoupled from the engineering attributes of the product. In Chapter 3 this is further developed in the context of transport service design. The limitations of this micro-economic approach in representing the diversity of preferences of people about products and services is countered by the introduction of direct enquiry methods that enable the diverse perceptual world of the individual to be explored.

The application of this set of ideas to an interaction between an engineering based service (a railway) and the people it serves is demonstrated later in Chapter 3. This case-study serves to draw attention to the interior world of technically based organisations on the one hand and on the other hand to the co-evolution of this technically based world with the natural and social systems in which environmental and sustainability issues arise.

Many organisations depend for survival on access to technical knowledge from outside, and the ability to innovate technically. This requires the ability to recognise and access relevant external knowledge and thus the ability to map between technical attributes in some other circumstances and the circumstances within the company. It requires the non-technical as well as technical ability to exploit that knowledge within the organisation. The capacity to innovate was explored in Chapter 4 within manufacturing companies by focusing on the amount of effort that companies put into the activities and facilities that promote this capability and which focuses attention yet again on the capability of individuals to participate in knowledge processes. The interactions between such organisations was considered from the point of view of the external knowledge dynamics between companies and within industrial sectors and again the crucial role of knowledge translation by individuals is demonstrated at this level. A further step examined this interior world of the organisation in terms of knowledge types and dynamics. That knowledge is essentially associated with human qualities rather than material properties serves to focus on the knowledge translation and transfer properties and activities in organisations as a human rather than technical activity. The ideas of knowledge translation and mapping are a helpful way of conceptualising these situations.

In the other strand of work in Chapter 5 the same issues, mapping and knowledge translation, emerge as a methodologically relevant way to investigate a variety of complex situations. How mapping works hierarchically in integrative research is a straight extension of the thinking in the history of mapping. This takes place in a context that requires knowledge translation and transfer between external knowledge (specialist disciplines) and representations of various levels of the hierarchy. This is termed integrative research. This idea was further developed in situations in which there is no longer an "autonomous" single decision maker but where the individual decisions result in actions and interactions in the physical and technical worlds and subsequent emergent (unexpectable) phenomena that can only be managed at the level above the individual. The investigation of this class of phenomena is termed policy relevant research since it is intended to contribute to policy formulation at any of a number of appropriate levels.

How physical engineered artefacts and systems might be designed to better fit into such situations, or indeed to obviate them, is then considered. This returns us to the particular issues of mapping between physical attribute domains, but now the domain is extended to include the interactions in manufacture and use of physical engineered products and systems. In the near future the way in which companies go about designing and implementing novel engineered systems that contribute to sustainability will be researched and the conceptual framework for that work is explained.

The common feature of all this work started with the initial idea of mapping functions and knowledge translation and transfer. Much the same conceptual tools used to represent the knowledge processes in organisations can be applied in practice to the investigation of social/technical/natural system interactions. The final sections of this thesis tentatively develop the way in which this research into the substantive world of technically based organisations, policy relevant issues and sustainable engineering design can be viewed from a common "knowledge management and policy" perspective.

6.3 Decision and policy relevance

A distinction can be made between policy and decision relevant research in the context of this thesis. Chapter 2 showed examples of mapping functions developed to better understand consumer decision making and in Chapter 3 an example (Seaton and Black, 1987) was given of the relationship between the quality of provision of a railway service and the decisions of travellers about that service. It was suggested in Chapter 5 that the examples of integrative research, Park and Seaton (1996) and the Argolid study involved decision issues for individual farmers. Where the issue is about individual choice (subject perhaps to social pressures) it is normally referred to as a decision. However the actions resulting from such choice themselves interact with each other, sometimes through bio-physical systems or within organisations, resulting in emergent phenomena. When action is taken about that emergent phenomena to influence the decision space of a set of individuals and how they interact between themselves and their environment it is useful to describe it as policy-relevant rather than decision-relevant.

Emergent phenomena, as a concept in this thesis, have never been experienced before and so their behaviours cannot be anticipated. They are "surprises" and thus the reason why organisations and societies have to have adaptability and flexibility if they are to survive. In "complex" situations this almost always involves, by definition, hierarchical interactions. In an organisation this is not just a matter of formal organisation hierarchy (and thus performance and accountability), but also of knowledge hierarchies. Any form of organisational developmental activity has implications for changes in these structural knowledge properties of the organisation and its functions. This can be seen in terms of the need to change decision and action spaces and their interactions within successive levels of the hierarchy and thus the exploitation of individual developmental and instrumental knowledge. In these terms the research presented in Chapter 4 is about policy and, since it deals with interactions which involve the technical aspects of organisations, can be described as a contribution to understanding technology policy at the level of an organisation.

In a similar way, policy relevant research about environmental issues is also prompted by the need to formulate policy and facilitate decisions about some emergent phenomenon. Again the emergent phenomena have never been experienced before and cannot be anticipated although they frequently arise from wider sets of systemic interactions than those in an organisation. The academic study of emergent systems is an intellectual response to the challenge of understanding new classes of phenomena. Such research is policy relevant when it investigates a situation, not with the intention of promoting new disciplinary theory, but of providing knowledge about the consequences of intervention in it.

The problem common to both types of policy relevant research, in organisations and about emergent environmental issues, is that of knowledge translation and interactive knowledge transfer either as the subject of investigation or as the means of investigation. Much has been learned from the work on knowledge translation and transfer in organisations which has implications for research methods in the areas of policy relevant environmental research.

6.4 Knowledge management

6.4.1 Introduction

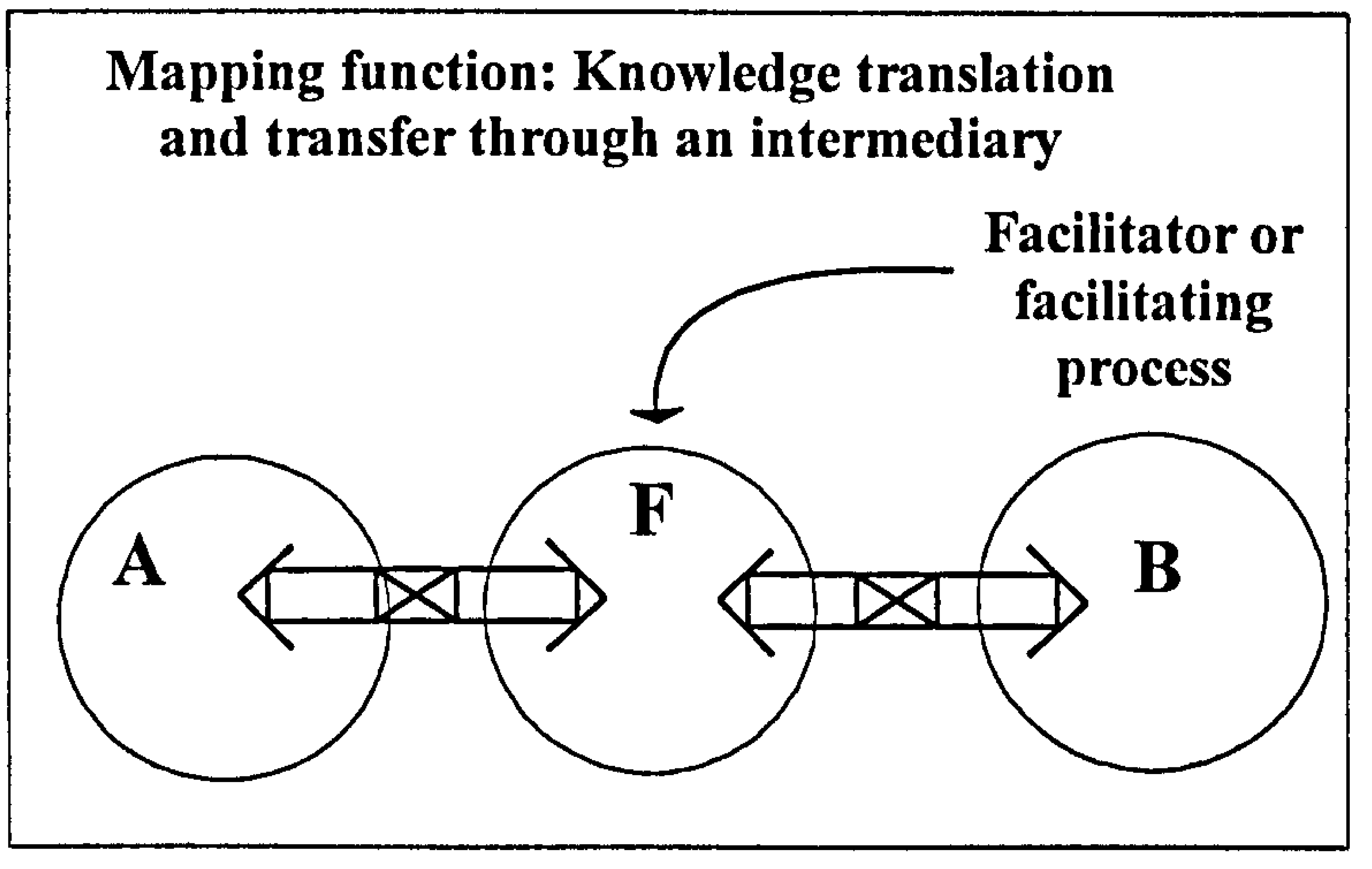
This section on knowledge management draws upon two recent research projects which are ostensibly quite different. One is the research about interdisciplinarity within the EPPM (1997) project noted earlier. The other is specifically about knowledge dynamics within BT, the main provider of telecommunication and information services in the UK. This latter project, was undertaken for a group of Business Systems modellers at the company's research laboratory. It involved interactive research in two operating businesses of BT in which the perceptions of employees and managers about knowledge processes were elicited.

The activity of knowledge transfer can be seen as an interactive process which requires some form of knowledge translation, as noted earlier. In as much as it requires interaction between people there are likely to be better or worse ways of facilitating such situations. This important issue has a substantial literature of its own, much of it focused on team building and problem solving. In a similar way if the knowledge domains of individuals within an organisation (which are usually aligned along function) are intellectually or physically a long way apart it may not be easy for an individual or a group of individuals to find an appropriate mode of discourse. Until that mode of discourse, an agreed mapping function between the two, can be made to work no effective exchange of knowledge is likely to occur.

In interdisciplinary research where the knowledge domains of two (or more) disciplines address a common phenomenon which is on the research agenda of each, a mapping can be developed between the domains. This means identifying how the characteristics or attributes of the phenomenon as seen by one discipline reveal themselves in the attribute space used by the other discipline. This often exposes taxonomic differences, one domain perhaps making subtle distinctions not recognised in the other domain. Sometimes the mapping can be formalised, more often it is characterised qualitatively; sometimes it is not possible at all. The idea of distance between disciplines is a major issue in the interdisciplinary experiment reported in EPPM (1997). If the domains are a long way apart it may not be easy for an individual or a group of individuals to find an appropriate mode of discourse.

Where this situation occurs one mechanism is to bring in a third party to facilitate that process as shown in Figure 6.1.

Figure 6.1 Knowledge Intermediaries



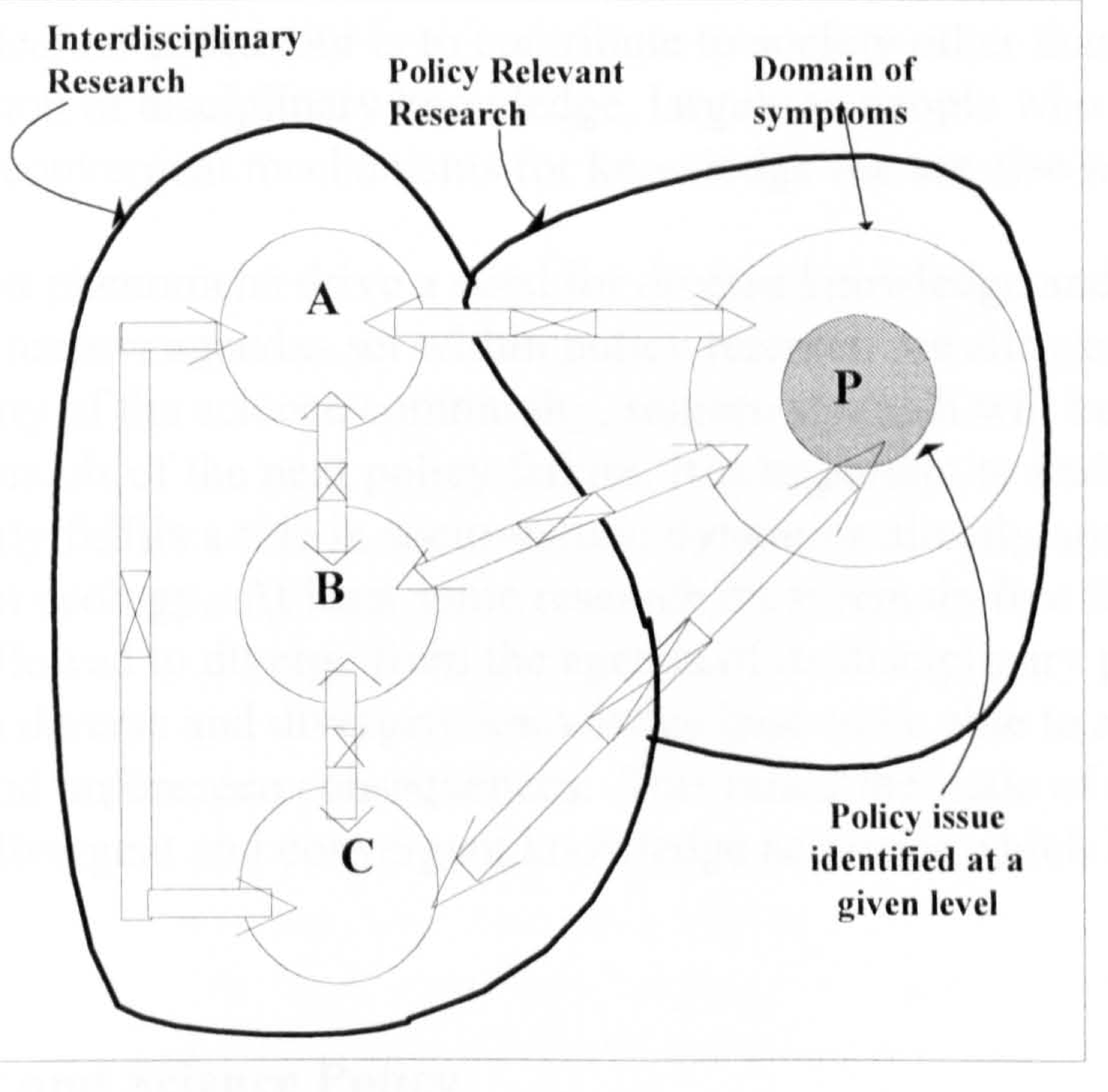
An analogous situation can occur in organisations which employ people to scan the outside world (and sometimes the inside world of the organisation) purposefully. It ought, in principle, be possible for most members of an organisation to undertake some scanning without an intermediary as was the situation in ICI (Trott, Cordey-Hayes and Seaton, 1995). A similar issue, as our recent research in a telecommunication company shows, can also occur with internal knowledge interactions where the knowledge distances or decision and action spaces are very far apart. This model was first derived from an experiment in knowledge interaction between two members of the EPPM project research team, a sociologist and a mathematical modeller where it was found necessary to introduce a third party, a specialist in Technology and Society, to bridge the domains.

6.4.2 Disciplinarity and Policy relevant research

Theoretical research within a given discipline tends to be dominated by its own peer group and agenda. The knowledge generated by a number of these disciplines may be diverse and even divergent. Disciplinary autonomy prevents the establishment of a perfect orthodoxy thereby maintaining and protecting intellectual diversity within the whole research community. Multidisciplinary research may generate a diverse and, on occasions, internally irreconcilable knowledge base to the intense chagrin of some commentators. In contrast, a convergence of knowledge is essential in the *policy relevant* domain (van der Leeuw *pers. comm.).* The notion of divergent and convergent knowledge which van der Leeuw offers is considered further in Section 6.5.

The relationship between policy relevant research and disciplinary research is shown in Figure 6.2. The various relevant disciplines are denoted as A, B, C. The diagram also includes the mapping functions which are needed. There are now mapping functions between disciplines and the policy relevant domain as well as between disciplines themselves. Some disciplines may have knowledge domains appropriate to the diagnosis of the emergent system while others may have the capacity to contribute towards structuring analytic frameworks for policy investigation (P). That the process is interactive and that disciplines can derive new knowledge within their domain is denoted by the interactive nature of the mapping activity. How the mapping functions between disciplines and the issue is integrated constitutes a knowledge management issue.

Figure 6.2 Interdisciplinary and Policy relevant research



What is within P (policy investigation) is usually complex and hierarchical since it is normally associated with an emergent complex system. For instance, in situations of environmental degradation, P can be described in terms of S (social), T (technological) and N (natural).

The identification of the appropriate, (apparently) relevant knowledge in different disciplines (A, B, C) and the formal integration of that in the policy relevant domain is termed "integrative research". Sometimes it is possible just to translate and transfer knowledge from a discipline, or a specific field of study. On other occasions it may be a more interactive process in which the investigation of the policy issue itself influences the trajectory of the disciplinary knowledge domains. Integrative research (about sustainable agriculture) was described in Park and Seaton (1996) and in the report on the research in the Argolid region of Greece as part of the report of ARCHAEOMEDES I. (Allen, Black, Lemon and Seaton, 1994) in Chapter 5.

What is sometimes evident is that one or more of knowledge domains A, B, C have simply not evolved in a way that enables translation and transfer to occur without prolonged negotiation and further research within that domain. On occasions we have found that the policy-relevant research project has itself to undertake research within a disciplinary field (in a limited way) in order to provide appropriate knowledge. This might be considered simplistic within the discipline itself but often draws attention to interesting possibilities for further disciplinary research and thus contributes to the research agenda for the discipline. This gap seems to most often occur when the policy relevant research focuses on hierarchical linkages.

Policy relevant drivers for disciplinary research (in the context of environmental issues) depend on which emergent systems most often have an adverse impact on societies and which will need management to mitigate those effects. Disciplinary agendas cannot have conceived of such new phenomena as a focus for research without external reference. If intellectual endeavour is to contribute to society other than by some diffuse dissemination of disciplinary knowledge, largely to people who can readily assimilate it, then convergent mechanisms for knowledge use are also needed.

However, emergent phenomena drive a need for diverse knowledge and knowledge generation. If the narrow agendas set within policy research are allowed to stifle the intellectual diversity of the science community, science research will be unable to respond to the demands of the next policy failure. It is important to understand that intellectual diversity fulfils a role in socio-natural dynamics directly analogous to that of genetic diversity in ecology. At least some research must remain free from policy direction and be allowed to diverge from the agenda of its disciplinary peer group. We need to maintain a diverse and divergent knowledge base to be able to respond to emergent issues and unforeseen consequences. This raises the issue of the appropriate balance between divergent and convergent knowledge activities which is developed in the next section.

6.5 Technology and Science Policy

6.5.1 Top-down

A distinction needs to be made here between "substantive" policy such as Environment, Education, Agriculture at various levels of government, or, say markets, engineering systems, and training in organisations and policy towards the knowledge base that they need. Substantive policy, in these terms, tends to be formulated on a top-down basis and comprehensive reviews are available at EU and at national, regional and local levels in many countries. For instance Wallace and Wallace (eds, 1996) have produced an updated book, "Policy-Making in the European Union" which reviews the politics and policy-making activities in the substantive areas of EU policy. Interestingly the index to the book fails to note DGXII, the Directorate for Science, Research, and Development and there is no significant part of the book devoted to Science Research Policy.

Perhaps more indicative of recent concerns are the proceedings of such events as the "Scientific Expertise in European Public Policy Debate" at the London School of Economics, 1994, organised with DGXII as part of the European Science and Technology Forum. Even then the debate seems to be carried on in terms of disciplines rather than the exploitation of knowledge. Knowledge from science is seen either as an influence on the intellectual positioning of policy or as solving a well diagnosed "problem".

More recently in the UK, perhaps as the consequence of a series of unpleasant "surprises" (such as BSE) a somewhat more progressive view about the role of "science, engineering and technology disciplines" has been articulated by the Chief Scientific Advisor to the Government. (Office of Science and Technology, Department of Trade and Industry, March, 1997). This appears implicitly to accept the notion of surprise, (para 4, p4), scientific uncertainty and of a multiplicity of constituencies and perspectives. However, it still promotes the notion of "scientific experts" while also suggesting that there is an issue of "knowledge aggregation".

6.5.2 Bottom-up

In considering the contribution of the ideas about knowledge management in this thesis to knowledge policy issues it is helpful to introduce the idea of Stochasts and Cartesians. The source of this idea, as used in this thesis, is Allen and McGlade (1987). The paper develops a mathematical computer model of the fishing stocks and fishing activity in the Canadian Fisheries off Newfoundland. Central to what is a complicated and comprehensive model is the distinction between the behaviour of different types of fishing fleets. Cartesians seek to fish in known locations with a good probability of high levels of fish stocks but in which they have to share the opportunity. Stochasts fish in a much more random fashion (and therefore at a cost of sailing further) throughout the area and so sometimes fail but when they do succeed they have virtually monopoly access to the fish stocks in the short term. As Cartesians exhaust known stocks they would like to move to the places where Stochasts are being successful while the Stochasts will try to avoid that possibility. There are many more features of the work than can be given here, such as information exchange, fish types and prices, intermediate combinations of the two behaviours, the relationship between individual boats and fleets and so on. A recent paper by two of our younger colleagues develops this theme as a way of structuring a conceptual framework to investigate "Sustainable Communities" (Jeffrey and Lemon, 1996), in which they also use the ideas of knowledge transfer between Stochasts and Cartesians in social networks.

The key question that the distinction between Stochasts and Cartesians generates for this thesis is:

> **What is the appropriate balance between the two behaviours for any given state of the fish stock?**

If everyone always behaves as a Cartesian then no new options will be known about when the current stocks fail. If everyone is a Stochast then there will be a failure to exploit known stocks efficiently. There are clearly issues also of scale. Does each boat behave in different ways at different times, or is it the proportion of a fleet that matters and so on. The interesting issue is that only having Stochasts or only Cartesians does not seem to be the best strategy. If the aim is to secure the sustainability of the fish stock as an economic food resource the policy issue is the nature of the dynamic intervention that needs to be followed by the Fisheries Authority (the de facto managers) about the balance between these two types of behaviour and what policy instruments would the fleets actually respond to. It should be remembered that the fish stock themselves are also influenced by other factors than fishing (climate, food chains etc.) so that any policy towards the fishermen (the decision agents) will have to take account of uncontrollable dynamics in that fish stock.

Recently we put forward a research proposal in which the properties of the fishing model would be compared to the work on knowledge dynamics that distinguishes between instrumental and developmental knowledge. It is with the fishing model above in mind that the following thoughts are offered.

The notion of technology policy has been developed in this thesis around the needs of organisations. Much of the research has been concerned with manufacturing or technically based organisations though similar concepts to those developed have also been applied to so-called knowledge based organisations, some of which are "not for profit" organisations. Instead of assuming, as would often be the case, that policy is something of concern only to governments (and we showed in our earlier work that, when it is, it confuses technical innovation with the capacity to innovate), this body of research approaches the issues bottom up. Starting with the knowledge roles of individuals and considering how they and their interactions give rise to the emergent properties which are needed by the organisation we end up with the view that technology policy issues in organisations can be "translated" into knowledge policy issues. It is then possible to see the wider, industrial policy issues also in these terms and to begin as in some of our current research to consider policy instruments based on ideas of knowledge and knowledge processes.

The concepts seem to be useful across a wide range of organisational types. In particular the distinction made in the paper by Gilbert, Seaton and Cordey-Hayes (1997) between instrumental and developmental knowledge is important in the following discussion. When developed with employees and managers in organisations this distinction is clearly understood and appeals to them as a way of articulating about their work. When individuals or groups are encouraged to talk about knowledge they do not become confused between knowledge and information. No attempt has been made with them to formalise the use of the word as it might be in philosophy, information theory, psychology and so on. In effect the research has used a form of elicitation in which the perceptions of the individual about "knowledge" are considered to be the most relevant.

This is important since there is currently a vigorous debate about the role of Information Systems and Technology in knowledge management in the context of so-called Virtual Organisations. In this debate confusion between what is information and what is knowledge is apparent. The danger is that the scope of the individual to think and learn, and to co-operate with others in doing so, could be reduced in some Taylorist fashion to simple instrumentality. At the end of his book Cooley (1987) alludes to similar issues of the potential threats of artificial-intelligence systems within technically based organisations and the need to "produce visible and meaningful alternatives to an infrastructure of machine-based systems" thus (p179):

> "The rate of technological change suggests to me that we have a mere fifteen to twenty years in which to do so, otherwise we will find, as an artificial-intelligence expert put it recently on British television, that humans will have found their natural place in the evolutionary hierarchy. Namely animals at the bottom, human beings in the middle and thinking machines at the top!"

and re-iterates his view about the relationship between individuals and technology on p180:

> "As we design technological systems, we are in fact designing sets of social relationships, and, as we question those social relationships and attempt to design systems differently, we are then beginning to challenge, in a fundamental way, power structures in society"

This capacity of individuals to acquire both instrumental knowledge, thus improving on what they do now, and developmental knowledge, their capacity not only to learn but also to see new options and to be able to take advantage of them, enables us to develop an analogy between the family of work on knowledge processes in organisations and the policy relevant and integrative research. It needs to be remembered that the concept of an organisation is not as a closed system. It is openly interactive with the external knowledge environment as an organisation, and the individuals within it also live their lives and learn in that external world. The co-evolution of the individual at work and the organisation also involves the other dynamic influences in the life of that person outside work. The policy question that is generated is:

> **What is the appropriate balance between instrumental and developmental knowledge at a particular time or stage in development of an organisation?**

The answer depends on what hierarchical level of the organisation we are considering, the dynamics of the situation the organisation currently finds itself in, and what knowledge type the organisation is. The first issue involves whether the new positions, using the fact of individual's developmental knowledge, that an organisations wishes or needs to move to, are in response to environmental surprise or are stimulated by some innovation possibility. The second issue occurs because of the periodic need for organisations to behave in different modes. At times the organisation will need to do what they do well even better and thus exploit instrumental knowledge. On other occasions they will want to move to a different position and, if they have invested in the developmental capacity of their employees, will want to call upon that. The analogy with the appropriate level of Stochastic and Cartesian behaviour is evident. The third issue concerns the nature of the business of an organisation, transformation of materials, intermediate goods, information, or knowledge. A manufacturing company is likely to require relatively higher levels of instrumental knowledge than a marketing department of a service company. A bureaucratic organisation will differ from an enterprise and so on. In due course our research intentions are to produce a taxonomy of organisations along these lines.

I am indebted to van der Leeuw, who in the course of editing our report on Environmental Perception and Policy Making offered, in the context of disciplinarity, the distinction between convergent and divergent knowledge. The argument from which this distinction arises is between policy relevant researchers and academic disciplinary researchers. The fear of the latter is the loss of intellectual freedom if the agenda of their research is dictated by the immediate needs of society. They want, indeed need, autonomous control of the research agenda. They see interdisciplinarity in terms of co-operation between two (or more) disciplines both in pursuit of their disciplinary agenda for knowledge. This perspective of open-endedness may be seen as the pursuit of divergent knowledge. Convergent knowledge is that which is needed in the integrative research process (which is essentially diagnostic in its early phases) and, as explained in the Park and Seaton paper, is dependent on the bodies of knowledge established by the various physical and social science disciplines. The policy question here is:

> **What balance must be found between disciplinary academic research (divergence) and research into the integration and application of that knowledge (convergence)?**

The issues that arise, given that in this century most research of any sort is funded by organisations and government and seldom by the individual, is how much to spend on "theory developing" research, how much on "policy relevant" research and so on. It is the divergent knowledge seeking which will provide adaptive positions for society in the event of unpleasant surprises. It well may also provide the source of genuine innovation, not just through the physical and biological sciences, but through better understanding of the ways in which people live their diverse lives. Perhaps then we may regard divergent and convergent knowledge as the equivalent, at a scale above, to developmental and instrumental knowledge in organisations. Similarly we might consider policies towards these as analogous to the selection of appropriate Stochastic and Cartesian behaviours.

It should be observed that whichever policies and at whatever level they are to be applied they must take account of nature of the policy instruments (and the authority to generate them), the feasibility of delivering them (almost always through organisations and thus through the individuals in those organisations) and the diversity of receptivity that individuals and groups will have to them. As van der Leeuw observes (*per. comm.*)

> "Furthermore, policy instruments, when they are eventually developed in response to an emergent system, constrain the range of options for decision making. Thus *policy research*, as defined in the introduction to this section, is constrained by its own policy instruments to work within a much smaller decision space than policy

> relevant research. As one moves from relatively "pure" multidisciplinary research along the spectrum connecting policy relevant and policy research, one sees an inevitable narrowing of perception."

With this in mind it is appropriate at the end of this thesis to return to the issue of human diversity and its implications for policy. Some time ago, in an attempt to understand the nature and character of different disciplines I asked a friend, a former student of History at Cambridge, for guidance. He gave me a copy of "The historian's craft" by Marc Bloch. In the last few pages of this book Bloch gives voice to a view that is not only apposite to particular case-studies in this thesis but which also, I hope, permeates it. I quote him through his translator thus (p162):

> "Whether confronted by a phenomenon of the physical world or by a social fact, the movement of human reactions is not like a clockwork always going in the same direction. Renan to the contrary notwithstanding, the desert is not necessarily "monotheistic", because the people who inhabit it do not all bring the same spirit to its scenes. Scarcity of watering-places would bring about the clustering of rural population, and abundance would disperse it, only if it were true that people made proximity to springs, wells, and ponds their supreme consideration. In reality they sometimes prefer, for the sake of security or co-operation, or even through mere gregariousness, to live in close groups even where every field has its spring; or inversely, as in certain regions of Sardinia, where everyone builds his dwelling in the middle of his little estate, they resign themselves to long walks for the scarce water as the price of the isolation on which they have set their hearts. Is not man himself the greatest variable in nature?"

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Decision-Support Systems and the Strategic Management of Train Service Punctuality

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INTRODUCTION

The material for this paper is derived from research sponsored by Director, InterCity, British Rail, undertaken in co-operation with the Transport Technology Assessment Group, British Rail Technical Centre. The views presented in this paper are the authors and not necessarily those of British Rail.

The purpose of the research was to derive the decision-support system required for Strategic level management in the InterCity Business Sector of reliability/punctuality and to demonstrate and develop through a pilot study the decision-characteristics, analytic methods, information and data required by the four Production Functions (Operations, Civil Engineering, Mechanical and Electrical Engineering, Signal and Telecommunications Engineering) to achieve profit effective failure management.

Initially failure and punctuality information flows and content were mapped throughout the organisation and it was found that the existing material was not in a suitable form to support comprehensive or effective decision-making in the newly restructured British Rail organisation. The creation of Business Sectors (InterCity, Provincial, London and South East, Parcels, Freight) gives rise to a new relationship between a Business Sector and the four Production Functions and to new accountabilities of those Functions to the Sectors. In this study the InterCity Business Sector has, essentially, a profit maximising objective. It was therefore necessary to consider how decisions should be made as well as the information and information systems needed to support such decision types. Clearly the former dictates the properties of the latter and therefore this paper initially describes the decision framework derived from the study and then considers the information requirements to support decision-making about punctuality and failure on a recurrent basis.

THE MANAGEMENT ISSUES

The initial brief for the research focussed on 'reliability' but it soon became apparent that a useful distinction could be drawn between reliability and punctuality. Reliability is defined to be the failure levels of equipment and people in the four Functions. Punctuality is a measure of the lateness of trains - in practice at the terminating station. From a commercial point of view it is late arrival as perceived by passengers which has an eventual effect on revenue. If the business objective of the InterCity Sector is to maximise profit then punctuality must be seen as an area of management decision, affecting both costs and revenue, that requires control. This paper examines decision-making about punctuality and reliability, and the consequent information needs.

Decision-making about punctuality requires an understanding of of the links between failures, en route delay, punctuality, late passenger arrivals and revenue effects. The figure below illustrates the key relationships:

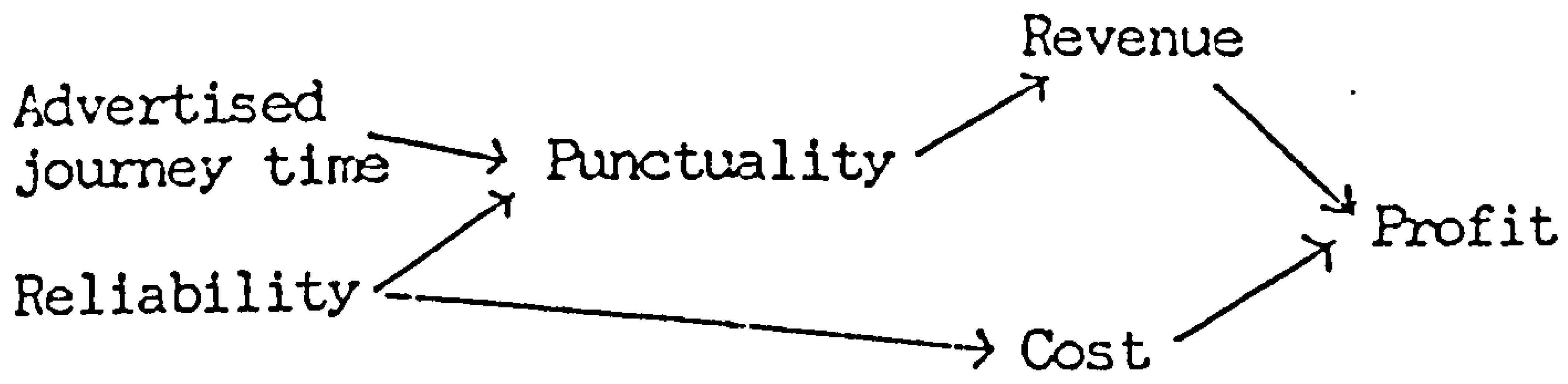

Figure 1: Reliability/Punctuality and Profit

The two main areas of decision-making concern:

(a) The level of reliability, which can be influenced in two ways.

- First, the Functions themselves can allocate their existing resources more effectively. This is only feasible if the relationship between failure, delay and revenue is made explicit.

- Second, the Sector can sponsor additional resources for projects within the Functions on the basis of their net contribution to profit through increased punctuality. This also requires a knowledge of the failure/revenue relationship for the relevant routes.

It should be emphasised that improvements to reliability are not only achieved by changes to equipment design. Improved maintenance, better failure detection, organisational improvements, better location and numbers of spares and personnel, as well as effective operations contingency planning can all lead to significant improvements in reliability.

(b) The trade-off between punctuality and advertised journey time.

At any given level of failure rate (which determines the en-route delay to trains) the Sector must decide on the most profitable combination of punctuality and advertised journey time for each service. The decision (given a failure rate) is between faster and less punctual or slower and more punctual services and this is controlled by the amount and location of 'recovery' time in the train timetabling. The balance is determined by the relative valuation of passengers of journey time and delay.

The following sections outline the relationship, information and procedures required for effective and efficient decision-making about reliability and punctuality.

<u>Reporting Procedures and Management Information Systems.</u>
There are three basic sources of data on reliability and punctuality:

- Comprehensive statistics recording train arrival times.
- Selective statistics concerning en-route delays and their immediate causes.
- Numerous engineering records.

Punctuality statistics provide an accurate detailed source of late train arrival times. Typically, delays of greater than 10 minutes are recorded with some attempt to indicate the immediate cause. Accurate estimates of the delay and identification of the precise cause are difficult to make at the time and hence such data can only provide a broad overview.

The four Functions collect large amounts of detailed data on equipment and human failure. Most relevant details on time of failure, failure duration, failure mode and cause are collected at some level in the organisation. Unfortunately, this information is rarely collated in a form suitable for the systematic analysis of component reliability over time.

The relationship between failure and passenger lateness. The top row of Figure 2 outlines the key elements linking the failure of a railway system component (which may be engineering equipment or a member of staff) with the lateness of arrival of passengers at their destinations. The triangular boxes in this Figure represent the key decision variables which influence punctuality.

Four key technical relationships are involved in modelling the link from failure to passenger lateness:

(a) The link between the failure mode of a component and the disruption to a route or track.

(b) The effect of track disruption on train delay, and especially 'reaction'.

(c) The effect of en route delay on the lateness of train arrivals at stations.

(d) The relationship between late train arrivals and late passenger arrivals.

The first of these relationships is specific to the component involved. In general, the severity of disruption depends on the degree of redundancy in the system and the response to the failure in terms of repair times or operating measures.

The total delay caused by a failure, including reaction, could be estimated from historical records, but problems of dubious accuracy of such records, the attribution of cause of delay and limited sample size (for any specific location) militate against this approach. A process of synthesising the expected delay from a failure is, therefore, proposed. A simulation approach, using Working Timetable or random headways, confirms the general form of the relationship. If a diversionary route is available this relationship changes somewhat after the diversion is established, diverted train numbers being proportional to the duration of the delay, and the total delay growth being linear. Problems such as emergency TSRs, traction failures etc., can be dealt with in a similar fashion.

Between the time at which a delay is incurred by a train and its arrival at subsequent stations, the train may recover some of the lost time. Records show that this is often the case, especially for smaller delays. A 'synthetic' approach is again productive and compatible with the historical records. This approach shows that the benefit of recovery depends critically on delay location and magnitude.

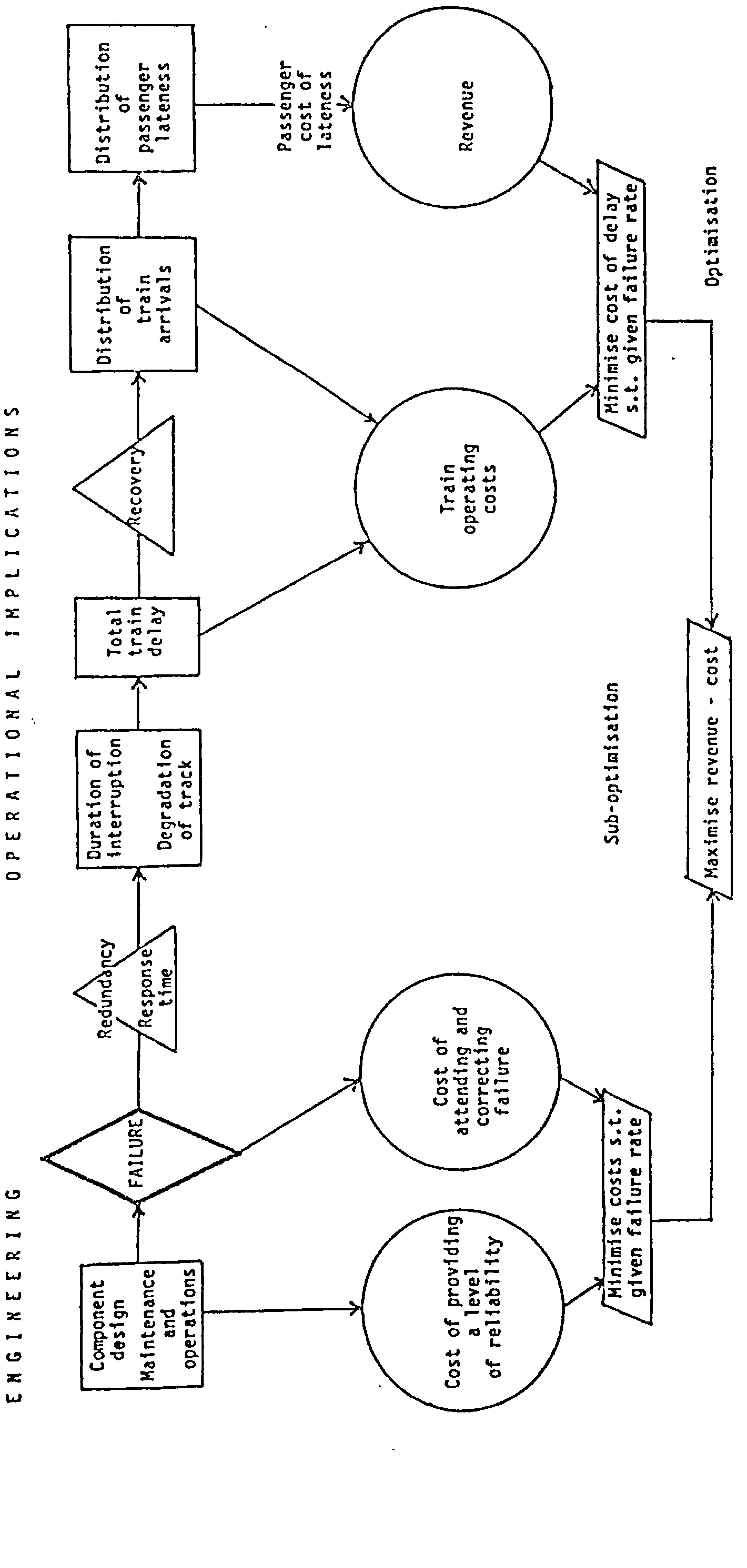

Figure 2: The Impact of Failure

On the whole, small delays can be seen to have little impact on late arrival. It can be shown that even if recovery time and mean total delay are equal, a significant proportion of trains will still arrive late. This is due to recovery slack being fixed, while total delay is above average in a significant proportion of cases, and a substantial proportion of recovery is also 'wasted' by trains waiting time at intermediate stations.

Total passenger lateness (e.g. on a service group) is obviously not accurately measured by train loadings and arrival times at terminating stations. Average lateness of each passenger tends to be overestimated as train lateness at intermediate stations is less than at terminating stations. On the other hand, maximum train loadings are an underestimate of alighting passenger numbers, due to passengers joining and alighting en route. Current punctuality reporting systems would, therefore, need to be somewhat adapted, so as to accurately reflect passenger lateness.

The case of a junction between fast and slow lines, and the failure rate and failure mode data from such an area were used as an example. For each failure mode of each point set the traffic effects can be calculated using the details of lines affected, train headways, and the Mean Time To Repair (MTTR). These traffic effects can then be multiplied by the annual failure rates to give total annual traffic effects. Some failures only affect traffic on the slow lines and others only affect movements between fast and slow lines, not through movements on the fast lines. The findings emphasise the problems associated with attempts to use historical data at this level of detail due to low failure frequency and low incidence of consequent delays, which provide an inadequate statistical basis for the application of reliability engineering techniques.

Using the above example, a number of reliability improvement options were assessed: reduction of point end failure rate i.e. Mean Time Between Failures (MTBF); reduction of failure duration (MTTR); operating solutions such as manual operation; and separated detection for point ends of crossovers. These were merely examples, but involved such factors as design and maintenance, operation contingency plans and logistics and engineering change . The nature of the impact on delay was shown to be markedly different for each measure, especially in the proportion of trains suffering long delays.

Passengers' reaction to late arrival.

Even if it is possible, as described earlier, to estimate the impact of en-route delay on late passenger arrivals, there still remains the problem of identifying passenger reactions to different levels of punctuality. This is a complex task and it is worth noting that a similar style of research over the last 15 years has struggled to identify with accuracy passengers' response to changes in speed (speed elasticity). There are two basic methods of measuring passenger attitudes and reactions to late arrivals. Either one can observe behaviour and deduce their relative valuation of punctuality (the revealed preference approach) or passengers can be interviewed and asked to state their preferences. In the case of punctuality it was not possible to isolate situations where the effects of a change in punctuality could be measured. The research, therefore, used interviews. The main findings of the survey were:

- When asked to name a number of minutes of the train's lateness on their current journey which would cause them disruption and/or annoyance, few users (5%) cited times of under 10 minutes.

- Distinct steps in the overall proportion of users disrupted/annoyed were noticeable at 20 minutes and 30 minutes.

- More experienced travellers tended to cite lower thresholds of disruption/annoyance.

- Users' perceived proportions of late trains varied considerably but were, on average, slightly higher than punctuality records would suggest.

- The survey incorporated a phase in which the travellers were presented with various levels of fare, different proportions of late trains and levels of lateness. From passengers' ranking of these in order of preference it is possible to deduce an implied monetary valuation placed on a unit of lateness. Not surprisingly, the implied value varied considetably between passengers. As with all results from trade-off games these values should be treated with caution. Passengers were trading off notional money against notional lateness, For instance, business travellers responded as if they were prepared to pay much higher fares in exchange for an improvement in punctuality. Their behaviour when faced with real monetary sacrifice might be different.

If it is accepted that the cost of lateness is four times that of advertised journey time (as suggested by the survey) then it is possible to argue that a change in lateness of five minutes is equivalent to 20 minutes change in advertised journey time (and pro rata) with corresponding impacts on patronage and revenue. An alternative approach is to view a change in lateness as equivalent to a change in fare, with consequent patronage and revenue effects.

Following this line of reasoning it can be estimated that the effect of eliminating all late trains would lead to an increase in revenue in the short term. However, in the longer term, improvements in punctuality should lead to reductions in advertised journey time and some savings in spare capacity and infrastructure resulting in a further benefit.

Decision making: resources and punctuality.
Two major decision areas are:

- The level and distribution of resources devoted to improving human/engineering reliability.

- The extent and location of the recovery allowance in train timetables.

Decisions about the former require information from the responsible Function about the cost and the expected improvement in component reliability. Coupled with knowledge about the impact of failure on delay and late train arrivals it is then possible to estimate the revenue impact and hence whether the financial effect is positive.

The level of resources will, in conjunction with other factors, determine the amount of en-route delay. Recovery is similar to redundancy: it can reduce the eventual impact of failure by inserting a buffer between delay and late arrival. However, the timetable planner faces a dilemma. A large recovery allowance can be inserted ensuring a low proportion of late arrivals but a high advertised journey time, or a low recovery can be inserted leading to many late trains but a more attractive advertised journey time. The problem can be resolved by identifying the relative weight passengers place on a minute of advertised journey time and a minute of lateness. The lower the ratio the higher the recovery allowance should be and the fewer late trains there will be.

If the idea of punctuality targets is adopted two factors must be recognised. The choice of a target proportion of late trains must be associated with decisions about recovery and advertised times as well as a knowledge of the level and distribution of en-route delay expected. Additionally, there must be a mechanism for identifying significant deviations, their cause and appropriate remedial action.

The Development of Punctuality and Reliability Management.
The effective translation of these principles into practice

requires the following initiatives:

(a) The systematic application of reliability assessment and engineering techniques throughout the Functions in order to quantify the relationship between failure and costs. This requires the design of information systems (based largely on existing data sources) and the implementation of pilot reliability assessments (through a series of projects) undertaken within the Functions.

(b) The institution of a formal and explicit reliability decision-making process between the Functions and the Sectors.

- The management of reliability in railway operations requires not only an understanding of engineering systems, but also of human factors, organisational structure and the spatial properties of the railway. Since each Function contributes to the overall level of unreliability they must all be involved in generating and evaluating improvements. This needs an understanding of the effect of failure on train delay and in turn on late passenger arrivals (punctuality) and hence on revenue.

- The production of route models to estimate the relationship between failure and late arrival.

(c) The explicit use of the revenue implications (derived from the values which passengers place on lateness) for decisions about resource allocation both within and between Functions.

- This requires the InterCity Business Sector to specify to the Functions the value of time for savings in pas senger delay. An important aspect which should be resolved is how the cost of a unit of passenger late ness changes as lateness increases.

IMPLICATIONS FOR INFORMATION SYSTEMS DESIGN

From the preceding discussion it can be seen that there are two focal points for decision-making; the Business Sector (in this case InterCity) and the production departments referred to as Functions in British Rail - i.e. Civil, Mechanical/Electrical, Signal/Telecom engineering departments and the movement control activity (Operations).

A cybernetic approach to these two would suggest an increase in autonomy of resource management should be developed in the Functions by providing them with internal performance criteria consistent with Sector business objectives. For any given level of punctuality the Sector is then left to optimise its business by manipulating advertised journey time, and by monitoring the decisions of the Functions. Other than to sanction profit justified changes in resources, the Sector has no particular need to intervene in Function affairs except when monitoring (by exception) draws attention to a failure by the Function to fulfil its agreed bargain on profit effective resource expenditure as regards punctuality. There are two complications to this. Firstly, punctuality is only one variable in service design. Secondly, there are, as exposed by the research, a number of situations where reduction of resources in one Function will be more than compensated for by equal increases in another, or where, for technological reasons, a joint activity is needed. Quite how, in detail, these relationships are practically organised is not clear and will depend on the particular organisation and its culture. Such developments are best left to the organisation itself and are evolving in BR at the moment.

The information requirements for the Sector have been outlined earlier. It consists of the relative values of revenue effects of speed and punctuality derived from market research. The decision consists of choosing advertised arrival times that optimise the relative contribution of speed and punctuality to revenue at a given level of punctuality. We have shown that recorded arrival time data is in itself of no particular use; but when used to calibrate an arrival time distribution provides the basis of a statistical model which provides a mechanism for identifying optimum journey times and hence optimum advertised arrival times.

The Functions' requirements for information are of two types. Firstly, they need to know the characteristics of "failure" rates and failure modes for equipment and people. It was found that current attempts to relate delay to cause would be ineffective in two ways.

1. Not all failures lead to delay. Some may be noted at routine inspection or ad-hoc and be rectified before a delay incident actually occurs. The relationship between failure and delay depends on factors such as maintenance frequency or repair quality.

2. The persons best placed to note delay are, generally, least able to attribute cause at more detail than a macro-system level, certainly not at component level.

The consequence is that Functions need to record all their own failures, regardless of which lead to delay, since only by changing the component failure rate overall can a proportionate change in failures leading to delay be made. This is, of course, a basic principle of reliability engineering, which relies on statistical forecasts of failure on an historic basis.

The second issue is the estimation of actual delay to passengers. A delay at one location would give rise to different overall delays of passengers than at another, since it will depend on how much further the passenger is to travel, the probability of access to recovery time, the probability of additional delays etc.. By using passenger loading data, probability distributions of further delay, and recovery times by location and timetables, it is possible to synthesise the expected arrival time distribution of passengers on all trains affected by a delay of known duration at a specific location on a given route. Thus it is possible to estimate the revenue affect of such a delay given the passenger valuation of late arrival. The Functions need, therefore, only specify the duration and location of a delay from their own information and can be provided with the revenue effect.

Assuming Functions have access to cost data they can now calculate the revenue and cost effects of any change in failure rates. In summary:-

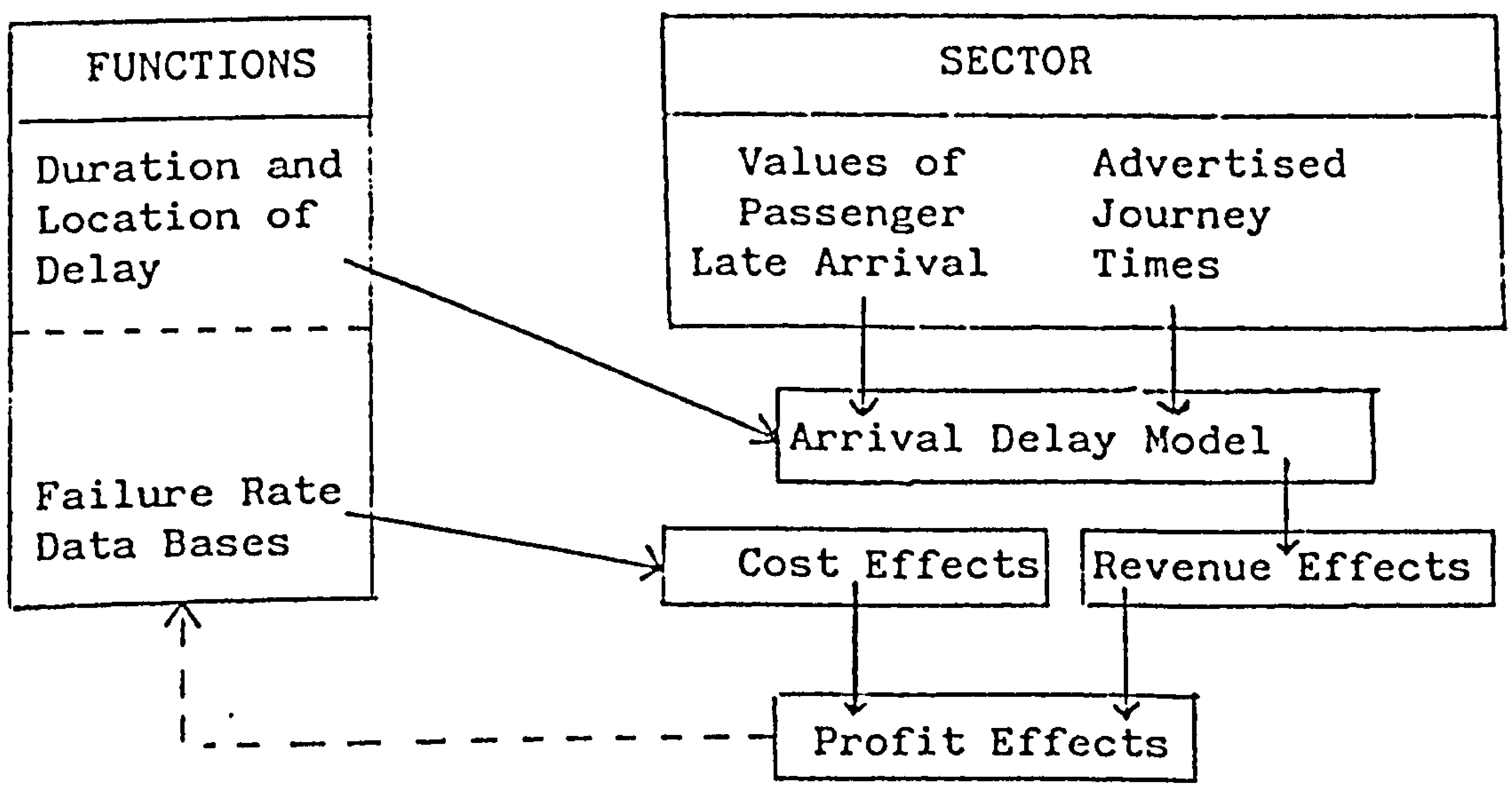

Figure 3: Information for Functions Decision-Making

RELIABILTY MANAGEMENT IN THE FUNCTIONS

This section of the paper was part of a pilot study to demonstrate the way in which information requirements can be identified for decision-making about detailed reliability issues within the Functions. It uses the results of an exercise by a permanent way maintenance engineer at a local level to identify the most profit effective methods of responding to the problem of broken and defective rails. As the analysis developed the need for information, data, models etc., became clearer. Similar exercises were undertaken by Signal and Telecommunication and Mechanical and Electrical engineers, and by Operations managers, as part of an attempt to demonstrate the difficulties and benefits of developing local level reliability management consistent with Business Sector objectives. One of the main objectives was to demonstrate the need for information systems that can respond to the much wider range of analyses that should be undertaken.

Broken/Defective rails on a 2 track section. The options available to change reliability fall into two main types. Mean Time to Repair (MTTR) affects the duration of the delay in that a reduction in MTTR will reduce the number of trains affected and reduce the amount of delay to those remaining trains that are still affected. Options that might be considered are:

LOCATION - location of replacement material and equipment.

COMMUNICATION - improving the methods of contact with maintenance technicians and supervisors to improve response time.

OPERATIONS - introducing faster procedures for initiating, operating and terminating single line operations.

Mean Time between Failures (MTBF), affects the frequency of rail failure rate and thence the frequency at which given delays occur. Options that might be considered are:

REPLACEMENT - altering the age/wear at which rails are replaced given that failures increase with age/usage.

CONDITION - increase frequency of maintenance of systems that contribute to rail failure.

Thus options that affect MTTR are likely to call upon logistical analysis and will require the application of, for example, simulation techniques. The cost functions within such models will need to be developed from equipment and labour costs, disaggregated with respect to such option types.

Options that affect MTBF could well extend back to initial design, but at a local level will centre on the probability of failure of a given type and changes in that probability. The engineer thus needs access to probability distributions by type, with respect to age/usage etc., as well as material and labour costs data structured around such options. It should also be noted that changing MTBF can also affect severity of incidents and thence safety.

Further development of the analysis of one option shows even more about information and analytic techniques that may be needed on a frequent basis far down in the organisation. The option considered is the timing of replacement of rail. As noted earlier the revenue effects of a 'blockage' of any given duration at any specific' location can be predicted using a suitably developed model. At any given point in time rail of a given age/usage will have a particular probability of failing and this probability can be computed into the future given the history of usage and forecasts of future usage. Given information on the relationship of failure to delay the revenue effects into the future can be computed and discounted to a net present revenue loss for any current rail condition. The problem then is to estimate the cost of replacing existing rail now, or in the future, and to compute the net present revenue effects, and thence net present value profit. This is essentially the classical investment timing problem, with life cycle costs, that exists in other transport modes. However, it should be noted that local knowledge of engineering conditions (soil, weather) etc. all contribute to the knowledge base of local engineers and that revenue effects are specific to track layout, location on route and local timetable. For these reasons it is argued that such analyses are a local problem requiring local access to data, models and analytic techniques. This one example of an option generates the need for the following:

- Data on probability of rail failure of given type for given age/usage. This in turn requires location of all rail to be known, its history (e.g. tonnes transit by speed etc.), and a failure probability estimate, based on historic data or by analogy to similar components in other systems.

- Future usage. Estimates of future demand translated into train/weight/speed movements.

- Costs. New rail, value of old rail, labour, equipment, reduction in future maintenance costs.

- Revenue. Estimates of location/duration of failures that cause delay as inputs to the arrival delay model for route; also required are estimates of the revenue effects of delay. In practice the local engineer need only use standard tables of revenue lost for duration/location for the local area as provided by, in this case, BR Operational Research Unit.

- Discounting procedure for life cycle costs.

This gives rise to issues of data capture, i.e. when, what and how to record contemporary events. Typically forecasts of future failure rates can best be made on historic data. When many options to many issues are considered a large requirement is placed on information and analysis. Much information is probably already available but often as written records, requiring one-off analysis for each problem so that collation, storage and access are the key problems for information system design. In other areas data is probably not captured at all. Additionally the analysis of such data needs computational packages to be readily available.

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The development and application of interactive models of industrial technology transfer

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Abstract

The paper begins by offering a process oriented description of industrial technology transfer. This is used as a basis for a brief review of the limitations of recent and current models of industrial technology transfer. In response to these limitations, an interactive model (and evaluative framework) is developed on the basis of three components: accessibility, mobility and receptivity (AMR). The deficiencies of identifying technology largely by its techno-economic attributes are discussed, and a multiple constituency approach is proposed.

After definition and discussion of these concepts, the paper illustrates the application of the AMR framework and the development of the multiple-constituency approach in four contexts. Each context is explored through an applied study in which a researcher from the team has spent two or three years working with an industrial partner, a group of companies or a technology transfer intermediary.

A final section gives the substantive applied conclusions from the four case studies and presents some general policy implications.

1. Introduction

The rate of industrial technological innovation in the UK is generally considered to have lagged behind that of many other industrialized countries despite the widely held belief, internationally, that the UK is still an effective source of inventions and innovatory technical ideas. The dependence of such innovation on the external acquisition and subsequent exploitation of new technologies by industrial organizations has been recognized in Government policy towards technology transfer. Less thought and research has been focused on the relatively low levels of technological innovation actually achieved and on the difficulties of exploitation of new technologies within companies.

Technology transfer has largely been seen in terms of making adequate provision of technical ideas on the assumption that increased exposure to these ideas would in some way result in beneficial technical changes in industrial companies. While such provision of technical ideas is a necessary part of technology transfer, it is only one component of a more complex process. In this paper,

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therefore, emphasis is placed upon the concept of technology transfer as a process and this wider view of technology transfer is taken to mean:

the process of promoting technical innovation through the transfer of ideas, knowledge, devices and artefacts from leading edge companies, R&D organizations and academic research to more general and effective application in industry and commerce.

This view of technology transfer has been developed as a consequence of observations about the limitations and deficiencies of much technology transfer research and practice. In the next section the characteristics of technology transfer mechanisms are briefly discussed as a prelude to a summary of their limitations and the development of a 'process' approach to technology transfer.

2. Technology transfer mechanisms

The emphasis on providing information about, and access to, technology is apparent in the range of technology transfer mechanisms that have developed over the last ten years or so. A substantial review of a wide variety of these mechanisms can be found in Dorf [1]. A selection of these is discussed below.

The *Regional Technology Centres* (RTCs), promoted by the UK Department of Trade and Industry (DTI), function as intermediaries, i.e. links between potential sources of technology and potential clients. They are each somewhat different but their central function is to provide information about available technologies, usually from some sort of database, to potential customers within a region. They can respond to specific requests, undertake to scan for particular types of technology, provide access to specialists and so forth. Their contribution to the technology transfer process is to improve access and to facilitate acquisition of known technologies. As will be seen later, some RTCs are aware of the limitations of this role and are seeking to understand how to develop a more interactive approach to the industrial and commerical population in their region.

A somewhat different approach can be seen in the functioning of *Defence Technology Enterprise* (DTE). This company was specifically set up to scan, within selected UK defence research establishments, for non-sensitive technologies that might be more generally useful to civilian industry. It then sought to license these to a subscriber list of customers by providing a database of technical summaries. The stock of technology generally available to industry is thus increased, although only the specific licensee has access to the potential commercial benefits. DTE resembled the RTCs in that it increased access to technology through disseminating information about technological opportunities. The licensing activity was a particular way of providing acquisition which was intended to make the enterprise financially self-sufficient.

Science parks can be seen as an attempt to reduce the problems of access through physical proximity and support. Embryo companies emerge, based on inventions — usually high-tech — originating in universities and, it is claimed, develop through their early stages in a protected environment until ready to stand by themselves. This 'incubator' model is intended to increase the survival rate of innovatory technology at the vulnerable stage where it emerges from the research world. The commonly held perception of what science parks actually achieve has been recently challenged by Massey *et al.* [2].

Joint ventures between independent vendors or universities and client organizations may both reduce some of the financial risks of innovation and improve the channels of transfer. These may take the form of teaching companies, exchanging staff, etc., with or without joint financing. The main contribution to technology transfer is in easing technological knowledge into a client organization.

It is interesting to note that science parks, and to some extent joint ventures, depend on the interactions between a relatively few 'knowledgeable' people. Technology transfer is actually being enacted by the transfer of knowledge between people rather than by the physical movement of equipment. It is also apparent that much effort put into technology transfer is concerned with high technology and inventions. In practice, for the large majority of small- and medium-sized organizations, particularly in manufacturing, an innovation to them may be well-established practice elsewhere. For many companies innovation is more a matter of catching up or edging ahead of competitors than of radical change.

3. Limitations and deficiencies in technology transfer mechanisms

The programme of research projects at the Innovation and Technology Assessment unit (INTA) at Cranfield Institute of Technology over the last four years suggests that most current technology transfer mechanisms exhibit one or more of the following limitations or deficiencies:

- They fail to recognize adequately the significance of recipient organizations' needs and therefore fail to address service delivery aspects of the technology and knowledge transfer process. That is to say, mechanisms tend to emphasize the marketing and selling of technology as products to organizations that have explicit needs and requests rather than provide a business service that aids the process of diagnosis, searching for and matching the available technology to implicit needs.
- The mechanisms tend to offer 'technology' primarily in terms of technical and economic attributes, i.e. as a product, thus failing to consider the responses of organizations and the individuals within them to the opportunities and threats generated by technical change. They therefore fail to understand the actual, and generally more limited, contribution of a candidate technology to competitive advantage or effectiveness.
- They underestimate the importance of the interactive processes and mechanisms between the donor (vendor, intermediary, R&D organization etc.) and the recipient, necessary for successful transfer. They fail to recognize that successful transfer seldom involves just a simple one-off transaction but is a process or dialogue between a variety of actors in the two parties and involves a continuing relationship to the point where real benefit accrues to the recipient.
- They assume that technical change is a priority as far as the organizations are concerned and, even when this is not so, that organizations are readily able to diagnose their problems in terms of technical change and subsequently to articulate their needs in well-specified technical terms. The tendency is to assume that organizations have a well-defined shopping list rather than a set of ill-defined business problems of which technical change may only be one.

The deficiencies outlined above arise because many transfer mechanisms and organizations fail to apply a sufficiently 'client need' oriented approach. The noticeable characteristic of technology transfer in the UK is a preoccupation with:

- creating new technology;
- making technology available;
- increasing information about what is available; and
- facilitating transactions between supplier and potential user.

There is a need to offer a framework which enables the key features of technology transfer to be identified in such a way that these limitations can be addressed.

4. Accessibility, mobility, receptivity

Given the above comments, it is suggested that technology transfer in the UK has been dominated by the two preoccupations of:

- *accessibility* — the level of technologies available and information about those technologies; and
- *mobility* — the ease of obtaining those technologies and the channels (e.g. intermediaries,

people) through which technologies are transferred.

Given the deficiencies noted above, and a process view of technology transfer as in the introduction, it is argued that technology transfer will be successful only if an organization has not only the ability to acquire but also the ability to assimilate and apply ideas, knowledge, devices and artefacts effectively. Organizations will respond to a technological opportunity only in terms of their own perceptions of its benefits and costs and in relation to their own needs and to technical, organizational and human resources.

The process view of technology transfer, therefore, is also concerned with creating or raising *the capability for innovation.* This requires an organization, and the individuals within it, to have the capability to:

- *scan for* and *recognize the value of* ideas, knowledge, devices and artefacts which are new to the organization;
- *communicate* these and *assimilate* them within the organization; and
- *apply them* for effectiveness or competitive advantage.

Such a definition also implies that there is a need for:

- the technical functions (such as product development, R&D, manufacturing, engineering, training and management information systems (MIS)) not only to support current business priorities but also to create new opportunities [3];
- such integrated functions to be part of well-designed external and internal networks;
- the development of employees so that they are capable of comprehending and functioning effectively within such activities; and
- the development of managers capable of shaping organizations to achieve these objectives.

An organization's overall ability to be aware of, to identify, and to take effective advantage of technology we refer to as *receptivity.* Other writers have recently described such a notion, specifically in the context of R&D, as 'absorptive capacity' [4].

The ideas of accessibility, mobility and receptivity (AMR) serve as a framework for a process view of technology transfer and provide a simple conceptual device which emphasizes a client organization's own view of its needs and problems. Diagnosis of a client's business problems in the language of the client, and information about its derived need for technology, have to flow back to the vendors and intermediaries if technology suppliers or intermediaries are to participate effectively. The two-way flow of information provides a simple interactive model of technology transfer, while the receptivity model provides an orientation for investigating an organization's internally based technology transfer processes.

However, within such a conceptual framework it would still be possible to interpret such an interactive view of technology transfer in a narrow techno-economic fashion and to focus only on the initial point of impact of the technical attributes of change. Clearly there is a need to deal with two further important limitations to the conventional perception of technology transfer, namely that it is technocentric, and that it implies change only in those parts of the organization that are immediately affected by the technology.

Information about the technical performance and cost characteristics of a technology is only a starting point for understanding the totality of financial and other resource costs and benefits arising from technology innovation. Too frequently, simple technical performance and financial costs are all the information that the vendor or intermediary offers. In practice the optimistic estimates of the benefits that technology innovations initially offer are seldom, if ever, achieved. For instance, the recipient organization may need to adapt its procedures, work organization, training etc. in order to obtain commercial advantage from the technology. Some organizations may be better suited to take such an advantage than others.

The ability to innovate effectively involves not only the individual in formal terms (job function) but also the perception of the individual about his role and about organizational needs. Adaptive behaviour in organizations is also critically dependent on managerial style and organizational culture. An organization evolves as a consequence of the accumulation of decisions and positions taken up by individuals and groups on their own behalf and on behalf of the organization. The fundamentally critical role of the individual has seldom been researched in a coherent way in the context of technology transfer.

Understanding the implications of technological innovation from the perspective of organizations and individuals, as well as from the technical and economic perspective, we refer to as a *multiple perspectives approach*, i.e. one involving technical, organizational and personal factors [5, 6]. There is also a need to identify the different types of perception and impact within the various technical, service and business functions; this we refer to as a *multiple constituency approach*. The use of these two linked approaches needs the application of a wide range of methods and techniques, whose development and application is an important component of interdisciplinary research into technology transfer.

5. Technology transfer research at INTA

5.1. Research programme

The research programme on technology transfer, together with related research on knowledge acquisition and on internal knowledge transfer processes in organizations, consists of nine completed or current two- to three-year projects. Four of these specifically address the limitations and deficiencies mentioned earlier.

One of the first two projects provided the basis for the development of the idea of differentiating accessibility, mobility and receptivity (AMR) as a conceptual device to enable receptivity to be identified as an issue for specific research. It was complemented by a project undertaken within a major manufacturing company which enabled the researcher to function as a technology transfer agent as well as to develop the elements of the multiple constituency and multiple perspectives methods and techniques.

Having developed the AMR framework, made an initial investigation of the individual as a knowledge transfer agent and developed an initial insight into receptivity, a current research project on receptivity directly focuses on the contribution of the individual to external technology transfer in a major chemical company with high levels of internal R&D. It concentrates on the attributes of the individuals and the company with respect to their ability to scan for, recognize the value of, and communicate ideas, knowledge, artefacts and devices.

The fourth project, in collaboration with a Regional Technology Centre, tackles receptivity from the point of view of small and medium-sized enterprises (SMEs) in the manufacturing sector. It focuses on the difficulties they have in diagnosing technology as a relevant business issue and on their ability to articulate needs for technology.

5.2. The development of AMR: the role of intermediaries in technology transfer

This research project started in 1987, initially as a collaborative three-year project with Defence Technology Enterprise, an organization set up with the intention of exploiting the supposed technological advances of the defence forces and industries in an attempt to increase their value by use in UK civilian industry. By enabling specialist technologists ('ferrets') to scan within specific research establishments, a wide variety of potentially useful technologies was identified and then marketed through a subscriber club or by direct contact with a limited number of potential clients. The intention was to develop a commercial intermediary from the profits of licensing.

For a number of reasons, commercial success was less than anticipated. The research project was expanded to investigate the way that intermediaries in general, and DTE in particular, interact with potential clients. The INTA research mainly focused on two surveys: one considered the views of industry about innovation and technology transfer mechanisms, including intermediaries [7]; the other focused on the activities and objectives of a number of intermediaries.

The industry survey revealed that:

- Intermediaries were perceived as minor contributors to commercially successful technological change. Over 70% of companies needing product or process technologies looked to companies in the same market. Conventional sources such as research associations and universities were also popular.
- The main issues in external technology transfer were seen as the provision of technical expertise and technical evaluation on behalf of the company.
- Small companies were more aware of external technology as an issue than large companies but less technologically competent to evaluate and implement it.

In the survey of intermediaries, all intermediaries emphasized access to technologies but far fewer offered technical expertise (although this is changing) and only one-third offered post-transfer support. The survey suggested that intermediaries can usefully be classified in the following way:

- the proportion of technologies they offer which are market ready, need limited development, or need long-term development;
- the distribution of their clients by turnover and technological competence.

The initial idea of the accessibility/mobility/receptivity framework arose from the realization that, in service delivery terms, intermediaries were 'marketing and selling' but not adequately supporting the overall 'scan, evaluate and implement' process which companies need to undertake to innovate effectively.

5.3. The development of a multiple constituency, multiple perspectives approach: the role of individuals, groups and the organization in receptivity

At the same time as the DTE project, another three-year project was initiated which used quite a different research method. In this case a researcher worked within GEC Traction on a daily basis over a two-year period on the selection and application of expert systems. The objectives were to:

- explore the role of an externally based researcher as a mobility channel in the process of inward technology transfer;
- study, from the recipients' point of view, the difficulties and processes by which a technological innovation is adopted (receptivity);
- further develop a multiple constituency, multiple perspectives approach.

The project demonstrated the need for consideration of a potential technology, not only from the ostensible technological and first-order economic effects, but also from the demands made on individuals to respond and adapt individually and within groups, and on the organization to enable such changes to occur [8]. If the penalties for such change are too high, then the additional costs to the organization may well outweigh any of the first-order technical and economic benefits. (It is these first-order benefits which vendors so readily identify without regard to the 'costs of change'.) The importance of the role, both formal and informal, of the individual in the scanning for technology, negotiation (externally and internally) and implementation, formed the focus of a further project, briefly described below.

5.4. The development of a model of receptivity: technology scanning and inward technology transfer

The opportunity arose in 1990 to start a further long-term project, this time with ICI Chemicals and Polymers. The project concerns technology scanning and evaluation within the inward technology transfer process, from external sources and from the company's own R&D function. The research has two main objectives:

- the further development of a process theory of inward technology transfer in a large innovatory company with its own R&D function;
- the application of these findings to the technology transfer process of small and medium-sized enterprises (SMEs). The second part of the work is complemented by the fourth project discussed below.

A research framework has been adopted along the following lines:

- the individual and the organization (the individual; the individual's formal and informal networks; the organization);
- technology sophistication ('blue sky', basic and applied research; development; technical services);
- stages in the inward technology transfer process (awareness; evaluation; adoption; utilization).

Within this framework, the project focuses on the individual and on the individual's formal and informal networks outside and inside the company and the contribution that participation in such networks makes to awareness and evaluation of applied research and development. (A variety of interactive research techniques is being designed to elicit the relevant information.) The individual is viewed as a potential scanner and evaluator of technology on behalf of the organization.

The extent of the individual's contribution to commercially successful innovation will depend on:

- his/her perception of the objectives and market opportunities of the commercial businesses (and how the organization disseminates such information);
- the formal and informal networks outside and inside the company and the extent to which the organization recognizes and facilitates these;
- the extent to which the information available is effectively channelled to and from commercial management.

5.5. Receptivity in small and medium-sized enterprises (SMEs)

As has been noted earlier, problem diagnosis — identification of need and articulation in technical terms about the contribution of technology (where relevant) — is a particular problem for SMEs, which generally lack an internal R&D activity and employees with high levels of technology evaluation expertise. A research project, started in 1990, is being undertaken in collaboration with the Eastern Region Technology Centre (ERTC) on these issues as a contribution to the evolution of a more effective role for such intermediaries. SMEs form a high proportion of the potential clients for the services of ERTC. It may be useful for intermediaries to offer a diagnostic and evaluation role with SMEs.

The research addresses the following questions:

- What do SMEs perceive as business problems and opportunities, and how do they articulate their needs?
- To what extent do they perceive technological change as a contribution to those needs, and to what extent can technology actually make a contribution to their business?
- What technology information networks do they have, compared to those of a large corporate organization?

The early output of this work suggests that many manufacturing SMEs do not articulate their needs in terms of technological innovation. They are therefore seldom able to link technological change to access to new markets and unable to respond to change in an entrepreneurial way. Further phases of the research will explore any difficulties in their ability to articulate their perceptions of market opportunities and their technology needs.

6. Conclusions

This paper has argued that most initiatives in the UK in the field of technology transfer implicitly focus (narrowly) on the accessibility of new ideas and technological innovations and appear to be based on a linear model of technology transfer. The paper has attempted to demonstrate the need to see technology transfer as an interactive process and has presented a conceptual framework, based on accessibility, mobility and receptivity, for the clarification and analysis of that interactive process. It also outlines the need to view that process from multiple constituency perspectives rather than from a single techno-economic rationale.

The application of these concepts and methods has been illustrated through a number of research projects undertaken within an institutional/organizational setting. The findings of these projects will be published separately, but we conclude with the following observations:

- There has been an over-emphasis on levels of technology available and the dissemination of information (accessibility) at the expense of consideration of the channels by which technology is actually obtained (mobility) and of the ability of organizations to relate to and act effectively on this knowledge (receptivity). A working definition of receptivity has been given, used and linked to the strategic management of technical functions.
- A large organization needs to recognize the importance of enhancing its knowledge base by scanning and networking activities. It also needs to develop the capacity to assimilate and exploit this knowledge by developing integrated and well-tuned linkages between the network and the internal functions and sub-units.
- It is necessary to help small companies to disaggregate their perceived business problems and to translate the technology-relevant aspects into effective statements of technology need. Presenting technical information without effective diagnosis and support facilities may indeed be counterproductive.

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Seaton R. and Al-Dhahab Al-Ghailani H. (1997) 'Innovative Effort' in small manufacturing companies in development economies" Proc. Sixth International Conference on Management of Technology - MOT 97, Gothenburg, Sweden

"Innovative Effort" in small manufacturing companies in development economies

Introduction

This research is focused on the way in which small and medium sized manufacturing companies who often have little or no internal Research and Development expend their resources on the processes and underlying activities by which they not only implement technical innovation but also develop their capacity to innovate. From the literature, it is not clear how small and medium-sized manufacturing companies behave during the process of innovation, particularly in many development economies.

The research takes a "knowledge" perspective as a way of exploring innovation in such companies and draws upon two broad fields of research literature, those of innovation and technology transfer. The research translates the theoretical and conceptual aspects of relevant research into the operational level (a set of resource consuming and identifiable activities described as Innovative Effort) which then become the subject of field work investigation. The final stage is to translate these activities (as verified and amended in the research activities) back into a conceptual model. Considering innovation in this way and in the context of this type of manufacturing company, a number of issues arise:

- How can research into the determinants of innovation and the process approach be combined to research the innovation process?
- What types of activities are required to perform each element of the overall process of technical change and technological learning?
- How can we identify the activities involved in the innovation process?

Much innovation research has been at the level of the economy or a sector. In addition, much literature focuses on radical change, whereas this research focuses on incremental change, the dominant mode of innovation in companies of interest. Macro and micro technological development theory explains the link between innovation and economic growth and asserts the need to improve innovation inside organisations through improving their competitive. However, this literature mostly uses an analytical approach (often statistical) which cannot reveal the organisations 'internal processes and thus cannot show the way to promote innovation processes intra-company.

The process models on knowledge transfer and knowledge accumulation place an emphasis on these processes of innovation into organisations, on sub-processes and the importance of prior knowledge, key individuals, communication, scanning, and networking. Concepts of human-centred effort to improve individual and organisational learning are also of interest to research in the context of development economies. While Inward Technology Transfer (ITT) and other models study the process in its abstract sense, this research, in contrast, attempts to understand these processes through the **activities** that underlie them and use these activities as building blocks for the proposed notion of 'Innovative Effort'. Thus intangible processes are identified in terms of tangible activities to enable their identification, testing and measurement in the organisations' daily life.

We need to develop a model that addresses the innovation process as it relates to small and medium-sized manufacturing companies with no internal R&D. Such a model would have two important contributions to the field by:

- Linking theoretical levels of process models with operational levels of 'Innovative Effort' by breaking down the innovation process into sub-processes which are further broken down to

their constituent activities. Thus the behaviour of individuals and organisations that can be translated into actions is the focus of the observation and exploration.
- Drawing upon research methods that enable operationalisation and illustration of the process concept.

Since shifting between research levels is a relevant part of the research method it may be helpful to locate this research device and its properties within the literature as shown in Table 1

Table 1 The relevance and the origin of 'Innovative Effort' from the literature

Research Level	Innovation	Inward Technology Transfer	'Innovative Effort'
Theoretical	Innovation Models	Process Model of ITT	Model of Innovation in Manufacturing Companies
Conceptual	Determinants of innovation	Acquisition, communication, application, and assimilation. Knowledge accumulation Individual and Organisational learning	Nature of 'Innovative Effort' Process thinking approach
Operational	Using statistical analysis	Scanning and networking and other activities	A set of operationalised activities
Type of Innovation	Organisational Innovation	Technical Innovation	Organisational and Technical Innovations
Relevance (Link with IE)	Radical change vs. Incremental change Sectoral vs. organisational	Large vs. small companies With vs. without R&D Units	Incremental technical and organisational change in SMCs with no R&D functions

Shaded boxes in Table 1 highlight mutual areas on which this research focuses, in order to bridge the limitations of both major strands of the literature. The level of the research activity is operational (the focus of applied research). The types of innovations studied are incremental, organisational, and technical innovations in manufacturing companies. Relevant queries for such a task include:

- What activities need to be included in a study of the innovation process?
- What type of effort in the process of innovation do small and medium-sized companies in manufacturing sector emphasise?
- Do companies invest deliberately in people to improve innovation?
- What will the innovation process model in small companies look like?

Understanding Innovative Effort

In this research therefore, 'Innovative Effort' refers to the amount of effort (in terms of resources allocated) small and medium-sized manufacturing companies expend to implement technological innovation and develop their capacity to innovate. As a preliminary activity, it will be useful to discuss and explain some important aspects of the notion of 'Innovative Effort' so as to understand the reasons behind proposing its use.
- It is clear that companies acquire different knowledge in management, finance, accountancy and other areas so as to operate effectively.
- The idea of cumulative knowledge is discussed for example by Cohen and Levinthal (1990). The ideas of a firm's prior related knowledge and absorptive capacity are linked to this notion, but the focus is on generating technical knowledge via the firm's own R&D. It is argued that this kind of

notion does not accommodate a whole range of firms which are not driven by the desire to gain comparative advantage through acquiring leading edge knowledge.

- The notion of receptivity has been proposed to amend deficiencies in previous technology transfer models. Receptivity, as it is proposed by Seaton and Cordey-Hayes (1993), is: *'a firm's ability to be aware of, acquire and make effective use of technology'.* Receptivity focuses on knowledge acquisition in the context of the technology transfer process, while absorptive capacity focuses on generating knowledge in the context of R&D driven firms. This idea of receptivity denotes the way in which a company relates and uses external knowledge. Receptivity highlights the importance of having certain abilities and qualities to enable a firm to acquire and exploit external knowledge (Trott, 1993, Gilbert, 1995). Receptivity needs to be investigated in more depth so as to understand its importance to the innovation process into manufacturing sector SMCs.
- The qualities of scanning, networking, assimilating, and other activities are seen to be good indicators of the innovation process. The assumption is that the better these qualities are in a firm, the better chance it has to acquire and accumulate technical knowledge. It is important to develop proxies for the innovation process in SMCs so as to identify its intensity
- It is important to acknowledge that 'Innovative Effort' is not only intended to be a device to quantify the capacity to aquifer and exploit knowledge, but also to extend our understanding of the totality of the innovation process and its various sub-processes and activities.

Research Activity

The initial phase of the research was to identify from existing research the range of different activities associated with innovation and technology transfer. Research then took place in Oman, a country with a typical development economy as far as manufacturing is concerned. There were three phases to the research activity.

The first involved a scoping questionnaire of some 14 questions obtained from some 50 small and medium sized manufacturing companies. This focused on three themes:

- Corporate change and the role of technological change
- Interactions with between internal staff and external contacts
- The ability to acquire new knowledge and the role of individuals in this process

The aims of the second phase was to:

- Identify the inward technology transfer process
- Expose the activities that constitute this process and the factors affecting it

It consisted of in-depth research in a selection of 10 companies chosen for as much diversity as possible. The research method was to use unstructured thematic interviews which were the analysed individually and collectively using cognitive maps as an interpretative device. It is these which provide much of the material for the synthesis of a new conceptual model at the end of the research. The third phase consisted of work with 8 companies and comprised:

- A questionnaire on the perceptions of the most senior manager about the importance of the component activities of Innovative Effort
- A semi-structured interview of some 88 questions about company resource expenditure on these, the organisational factors which enhance them and the type and role of individuals involved

It is from this third phase that much of the detail of Innovative Effort has been derived. Note that an attempt has been made within the practicalities of the research to involve companies that have considerable differences in order to explore the ability of measures of Innovative Effort to discriminate.

Table 2 Characteristics of the companies under study

Company	1	2	3	4	5	6	7	8
Products	Paints	Pumps	Food/ Sweets	Detergents	Food/ Biscuits	Food/ Dairy	Plastic Pipes	Food/ Oil
Employees	104	90	55	210	170	270	270	230
Production.	4.41	2.00	0.44	7.14	2.22	4.40	2.64	11.72
Capital	0.75	0.23	0.70	1.45	0.45	1.00	0.20	2.30
Wages	0.29	0.11	0.10	0.46	0.29	0.68	0.08	0.36
Exports	0.56	0.60	0.14	2.72	0.82	0.47	0.41	4.01
Current Assets	1.63	2.18	0.49	3.79	1.22	2.24	2.14	6.69
Current Liabilities	1.33	1.57	0.89	3.23	0.13	1.13	0.93	5.61

All the companies involved in the study produce different commodities. The products range from food to engineering products. Four companies are involved in food, one in detergents and cosmetics, one in paints, one in plastic pipes, and one in water pumps. Even the companies in the food industry are different in what they do with one company in each of the following activities; biscuits, dairy, sweets and oil derivatives.

All the companies chosen are a 100% locally owned, as is the case with most companies in the industrial sector in Oman. The major difference is that some companies are independent, whereas others are part of larger corporations that also deal with other related activities.

'Innovative Effort' Characteristics

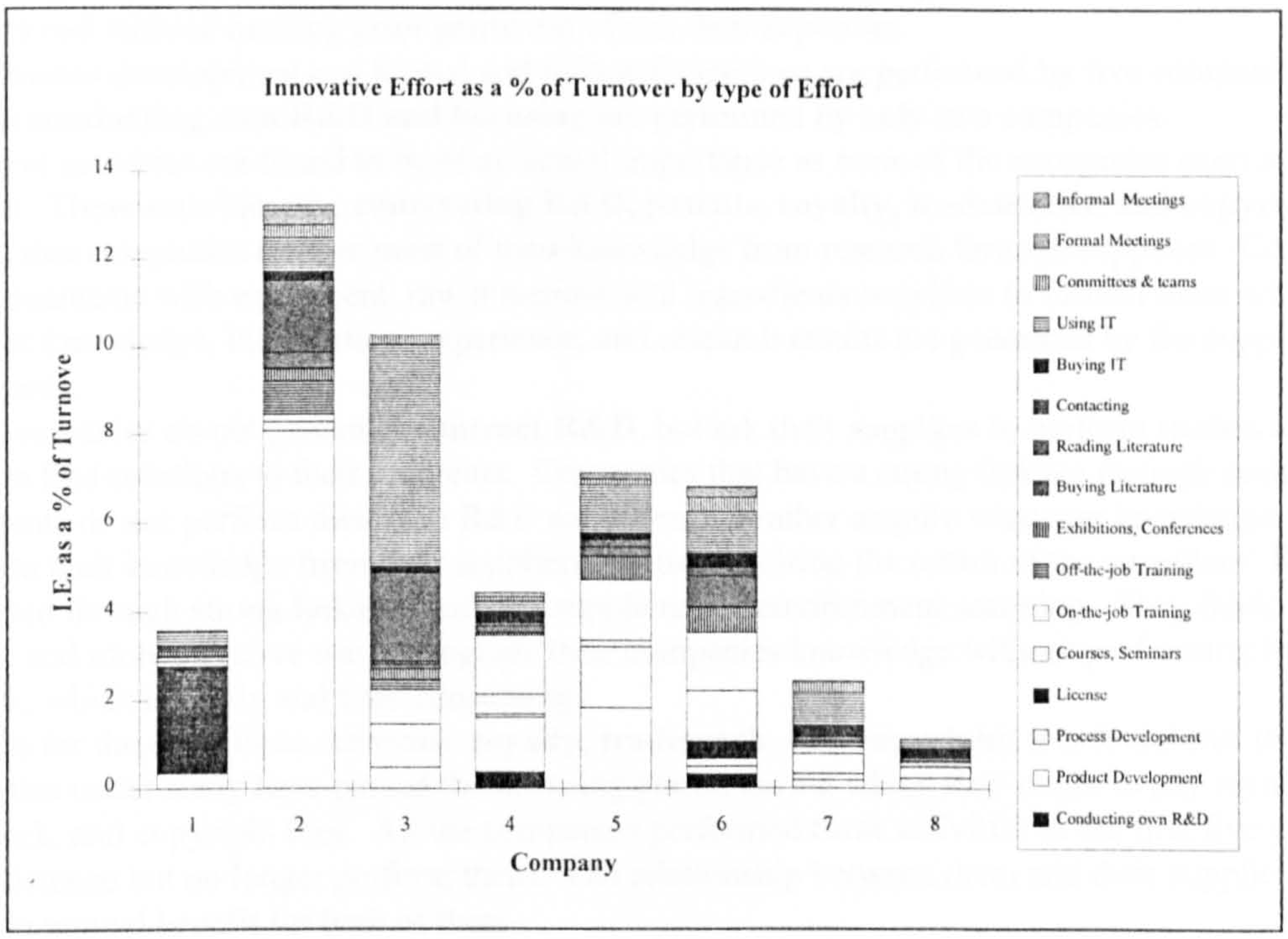
This section describes the practical application of the notion of 'Innovative Effort'. It refers largely to Phase 3 of the study and demonstrates a method for measuring the associated activities. Table 2 shows the range of research relevant activities that have been identified from the literature and the all phases of the research activity.

Table 3 'Innovative Effort' Activities

- Own Research and Development
- Contracting Research and Development
- Product Development
- Process Development
- Patents
- License
- Royalty
- Trade Mark
- Copyright
- Consultancy
- Formal education of employees
- Short courses, seminars, etc.,
- On-the-job Training
- Off-the-job Training
- Attending exhibitions and or conferences
- Buying specific literature; journals, books, etc.,
- Reading specific literature related to the field
- Contacting other people outside the company
- Buying and installing information technology
- Using IT for accessing an information the firm needs
- Buying and purchasing database, programmes, etc.,
- Committees and or Teams; like QC, Suggestion Teams, etc.
- Formal Meetings to discuss issues related to innovation and technological change
- Informal meetings and discussions

From the activities listed in Table 2, nineteen activities are performed by more than one company, and nine activities are found to be performed by all companies in the Phase 3 research. These are; product development, attending courses and seminars, off-the-job training, attending exhibitions and conferences, buying literature, reading literature, contacting people outside the companies, buying information technology, and using information technology to access outside information. Some activities are not represented in these companies at all. Figure 1 shows the general patterns of Innovative Effort by activity as measured by % of Turnover.

Figure 1 Innovative Effort by activity as measured by % of Turnover



Product development is found to be the most important activity that is performed by all companies. **Using information technology** is the second most important. Employing information technology in the product line, sales, raw materials, marketing and other areas will improve the efficiency of a companies' performance. Information technology in most companies is not used to access that outside information which might improve and develop technical people's knowledge. All companies, except number 1, have **committees and teams. Formal and informal discussions** are performed by most companies under study.

Attending courses and seminars is one of the most important activities that is performed by all companies. Most courses and seminars are local and they are attended by technical people. International events are usually attended by the general manager or members of the board of directors.

On-the-job training is another important activity which is performed by all companies. Training is subsidised by the government and mostly focused on non technical aspects; such as secretarial skills, English language, and others.

The data on **attending exhibitions and conferences** sometimes includes non-technical exhibitions; such as trade exhibitions.

Buying technical literature is also a common activity among all companies involved in the study. Although companies spend relatively little on this activity, owing to the fact that subscription to technical journal is cheap, it expresses the awareness of these companies to the importance of keeping their technical people abreast of new knowledge in the field. The **reading of this literature mostly at**

work expresses management awareness of the importance of reading as a mechanism of knowledge transfer. All of the managers responded positively when managers asked whether they consider reading at work as productive activity.

Contacting people outside the companies is one of the important activities performed by all companies. The main contacts for technical people to are suppliers and licensers. Most of the managers give a reasonable amount of freedom to their technical people to talk to their colleagues at the suppliers end without needing prior permission from their superiors.

Process development and formal and informal meetings are performed by five companies, whereas **conducting own R&D and licensing** are performed by only two companies.

Five activities are found to be of no actual importance as none of the companies exert any effort on them. These activities are; **contracting R&D, patents, royalty, trademarks, and copyright.** It is thought that companies acquire most of their knowledge from research through suppliers. Companies have agreements with equipment, raw materials, and ingredients suppliers to furnish them with whatever knowledge, information, experience, and research results are generated by the suppliers or their agents.

Companies do not generally **contract R&D,** but ask their suppliers to perform studies on their behalf to find solutions to their problems. Companies that have a strong linkage through such agreements do not perform their own R&D activities, but rather acquire whatever knowledge they need to update their knowledge from their suppliers. Thus, acquiring the cream of the **suppliers' R&D** is performed through strong linkages with the suppliers and environment scanning. They think this is a cheaper and more effective way to upgrade their companies knowledge without performing their own research, which is costly and time consuming.

As for the other three activities; **royalty, trademark, and copyright,** it is found that the companies under study have passed the licensing period during which they ought to pay royalties, trademark, and copyright fees. All the companies performed these activities in the first five years of their existence but no longer perform them. The relationship between them and their suppliers is now based on mutual benefit for both of them.

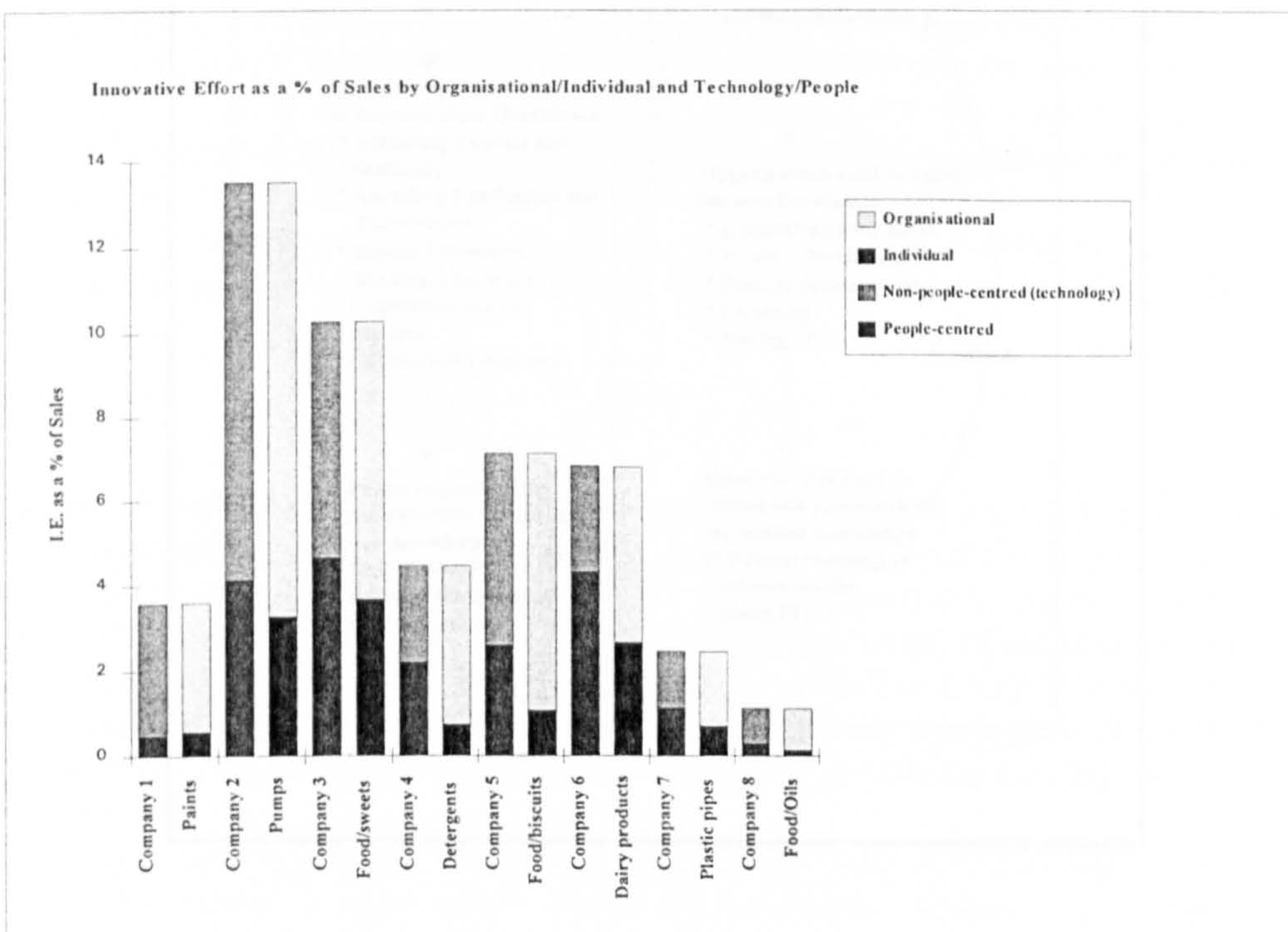
People versus non-people and individual versus organisation Innovative Effort

The research also aimed to explore the differences in the way effort was distributed between these two types of classification. This is because there is an interest in a development economy which is dependent on external knowledge for innovation about the extent to which it itself become engaged in that wider knowledge economy rather than provide capital and labour inputs. This issue in turn places a great deal more emphasis on how organisations use people as a part of their innovation activities and what actions governments can take to equip their populations with the skills required to take part at these two levels. As will be seen in the final part of this paper, models of innovation for companies in these circumstances which focus on the interactions between individuals and organisations and which place a somewhat greater weight on the knowledge and skills aspects are likely to be more helpful in developing policy. It is also relevant for small manufacturing companies in established economies to begin to identify the resource consuming activities that will enhance innovation capability and implementation in such a way that they can compare themselves with peer group companies. It is not possible to discuss the potential of this approach for benchmarking but research is underway to develop this in the UK. The Table below identifies the constituent activities and Figure 2 shows both of these comparisons side by side. The Figure also shows the variation in size of overall Innovative Effort among this disparate group of companies.

Table 4 People versus non-people and individual versus organisation Innovative Effort

People centred	Non-people centred	Individual	Organisational
Attending Courses & Seminars	Conducting Own R&D	Attending Courses & Seminars	Committees and Teams
'Attending Exhibitions & Conferences	Conducting Product Development	Attending Exhibitions & Conferences	Informal Discussions
Buying Literature	Conducting Process Development	Buying Literature	On-the-job Training
Reading Literature	Licensing	Reading Literature	Conducting Own R&D
Contacting people outside companies	Buying IT	Contacting Outside Sources	Product Development
On-the-job Training	Using IT	Off-the-job Training	Process Development
Off-the-job Training	Conducting Formal Meetings		Licensing
Building Committees & Teams			Buying IT
Formal and Informal Meetings			Formal Meeting
			Using IT

Figure 2 Innovative Effort as a % of Sales by Organisational/Individual and Technology/People

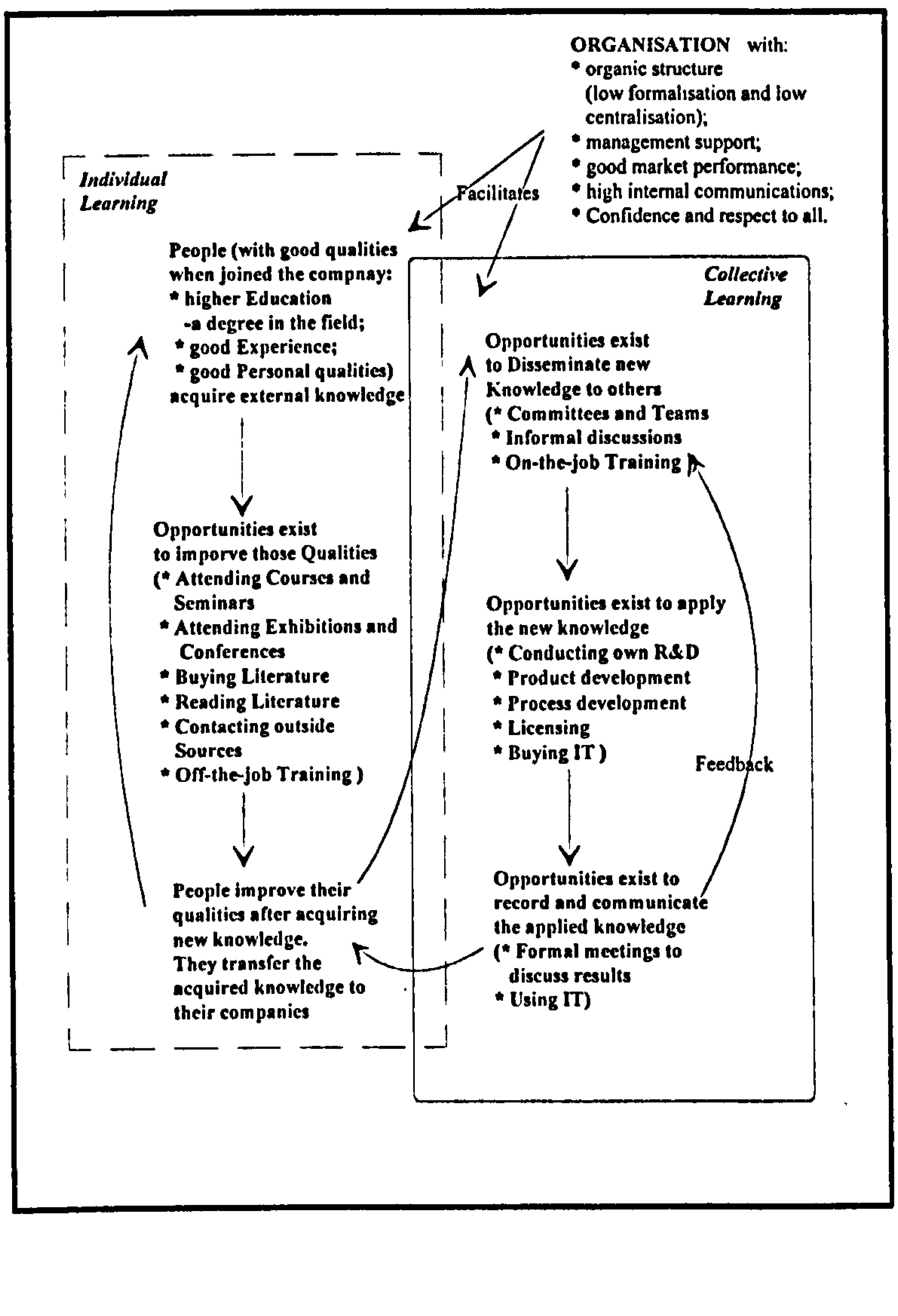


A Conceptual Model of Innovation using Innovative Effort research

Figure 3 presents a break down of a process model of innovation into activities which are considered as opportunities provided by the companies (Gilbert, 1995). It is depicted in a way that reveals the various concepts and activities that are used and discussed in this research.

First is the concept of prior related knowledge. The literature suggests that prior knowledge increases the ability to acquire new knowledge (Cohen and Levinthal, 1990; Willman, 1991; Nonaka, 1990, 1991). From the literature as well as from the fieldwork, it was concluded that to make use of external knowledge companies need internal capabilities. As knowledge starts with individuals (Cohen and Levinthal, 1990; Nonaka, 1988, 1990, 1991; Leonard-Barton, 1992; Kim *et al.*, 1993), the existence of individuals with certain levels of education, experience, technical skills and personal qualities are the central attributes in the process of innovation. Figure 3 shows those concepts and how they relate to each other.

Figure 3 A model of innovation based on 'Innovative Effort' activities



The individuals need to be provided with opportunities to enable them to acquire and make use of external knowledge. The more opportunities these individuals have, the more they will be able to acquire knowledge. It is suggested that organisations with organic structures (Burns and Stalker, 1961; Mintzberg, 1979; Hage and Aiken, 1970; Cohen and Turyn, 1984; Khan and Manopichetwattana, 1989; Damanpour, 1991; Kim *et al.*, 1993), positive market performance (Rothwell, 1986; Storey, 1994), and certain levels of respect and confidence (Trott, 1993) will support opportunities and facilitate these activities. Through these opportunities individuals promote and improve their knowledge, technical skills, experience and personal skills. This description is represented by the arrow in **the 'Individual learning'** area connecting the node **'People improve their qualities'** to the node **of 'People with qualities'**. So the first part of the diagram shows an individual learning process where the acquired knowledge improves the level of individual knowledge. When there is no opportunity to communicate this knowledge to the others in the company, the learning can be thought of as a single-loop learning process.

When individuals who acquire external knowledge are provided with opportunities to distribute this knowledge through various internal mechanisms, individual knowledge is transferred into collective knowledge. Organisations with organic structures, management support, positive market performance, and confidence and respect, support these opportunities and facilitate the activities required to perform them. The more opportunities the companies provide to disseminate knowledge, the more knowledge these companies acquire and make use of. The arrow connecting the **node 'People improve their qualities'** to **'Opportunities exist to disseminate'** explains the transformation of individual knowledge to collective knowledge.

The individually acquired knowledge is transferred into collective knowledge where it is evaluated, tested, developed, and applied collectively. The more opportunities the companies have to apply knowledge, the more knowledge they assimilate and accumulate over time. The applied knowledge which is routinised and recorded needs to be communicated back to others inside the companies through the same opportunities to disseminate knowledge. This is represented by the arrow which leads from the node **'Opportunities to record and communicate the applied knowledge'** to the node **'Opportunities to disseminate knowledge'**. This feedback represents a double-loop learning process, where the applied knowledge is routinised and disseminated to others in the company. If the applied knowledge is retained and left with the individuals who applied it, the learning will still be individual, which is represented by the arrow which goes **from 'Opportunities to record and communicate the applied knowledge'** to the node **'People improve their qualities'**. Hence the learning will be individual.

Conclusions

The idea of 'Innovative Effort' is far from complete and the following suggestions for future research are proposed. In depth studies undertaken to establish a comprehensive list of all activities involved in the innovation process. A broad range of companies need to be studied in different sectors with a range of size, age, performance, and organisational and technical capabilities. In addition, cross-sectional studies are needed to understand the perceived and the actual activities involved in the innovation process at all levels within companies. In future research it is suggested that the amount of effort on evaluation and assessing new ideas need to be separated from the amount of effort on product and process development.

The focus of this research has been to develop a practical method by which managers in manufacturing companies can apply (without involving themselves necessarily in understanding) abstract models of innovation. The originality of the idea of 'Innovative Effort' is in the use of tangible day-to-day activities that can be tested, identified and measured in a quantifiable manner. In addition, they can compare themselves with others in the industry using actual measures.

The idea of 'Innovative Effort' also helps government to understand the importance of innovation to their national economic growth and promotes their understanding of the innovation process inside companies in manufacturing sectors and the various activities which constitute it. Government awareness of the innovation process inside manufacturing companies will promote a shift in their focus that considers the manufacturing sector as a homogeneous group of companies that might respond to their policy initiations together.

In the context of Oman, this research suggests that the Omani government might attempt to help the manufacturing sector through promoting its competitive performance and sustaining indigenous involvement in order to improve the national knowledge economy. The Omani government in this context might use 'Innovative Effort' to identify those sectors that have a better capacity to innovate by enhancing and using the skills of the local population.

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Wider Economic Benefits from Technology Transfer from the UK Aerospace Industry:

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PREFACE

This study into the transfer of technology from the aerospace industry was sponsored by the Department of Trade and Industry's Aerospace Division which is reviewing the contribution of the aerospace industry to the UK economy. The material presented here is drawn from an initial report which was commercially sensitive: this version of the report has been cleared with both contributing organisations and DTI for limited distribution.

We would like to thank members of the DTI's Aerospace Division for their support.

The views expressed in this report are those of the authors, who also take responsibility for any errors that may have inadvertently occurred.

CONTENTS

SUMMARY

This report forms part of a wider review of the contribution made by UK aerospace manufacturing industry to the UK economy in general. In contrast to the direct benefits derived from UK aerospace in terms of turnover and export performance this review considers the indirect benefits, that may have been achieved as a result of technology transfer between the aerospace manufacturing sector and the wider industries in the UK. Where appropriate, findings about reverse transfer from non-aerospace applications of technology to aerospace have been reported.

Three broad areas of manufacturing were investigated:

1. Use of materials.
2. Manufacturing processes.
3. Avionics.

In each case there was a gathering of both qualitative and quantitative information to give either support or no support for any claims of transfer taking place. An overall aim was to seek evidence for economic and/or social benefits to the wider economy of the UK.

The structure of the study consisted of exploratory interviews in Cranfield University to tap a knowledge base, in-depth interviews with senior management in industry, feedback presentation meetings, case-study development and evaluation of wider benefits.

Our interviews indicated that there has been extensive technology transfer in the main case study areas of specialised glass coatings, adhesives and finite element analysis (FEA). In the subsidiary case study examples, hot isostatic pressing and simulators, there is evidence of rapidly growing transfer and, in the first of those, this may extend into many important industrial sectors.

Technology transfer in these specified areas has contributed to benefits in the form of improved products (often in the form of better quality, reliability or longer life), reduced costs of assembly (use of adhesives decreasing assembly time, 'hipped' products needing less machining) and reduced weight (use of FEA in structural optimisation). These benefits have been transmitted to the economy through product sales of as much as a billion pounds per annum, and they apply to a wide range of industries.

In most cases, the technology transfer involved significant adaptation to modify the stringency of the aerospace standards and to reduce costs. It was frequently expressed in the interviews that the aerospace applications had considerably reduced the Research, Technology, Development (RTD) risk and the adaptation costs were unequivocally worthwhile in the areas cited.

The successful examples of identified technology transfer in the UK often involved companies recognising the importance of scanning for new ideas/technology, sometimes using an intermediary organisation, often stimulated by the need for diversification and frequently benefiting from the inward movement of people with knowledge from the aerospace industries. An impression was gained that there were also very strong network effects, with those companies tuned-into that network being exceptionally good at technology transfer. We also perceived that significant useful knowledge transfer was flowing through the networks with major, but less detectable, benefits. These knowledge and technology transfer processes appear to be cumulative, with one success leading to another whilst other less receptive industries are not locked-in to this learning process.

There is also considerable latent potential for technology transfer that is unfulfilled, particularly in the areas of composite materials bonded by synthetic adhesives, where it was said that, in the construction and transport sectors, examples in Japan and some parts of Europe outnumber those in the UK by ten to one. Opportunities appear to exist here for knowledge transfer and supply chain innovation. The case study on artificial lower limbs usefully illustrates the potential of materials technology transfer.

LIST OF TABLES

1. INTRODUCTION

This report forms part of a wider review being undertaken by the Aerospace Division of the Department of Trade and Industry of the contribution made by the UK aerospace manufacturing industry to the UK economy in general. In contrast to the direct benefits derived from UK aerospace in terms of turnover and export performance this study considers the indirect benefits, that may have been achieved as a result of technology transfer between the aerospace manufacturing sector and the wider industries in the UK. Where appropriate, findings about reverse transfer from non-aerospace applications of technology to aerospace have been reported.

Three broad areas of manufacturing were investigated:

1. Use of materials
2. Manufacturing processes
3. Avionics

In each case there was a gathering of both qualitative and quantitative information to give either support or no support for any claims of transfer taking place. An overall aim was to seek evidence for economic and/or social benefits to the wider economy of the UK.

A companion consultancy report[1] covering gas turbines, creep feed grinding, electron beam welding, touch probes and composites applied to rotors has been produced by the Ricardo Group consultants.

[1] 'Wider Economic Benefits from Technology Transfer and Skills Diffusion from UK Aerospace Industry', Ricardo Group Consultancy, report to Air Division 1, Department of Trade and Industry, 1995.

2. STRUCTURE AND COMPONENTS OF THE STUDY

The structure of the study consisted of exploratory interviews in Cranfield University to tap a knowledge base, in-depth interviews with senior management in industry, feed back presentation meetings, case-study development and evaluation of the wider benefits.

There are three stages to the study:

i) Tapping a knowledge base
ii) Tracing the transfer process
iii) Evaluating the wider benefits

Tapping a knowledge base was done by interviewing relevant personnel at Cranfield University. Although an agenda of questions was devised beforehand, the interviews were totally open in approach in order to gain spontaneous ideas and views on aerospace technology transfer. The agenda was used when the planned questions had not been adequately covered by the spontaneous responses. This was done to overcome the weakness of questioning that it covers items of more interest to the question designer than necessarily to the respondent. The members of staff were asked to concentrate upon their own discipline and to focus upon technology transfer that had happened and/or was currently in use, and not about what may be possible or even planned in the future. Finally the respondents were asked to name, if possible, suitable contacts in industry who may provide case-study material.

The aims in tracing the transfer process were:

- To identify the research origins of the technology and its funding
- To describe typical UK aerospace applications of the technology being studied
- To describe the mechanisms found in the transfer process
- To identify key individuals and their roles in the transfer process

This tracing was conducted with contacts in industry (25 individuals in 9 companies), some supplied by personnel in Cranfield and others taken from the Kompass Directory of Companies.
Stage (iii), 'Evaluating the Wider Benefits', implicitly addressed the question: 'To what extent is the Aerospace industry a cost-effective way of providing technological opportunities to other British companies?' However, what is observed in practice can only arise from a congruence of these technological opportunities with the ability, or otherwise, of companies to be receptive and to exploit these opportunities. Research has shown that such receptivity is a cumulative, learning process. The study also attempted to gauge this degree of awareness and receptivity of organisations to possible technological opportunities. The issues seen as relevant to Stage (iii), which needed to be addressed in interviews in Stage (ii) included:

- the recipient organisation perception of the source, the benefits and costs of identified transfer; what would the recipient have done, if anything, to get these benefits from other sources,
- what would be the cost of achieving the same level of technology themselves or from other sources,
- would these other routes have been more expensive or too risky to have been followed in practice?

And, slightly more generally:

- what are the recipients perception of the wider technological opportunities offered by the transfer (including potential transfer) from the aerospace industries.
- what would the cost of achieving the same level of technological opportunities from other sources (own Research, Technology, Development (RTD), or from other activities such as Research Technology Organisations (RTO's) or universities?

For the identified areas of transfer:

- What proportion of the total market for the product/process was influenced by the transfer?
- What proportion of the company turnover is accounted for by the identified product/process?

3. SELECTION OF CASE STUDIES

The purpose of the interviews with appropriate specialists from the Cranfield University and elsewhere was to identify areas where, according to their experience, technology transfer from the aerospace industry to wider industrial use has occurred recently, and then to select possible cases for detailed study. Criteria used in selecting the case studies from the broader list of possibilities were:

- there should be multiple applications
- the transfer effects should be of sufficient magnitude to be important to the receiving organisation
- the possible different channels, or mechanisms, of transfer should be seen in the range of case studies
- the transfer should be reasonably 'direct' and occurring in a timescale of a few years.
- they should be amenable to policy influence

Initial suggestions for the case studies were listed under the broad headings Materials, Process Technologies/Production Line Techniques, and Avionics. The classification of possible case studies between these headings was somewhat discretionary because certain subjects fitted under more than one heading.

From interviews with Cranfield University staff and individuals suggested by them, the following cases were put forward under each heading:-

MATERIALS

Powder Processing
Carbon Composites
Coatings
Ceramics

PROCESS TECHNOLOGIES

Precision Machining
Honeycomb Panel Design
Adhesives
Castings
CAD/CAM
Production Control
Non-Destructive Testing (NDT)

AVIONICS

Simulation/Software Development
Advanced Braking Systems (ABS)
Portable Telephones
Navigation

Under the MATERIALS heading, the cases chosen were:

Powder Processing and Coatings Technology
- These areas are related and gave the possibility of following process development as well as material development. Two were taken because both had strong industrial leads. One was partly dropped at the next stage of the work once the industrial leads had been followed up. The other ideas were not used as the central case study for the following reasons:-

Carbon Composites
- Although clearly originated by aerospace the application so far appeared to be limited to sports goods and racing cars. Two major manufacturers have recently abandoned work in this area because the cost of the material is severely limiting its use. Carbon composites were not felt therefore to be a strong case to follow, except that in the study an important transfer to the manufacturing of artificial lower limbs was identified and followed through.

Aluminium
- The use of aluminium in rail vehicles etc. may be a source of technology transfer. However, many applications use different aluminium alloys suggesting parallel development rather than transfer. Also their full use in rail transport has yet to be developed.

Ceramics
- Another strong case although like carbon composites, cost is a problem in the wider use of ceramics. It was felt much of the use of ceramics would be as coatings rather than bulk material and so this area would be covered partially in the cases chosen.

The cases suggested under PROCESS TECHNIQUES were considered and Adhesives chosen as the most appropriate one to follow up.

Adhesives
- appeared to give a good example of transfer from aerospace into a wider range of industries and allowed for the actual adhesive development to be investigated in addition to joint design. The others were not selected for the following reasons:-

Precision Machining
- The suggestion focused on a trigger probe and it was felt that this may be too narrow to fulfil the criteria listed above.

Honeycomb Panel

- The lead for this was Ciba Geigy, and it was decided to follow this up at the same time as Adhesives to determine if it was useful.

Castings

- In the traditional sense of molten metal most of the technology was developed outside aerospace. In the wider context of near net shape processing it is dealt with under Materials, and as Hot Isostatic Pressing.

CAD/CAM

- Felt to be a specific part of Simulation/Software development, hence will be considered in Avionics, and it was also understood that this broad area was investigated by the Ricardo Group.

Production Control

- Technology developed outside aerospace where cost has been the main driver. Aerospace are now using techniques developed elsewhere to reduce cost.

Non-Destructive Testing (NDT)

- Some leads particularly pointed to the inspection of non-metallic joints and the philosophy of inspection. Adhesives felt to fit the criteria better than the former while the latter may be very difficult to prove or quantify.

The case chosen under AVIONICS was

Simulation/Software Development

- which is essentially the use of computational modelling techniques and includes finite element analysis and computational fluid dynamics. This should allow transfer of ideas and approach through the supplier chain to be investigated. The reasons for the rejection of the remainder were:-

Advanced Braking Systems

- Very specific example, software felt to fulfil criteria better.

Portable Telephones

- No real link found with technologies initiated by Aerospace.

Navigation

- Aerospace systems and the rest, particularly Marine, have developed in parallel with little or no consultation. Hence no significant transfer has taken place.

It was felt that these broad case areas chosen for fuller investigation **Adhesives, Software Development, Coatings and Powder Processing** covered the criteria required in addition to giving a range of technologies and transfer mechanisms.

To bring these broad case study areas down to a more specific product and process focus, further interviews were held with a number of industrial organisations. When tapping the knowledge base at Cranfield, one company more than any other was given as an example of linking aerospace technology to wider industry and this was Ciba Geigy plc. Professor Bucknall at Cranfield pointed out that the company was very adept at buying R&D, and aerospace was the major source. The company was in fact developed out of the aircraft industry in the early 1930s and has gone on to become a multi-national organisation that has expanded its range of specialised chemical products. It was for this reason that the first field-work contact was made with a Director in the composites division of the company who is responsible for technology transfer, the development of new markets and closer liaison with customers. From information gathered at this interview it was possible to begin the mapping of transfer linkages, see Figure 3.1. Apart from the close link with the adhesives (polymers) part of the company (composites cannot be used without adhesives) there were strong transfer channels to other organisations that could be a source of case-study material. To help develop the network further, a second contact was made with TWI, formerly the Welding Institute, because they provide a wide range of companies with an R&D and consultancy service in the areas of materials technology and materials joining processes. Three senior personnel at TWI helped extend the possible linkages from UK aerospace to other uses.

Both Ciba Geigy and TWI personnel agreed that in the use of composite materials there was a direct transfer of technology from UK aerospace to other applications. However the examples of such transfer were quite difficult to identify in the wider UK industry; the Director of Ciba Geigy referred to industry in Japan as having ten uses for composites for every one in the UK. Examining possible reasons for this situation was outside the brief of this study, but it is relevant to the eventual choice of case study in the area of the materials use. A clear example was given of technology transfer from UK aerospace to artificial limb manufacture, and this was chosen as suitable for fieldwork because it involved the use of materials, joining of materials and joint design, all with stated links to UK aerospace.

The area of coatings and in particular powder coatings became problematic in the search for suitable case study material. A contact at Union Carbide pointed out that coating technology in manufacturing tends to be used most in solving problems. In many cases companies are reluctant to discuss such problems openly and when the coating solution has been found are still reluctant to discuss the application. A further complication is that coating technology is difficult to assign directly to aerospace; the source has come most frequently from research in the oil industry at Shell Chemicals and in Germany with Bayer AG and BASF AG. During the interviews at Cranfield, it was pointed out by Dr Stephenson that in the area of wear resistant coating, in particular ceramic coating, the main applications are to be found outside the UK, 'if we were sitting in Japan now I could go into more detail'. Three respondents at Cranfield gave glass coatings as one possible example that could be said to have its source in UK aerospace, and the name of Pilkington was given each time. The first contact was with the Director of R&D at Pilkington Aerospace, and at this meeting it was established that coatings to provide low emissivity (low E) flat glass, for heat conservation for domestic and industrial applications, came from UK aerospace. For this reason the development of flat glass known as Pilkington K was followed up. There is too the use of security glass that falls into the same transfer category, but this product has more specialised markets, such as VIP transport and screens for bank security, therefore K glass, with wider domestic and industrial markets, was chosen. The Director at Pilkington Aerospace also described the development of so called 'intelligent glass' for the automotive industry where a number of applications can be built into the product, and which had sources in aerospace, this transfer was recorded but was outside the brief for further study.

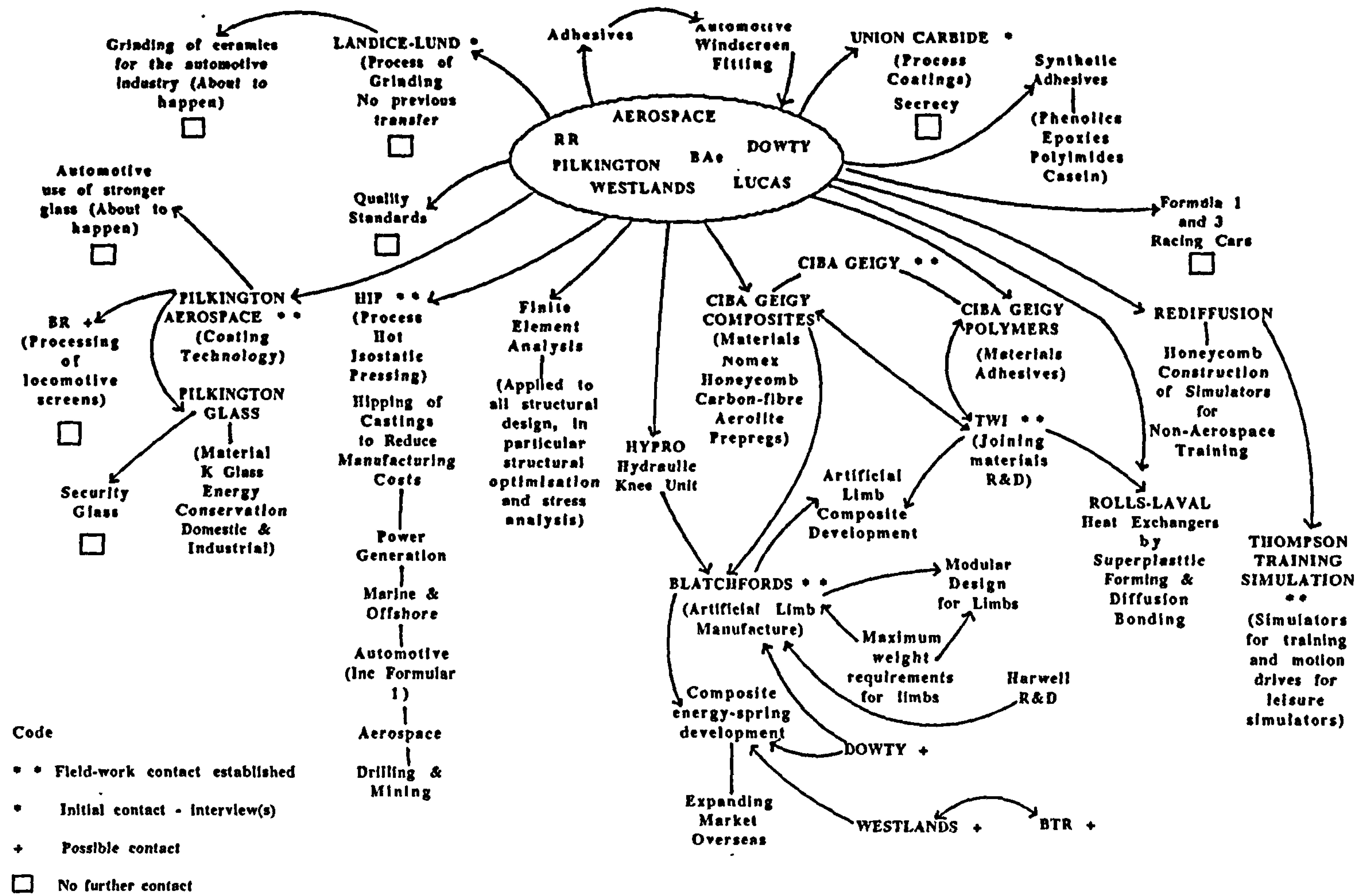
A pure manufacturing process that was felt to have close links with UK aerospace, supplied by contacts at Cranfield and TWI, was Hot Isostatic Pressing (Hipping). This is a relatively straight forward process where metal castings or composite parts can be heated to around 900 degrees centigrade and pressed at 15000 psi to remove porosity which gives to castings the reliability of forged components. The advantage is that the process can improve the performance of near-net-shape parts and thereby reduce or remove the need for machining. This process provided an example of a technology that had its source in the high speed steel/machine tool industry (Sweden) in the 1950s but owes all current and future applications to the development work done in UK aerospace during the 1970s and 80s. It was essentially the demanding specifications of aerospace that made the exploitation of the relatively expensive hipping process worthwhile, and which would have been almost impossible for other industries to develop further. It was for this reason that contact was made with the Director of a major hipping company (HIP) and the process adopted as a case example.

A case example, in the area of avionics, proved difficult to establish; there were no ready examples of technology transfer, although the general feeling was that there ought to be. The field of telecommunications, it was felt, should benefit from research in avionics, but a Professor in the avionics department at Cranfield said that development of this technology in private, public and aerospace sectors had been done in parallel, he said that 'researchers would occasionally look across at what was being done elsewhere, but the contact was little more than this'. It appears that duplication of effort may have been made here but this could not be pursued further in this study.

The development of simulation techniques and the building of simulators is another branch of aeronautics work that has been followed up. Hughes Rediffusion, now Thompson Training Simulation, have been active in the development of flight simulators, and it is this technology that is being transferred to other applications. A contact at the Lancing site of the company made the point that it was an idea of Barnes Wallis, after the war when working as a consultant, that has enabled the company to offer simulation at a competitive rate. Both industrial and leisure applications of simulation use have been reported.

Figure 3.1 maps the linkages that were described during the interviews.

Figure 3.1



Influence Diagram: Examples of Technology Transfer from UK Aerospace

November 1994

4. CASE STUDY FINDINGS

4.1 INTRODUCTION

There were nine organisations involved in providing detailed case study material:-

Ciba Geigy
HIP Ltd
Pilkington Aerospace
Pilkington Plc
TWI
Blatchford & Sons
Thompson Training Simulation
Rolls-Laval
Cape Environmental Engineering Ltd

Possibly the most significant outcome was that all transfers of technology from aerospace to other uses had gone through processes of adaptation; there were no examples of direct application of a product, a material or a process. Also one of the most critical adaptations was in cost reduction. On the evidence gathered here, there is a common belief in industry that aerospace technology does not transfer well due to the high cost of materials and of the processes in use. The organisations featured in these case studies have demonstrated that benefits can be achieved that outweigh the initial cost of adapting technology from aerospace. A significant comment that was made often was that aerospace have taken away a substantial part of the risk inherent in the development of any new technology, and all that remained was for them to make the necessary adaptations. The risk avoidance is for them a qualitative statement, and something that is simply felt generally.

All participants were most helpful in giving their time and showed a good deal of interest in the subject. There was an overall feeling that technology transfer tended to be a hit and miss business and much was left to chance. However two large organisations and one small had taken positive steps to formalise the transfer process by putting transfer channels in place. A critical part of such initiatives is for organisations to have one, two or three people who keep their ear to the ground, read technical journals, visit trade shows and generally know as much as possible about developments in the world outside, but again organisations seem to find themselves with such people by chance, and those that do are able to develop transfer channels quite effectively.

The information contained in this section is qualitative, there is not attempt to provide quantitative measures of any benefits that have been gained; this is the subject of the next section.

4.2 MATERIALS TECHNOLOGY

4.2.1 Glass Coating

Pilkington Aerospace has a turnover of £13 million and employs 230 people on the Kings Norton site. There are three major markets: aerospace, rail and security vehicles. Aerospace accounts for 60% of business. The production of windows for aerospace is a highly demanding process, each window is a multi-layered assembly, electrically heated and is part of the primary structure. For example, each front window for a Boeing 747 costs $20,000.

The development of flat glass that can reduce the flow of heat from buildings, known as low emissivity or Low E glass, is of enormous importance to the UK economy in terms of energy conservation and cost reduction. The coating of glass to achieve this property has its source in aerospace.

There are two perspectives on the transfer mechanism at work here, depending upon whether viewed from that of the technology provider or technology receptor. The view from Pilkington Aerospace is that a direct transfer could be observed from aerospace coating technology to domestic and industrial applications. The view from the manufacturers of flat glass at Pilkington is that the transfer was indirect. When these perspectives were put to Sir Robin Nicholson, he said that both are correct. 'The aerospace process, that came first, was done off-line by a sputtering process, and when transferred to high volume flat glass production had to be adapted to be done on-line'. To Sir Robin Nicholson the idea of transferring a technology as a package is a misleading one, the process, in his view, is more complex and dynamic in which people contribute and take out, as in a bank. This view corresponds with the approach of Pilkington to the transfer of technology. The transfer channel consists of a cross-company Technology Management System, where members of staff come together to develop and share ideas. It was through such a channel that coating applications have been transferred from aerospace. In some respects it is a concept transfer at this stage, and it is not until the concept has been converted into an alternative use that the technology can be said to have been transferred. In this case the conversion was from off-line to on-line and this was done within Pilkington Glass with no aerospace source, hence the view of an indirect transfer.

The view from aerospace is that direct transfer took place, and only some adaptation was necessary.

Another example of idea sharing, given by Sir Robin Nicholson, was in dealing with a problem recently in the mechanical failure of a coating. The problem was solved partly within flat glass manufacture and partly from technology transferred from aerospace.

The product that resulted from this transfer is, in terms of growing sales worldwide, of vital importance to the Pilkington business. In addition to the coating of large sections for architectural purposes in commercial buildings, a whole new industry has developed to manufacture double-glazed units using only Pilkington K.

The business of toughened and security glass has a more specialized market, but nevertheless certain requirements have been met in the non-aerospace sectors that would have been difficult if not impossible to achieve without the initial funding of R&D in aerospace. For Pilkington Aerospace 40% of business is split between rail applications (driver's windows world-wide, rather than side windows) and security glass for VIP use again world-wide; both applications are the result of spin-off from aerospace technology. BR have the standard requirement that for driver's windows on high speed trains the glass must withstand a 2lb steel cube at 225mph impact. This requirement could not be met without the technology that has come from UK aerospace; BR could not afford the development costs of such material. The Technical Director, Bob Bruce, claims that trains would be much less safe without the spin-off from aerospace technology.

The security glass, used in VIP transport and screens found typically in banks, is formed with polyurethane and polycarbonate coatings with a process that has been spun-off from aerospace.

There has been a reverse technology transfer recently from the automotive industry to aerospace. Urethane bonding of windscreens on road vehicles contributes to shell stiffness and improves performance aerodynamically, and is simpler and quicker to use than the rubber fittings. This type of bonding has recently been applied to the fitting of helicopter windows, and is expected to have wider applications in aerospace.

4.2.2 Lower Limb Prosthesis

Blatchford Ltd is 104 years old, Stephen Blatchford is the fourth generation Managing Director. To meet increasing national and international competition, the company had to innovate and introduce new technology into the product design and into the process of manufacturing.
The origins of the technology transferred from UK aerospace began with the search for the means to develop a modular construction of the artificial lower leg. This initiative began in 1980 with a project done with Harwell R&D, and subsequently developed further with the help of Dowty Aerospace. When the innovation was being planned, applications were made to Health Departments for funding, but none was forthcoming so the investment was made by Brian Blatchford, the then owner of the company. The modular design now enables hospital on-site construction of each limb in a purpose-built flexible way. Soon afterwards it was realised that composite materials, developed in aerospace, offered the best possible means of achieving this full modular construction. Samples of this material were bought in and experimentation began, it was at this point that engineers from Dowty became involved.

The initial transfer process was helped by Dowty giving free consultancy days in return for being allowed to use the project information in their advertising. John Shorter said that the days of consultancy input by an aerospace engineer from Dowty were worth many months of development time. The initial Dowty contact was by chance at a DTI sponsored investment/innovation event. It was then that the initial idea of using composites was explored. Costs of the new material had to be negotiated with Ciba Geigy; Blatchford had to point out that not many of their customers go through the sound barrier, so standards could be relaxed. Having said this, Blatchford continue to buy materials from Ciba Geigy when it is possible to get them cheaper elsewhere because the strong link that Ciba Geigy have with aerospace ensures the highest standards of production. The company is now considered to be a world leader in the design and manufacture of lower limbs, and to put this in perspective has, over the past twenty years, been near to going out of business. Two reasons were given for the recovery, one was the vision of Brian Blatchford, and the other was the input of consultancy, and materials technology from aerospace. Others in the company also gave the work of John Shorter as another reason, but at the interview he was too modest to admit to this.

John Shorter came to the company from aerospace, and this provides an example of a transfer mechanism at work through the migration of skills and knowledge out of aerospace to other areas. The main and best source of materials technology relevant to the company needs is to be found at the Farnborough Air Show.

John Shorter had not heard of the Materials Matter initiative by DTI that had been spoken so well of by Dr Rickinson at HIP, (which now seems to have faded), but did point to the need for more formal methods of technology transfer for the smaller firms such as their own.

The adoption of the new technology led to the loss of nearly 300 skilled jobs of people who used the traditional skills associated with wood and leather working, but this John Shorter saw as inevitable, and cost containment is now one of their main concerns of which labour costs provide a high proportion.

The major benefit to be derived from this transfer process has been to the customer, who now has a limb that weighs around two to three kg instead of the original design of around twenty kg. This allows for far more involvement in the labour market, and in sporting activities that were previously difficult or impossible to follow. A further benefit is to the company that now has a world lead and market advantage in the manufacture of lower limbs. This has been achieved through the modular innovation which in turn prompted the adoption of alternative materials.

To quote John Shorter "The lead in the world market suddenly seemed to come from nowhere or like outer-space, in fact it came from aerospace, we now export to 28 different countries". The USA provides a huge potential market for Blatchford but the distribution add-on costs are too high at present. The company has recently set up their own distribution system in an attempt to penetrate the USA market. In the UK, where Blatchford supply 70% of all lower limb hardware used, the sole customer is the NHS. In the USA the nearest to this outlet is Medicare, but there are still serious distribution problems caused by not having a national health system. Germany is the largest overseas market, despite there being a lower limb manufacturer in that country. The German company has gone along the alloy construction route, as Blatchford started to do before contact with Dowty, and this is not competitive with the composite models. Blatchford is the largest 'prepreg' user outside the UK aeropace industry.

The advanced design of the lower limb, that contains a microprocessor, is not viable for the Third-World markets, but the company is looking at the development of a mixed thermoplastic/carbon design as part of a DTI supported project to provide an alternative technology in this area.

The microprocessor has been supplied by Kobe Steel in Japan, but the processor and associated fittings are being developed in the UK at the initiative of Blatchford and a prototype will be available in April 95.

In the past, the company has made use of aerospace for fatigue and vibration testing, this is often done out of curiosity on the part of engineers in aerospace to see how far they can extend their expertise.

There has been use of aerospace technology in the design of a hydraulic knee unit. The initial idea came to John Shorter when looking at a hydraulic auto-pilot on a racing yacht. It is an ex Rolls-Royce fuel system designer who has now developed the idea for Blatchford in a company he has set up called Hypro.

The company also makes use of services from aerospace for stress and impact analysis in their R&D work. A finite element analysis package is also used in the design of lower limbs which provides another example of spin-off from UK aerospace technology.

The joining of composite to composite and to alloys requires the use of synthetic adhesives. Here the company is using an epoxy-based product that had its source in UK aerospace through the development by Ciba Geigy who supply Blatchford with this product The use of adhesives is under constant review in the company, and in proportion to its size, of 300 employees, Blatchford have one of the largest R&D departments in the business.

The UK market for new limbs fell 18% last year (1993), this is due to a policy of NHS to spend more on repairs and maintenance of existing limbs. Given these changes in the home market it has become vital for the company to expand the overseas market, and John Shorter spends many weeks abroad each year on marketing activities.

4.2.3 Heat Exchangers
TWI have recently been involved with Rolls-Royce in the development of a lighter and more reliable heat exchanger using the technology of superplastic forming and diffusion bonding of titanium alloy. The exchanger is based upon the plate fin design which has many advantages over the shell and tube exchangers. Although this is about to happen in terms of reaching the market place, the transfer of this bonding technology from aerospace to the building of heat exchangers has been developed over the past four years.

Rolls Royce had the necessary bonding technology from aerospace but not the heat exchange building technology; for this they went to Alfa-Laval in Sweden, and now a new company has been formed called Rolls-Laval with a new site opening in Wolverhampton creating jobs for technologists, technicians and craftspeople.

This is an example of transfer through diversification, where an aerospace company uses existing technology within aerospace to develop a new version of a product that has changed little for many years. Dr John Fowler of Rolls-Laval made the point that Alfa-Laval could not have developed this alternative heat exchanger by themselves.

There are wide applications for heat exchangers, and extensive benefits to be derived from any innovation that results in them becoming lighter and more efficient. There are many process industries, chemical works and marine requirements for heat exchangers, and for offshore applications in particular the saving in space and weight from the new design can save millions of pounds. Conventional offshore compact heat exchanger has a dry weight of 6500 kg the Rolls-Laval SPF/DB design is 600kg.

This new venture on a greenfield site in Wolverhampton is only possible as a result of spin-off from the aerospace industry. Rolls Royce had the process technology for building lighter and more effective heat exchangers, while Alfa Laval had the heat exchange technology and building capability.

The aim of superplastic forming and diffusion bonding (SPF/DB) is to give all joints 100% parent material properties. The reliability of the joints means that in marine work the sections containing sea water can now be contained within the hull because there is very little danger of leakage.

John Fowler finds manufacturing technology the hardest to transfer, materials technology he finds comparatively easy. He makes the point that if this had been a mature technology he would have gone to somewhere like Taiwan to have the heat exchangers manufactured, due to the UK and Swedish costs. In his view it is only new technologies that are worth adopting and manufacturing in the UK, mainly because there is a strong technology resource on hand of which aerospace is the strongest. Hence he sees innovation as essential and is annoyed at the lack of Government support for this type of activity.

4.3 PROCESS TECHNOLOGIES

4.3.1 Adhesives Technology
The development of adhesives technology has been largely driven by the need to find alternative methods of joining metals in the aircraft industry, although the first serious use of adhesive-bonded structures were in wood in the building of the Mosquito aeroplane. The main advantage in using adhesives in this type of construction is to avoid the drilling of holes for riveted joints, which then cause areas of weakness. The first major advance was made in bonding aircraft metal parts with the introduction of edux 775 by Ciba Geigy in the 1940s, and which is still a key product in the company's business.

Currently, structural bonding adhesives and two part curing sealants are identified as being derived from aerospace applications. One aerospace-based adhesive technology to be transferred extensively is the use of anaerobic adhesives, developed primarily for helicopter manufacture. This adhesive is used to provide thread locking, and saves considerable manufacturing costs by avoiding the need for push or shrink fits for jointing.

ICI have developed an acrylic resin that cures under UV light, and this has been taken from aerospace applications.

The development of cyanocrylates or superglue tend to be limited to the bonding of small areas due to the relatively high cost of this product, but does have very wide applications. For example, apart from sticking fingers together effectively, it is now possible to make modern high performance loudspeakers without this adhesive, and a large range of diverse materials can be bonded using this adhesive.

The urethane bonding of windscreens in the automotive industry has already been referred to, but there are other uses for adhesives in the manufacture of cars. The anaerobic adhesives are used for thread locking, some manufacturers bond composite drive shafts to metal fittings using adhesives, and internal trims make extensive use of adhesive bonding. The early application of adhesive bonding to the shell construction of cars has been replaced with the introduction of the monocoque body design.

At Ciba Geigy, the comment was made that the construction industry in the UK is slow to respond to composite and adhesive use (the two do go together because composites cannot be used without adhesives).

This comment about reluctance to use these technologies in the building industry was repeated independently at TWI. The example given at TWI was of the extensive use made of adhesive bonded composite patches for weakened structures, particularly road bridges. In the UK, metal patching is used which is cheaper but involves lengthy road delays. In Switzerland they take all factors into account in costing the repair and can fully justify the use of composite use.At TWI they can demonstrate how composite patches can bond to both concrete and metal structures, giving greater strength and longer life.

The view of Tony Bonnington is that the company find great difficulty in developing the composite market in the UK. Railways, as in the rest of Europe, ought to provide a significant market, because the new high speed trains can be a commercial threat to regional aircraft. In France there is now extensive use of composites and honeycomb for rail vehicles, particularly with the introduction of double-decker designs and weight on weight savings. With respect to road vehicles, the lack of a significant truck industry also restricts outlets for future composite use.

The light, strong composite structure, known as honeycomb, is bonded using adhesives. There are many potential uses for honeycomb, in this industrial sector, for example an impressive office block has been constructed on the Ciba Geigy site in which the main construction is honeycomb. The Docklands development is a good example of where honeycomb could have made significant improvements to costs and to maintenance over time, but the UK construction industry appear to be largely unaware of this technology. Ciba Geigy's largest market for adhesive bonded honeycomb is now in Russia (CIS).

Ciba Geigy have supplied £2 million worth of honeycomb panelling for Heathrow Terminal 4 but this was only a one-off project, and the adhesive bonded product has been used recently to replace doors in London Underground to help reduce fire hazard.

At TWI, Gareth McGrath has had contact with British Architect Ray Ogden who would like to see developed the idea of bonding sheet marble to honeycomb for building in Italy; this is to overcome the problems for marble in that climate. Gareth McGrath ponders over the reasons why such ideas are so difficult to get adopted. TWI could, with support, develop bonding of this kind, and in doing so would draw heavily upon aerospace technology.

Also at TWI, a visit has been made to boat builders FBM on the Isle of Wight where five high speed craft are being built for a Hong Kong company. The TWI staff were amazed to see miles of aluminium MIG welding on the superstructure and on planks of extruded aluminium for the decks. Why not honeycomb and adhesives ? This repeats the comments made by Tony Bonnington at Ciba Geigy. The answer given by Gareth Mcgrath is that people in industry do not know that this technology exists, or if they do they consider it will be too expensive coming as it does from aerospace. TWI can demonstrate that this perception is not correct, but of most concern is the fact that so much available technology is not known to many parts of industry.

Aerospace was the earliest user of synthetic adhesives, and according to Gareth McGrath the technology of all adhesive manufacturers has been driven by aerospace: Bostick, Evode, Loctite, Colas, Ciba Geigy, Unilever, British Vita all based in the UK serving a market worth around £850 million. The estimate of UK end users of adhesives is 38.5 million.

There is still expansion in this market, and a new epoxy resin plant has been established at Ciba Geigy Duxford. The plant can also produce matrix resins for adhesives used in joining composite material.

Tony Bonnington of Ciba Geigy said that there are numerous applications for aerospace technology in the field of composites and adhesive bonding, but unfortunately nearly all have been taken up in Japan, and others in the rest of Europe, with little in the UK.

4.3.2 Hot Isostatic Pressing (HIP)
John Thompson at HIP started the company in 1976 with £100. After working almost entirely for the aerospace industry, the business now has 80% non aerospace work and the market for their process is expanding each year. A clear measure of expansion at Hip is that over 15000 hipping cycles have been completed since 1976 and a third of those have been done over the past four years.

HIP and Infutec were purchased in 1991 by Bodycote International plc, within this group there are also three companies in the USA for hipping ATS, IMT Inc and IPS Inc.
The source of Hipping processes is found in two areas of application: machine tooling in Sweden and the nuclear industry in the USA.

During the 1950s there was a drive for improvements to the casting of metals, but it was not until 1970 and through to 1990 that the process became fully developed by aerospace, and at this time became dominated by aerospace. The drivers of this technology all concern the removal of porosity from manufactured materials, to overcome problems, improve properties of the material and improve consistency. A typical application was in overcoming fan blade failings in Rolls Royce.

One of the major blocks to further development for HIP is the perception that Hipping is a relatively expensive process and only suitable for aerospace applications. Dr Rickinson the Managing Director makes the point that this perception is some years out of date.

Hipping for aerospace application led to high and limited specifications and low yield. Now the yield is higher and the manufacturing costs have come down. There was a review of specification requirements and costing methods that resulted in a process given the title of DENSAL in which the new charge is by £ per kilo instead of by volume cycle price. A target figure in the industry was given as $1 per lb to be fully competitive, this still seems unrealistic, at present it is $2.25 per lb from 5 times this amount originally; and at that business is going well. There has been, and continues to be, expansion in UK hipping facilities, (a new HIP site is being developed in Hereford). Between 1991 and 1994 HIP have become the biggest hipping sub-contractors outside the USA. At the Chesterfield site the output is 150 tons of hipped aluminium parts per year to a wide range of customers. The customers are served on a confidential, sub-contract basis. The areas served are in aerospace, power generation, automotive, telecommunications, drilling/mining, defence, marine and offshore.

While the market for the hipping process cannot be described as wide in terms of manufactured components in the engineering industry, the process does now provide a cost effective solution to the supply of specialized components that are critical to areas such as power generation, offshore operations and the automotive industry; in this sense there is an indirect, but significant influence upon the wider economy.

When it was realised that specifications and costing methods of aerospace could be adapted to increase size of the process and increase yield, so making the process competitive for non-aerospace applications, a major decision was taken to commit £4 million in capital to increasing the size of production units. This decision was based partly on a market study, which although, in hindsight, was largely incorrect in its findings, did not lead to a failure of the enterprise. This was in 1985, and the DTI contributed 8% towards the investment in new plant. The largest hipping press from ASEA in Sweden cost £2.5 million and has 80 times the working volume of the first press that John Thompson installed.

The hipping process is used for densifying castings, diffusion bonding, improving coatings performance, applying cladding, consolidating encapsulated powders, densifying sintered powders and uprating magnetic properties

There is wide application in the manufacture of valves, not the total valve but critical parts such as the valve seat and valve lid where most damage and failures take place.

One application developed from a chance event. Dr Rickinson was giving a presentation on the process, and in the audience was a Rover manager who followed up with the idea of using the process to provide a tough capping on press tools. HIP is now the prime supplier to Rover of this application. Infutec (part of the Bodycote group including HIP) bond a layer of cobalt alloy onto the working surface of the tool then hipping is done at HIP.

In the medical field a major use of hipping is in the manufacture of hip joints.

HIP has developed a valve body using diffusion bonding of bar material - ex stock, the assembled bar sections are hipped at 920^{0} C for three hours at 15000 psi to develop a high integrity monolithic structure. The company is having difficulty in gaining acceptance of this method. Again there is a need to transfer the technology of bonding used in aerospace to non-aerospace use. The main block to progress appears to be the setting of new standards for manufactured components in line with developing technologies. Dr Rickinson feels that the DTI have a role to play in this respect. The technology in question here is assembly using IP diffusion bonding. The process has been known for 25 years but over the past seven years as a direct consequence of aerospace industry requirements many resources have been diverted to developing the process.

The business of HIP was 80% to aerospace in 1984, before the major investment described earlier, now in 1994 aerospace work accounts for only 20% of business, there has been a significant widening of aerospace-based technology to other applications.

The initiative of the DTI on Materials Matter Programme was described by Dr Rickinson as superb and excellent, however it has 'run off the rails' and HIP have eventually pulled out of the programme. Dr Rickinson said that a means of transferring technology, such as this programme, is sadly lacking in the UK.

4.4 AVIONICS/SOFTWARE

4.4.1 Finite Element Analysis (FEA)

Professor Morris at Cranfield College of Aeronautics, Cranfield University, made the point that virtually all structures built at the present time use FEA, and that there is an extensive market for software that can satisfy the many applications of FEA. Most of the key development work that has led to this situation was done in the 1960s. Professor Morris said that all pioneers in this field either worked in aerospace, including UK aerospace, or worked in Universities where aerospace work was being done; the market for FEA that now exists has been totally driven by aerospace technology.

The first company to actively transfer FEA from aerospace to other uses was SDRC who began by developing programmes for vibration analysis, and applied these to non-aerospace applications. Another significant transfer channel occurred when there was a migration of technologists from the aerospace industry in the mid-1970s and many small companies were set up to develop programmes in this area of analysis.

Professor Morris said that without the funding and early development of FEA in aerospace the method, as we know it now, would have died, and a number of advances in manufacturing and construction would not have been possible.

One of the most important current FEA programme applications, according to Professor Morris, is in the field of structural optimisation. The weight reduction programmes in the automotive industry have been achieved directly as a result of these programmes, and they are being applied to numerous structures at the present time.

Contact was made with an end-user of finite element analysis programmes, this was Steven Meredith, Managing Director of Cape Environmental Engineering Ltd, a large engineering consultancy. He said they do work for both aerospace and non aerospace; they us FEA programmes extensively, and he is fully aware of their aerospace-based source in terms of early development. Typical recent applications are:

- Auto clutch system and the stress analysis of mountings for a new system.
- Automotive oil filters, stress analysis of paper filters.
- Thermal and structural analysis of large rack systems for electronic use including telecommunication systems.
- Fork truck crane system, structural analysis.
- Signalling control equipment for rail systems, stress analysis.
- Doing increasing work for road transport vehicles using FEA programmes.
- Stress analysis of large motorway signs.

Although FEA can be seen as basically a mathematical technique, it was not until the wider use of high speed electronic computing became available in the 1960s that the full potential of the method was realised. It was at this time that a large aerospace investment was made in software development, particularly in terms of man-hours in the thousands.

In the 1970s, the spin-off to other uses and to other markets began and UK aerospace played a major part in this transfer through the involvement of people who had worked through the earlier development. The UK is now second only to the USA in this software field.

4.4.2 Simulation

The company Thompson Training Simulation has two main markets, one is in the defence industry and the other is in leisure.

The leisure application of simulators makes use of only the motion technology from aerospace, that is the hydraulic platform that provides movement to the simulator body. Initially, some of the software that was used in controlling the movement was taken from UK aerospace but now the company develops its own software. The visual technology use in flight simulators has not been adopted here; conventional filming techniques are used. Paul Spence at Thompson Training Simulation said that the contribution of motion technology from UK aerospace was vital to the development of simulators in this new market. The leisure market for this product is estimated to be worth a total of £100 million world-wide, and Thompson Training have a 10% market share.

The training use of simulators makes more use of aerospace-based technology because much of the visual imagery reproduction has been transferred.

A major cost-saving innovation has been the application of thin-film mirrors. The ground-glass equivalents cost £500,000 to produce for each simulator, the thin-film alternative, using a plastic membrane costs £7000 to produce. This saving helps to bring the use of simulators into the general training market. The potential use for this type of construction has been latent for a number of years since Barnes Wallis first came up with the idea when working as a consultant after the second world war.

The technology has been pioneered by Rediffusion Ltd in the UK and used for civil airline simulators since 1979, and adopted for general non-aerospace training application since 1992.

Tony Nordberg at Thompson Training, who was responsible for bringing the technology into the company, pointed out that, in transferring the technology, adaptation had to take place. A different geometry was needed and therefore changes had to be made to basic operating/design theory to a point where the specific application had been patented. The fact that it had been achieved at all, in UK aerospace, was the spur to our adoption of the technology for general training use.

The benefit derived from this technology is that the company is now in a market sector in which they were not involved previously. The forecast for the new business centre is to generate £4 to £5 million per annum. The development cost to the company of this technology is estimated at between £70 and £100 K. Without the R&D from aerospace it is estimated that this cost would have doubled.

The company has 50% of its business in aerospace, and Tony Nordberg said, 'you could argue that the other 50% of business would not be there without aerospace business'.

A significant part of training simulation, transferred from UK aerospace, is being done for the Army, particularly the simulation of gunnery training that allows for both day and night simulated training in a wide range of conflict situations. A major benefit here is to reduce the need for outside gunnery training work.

5. EVALUATING THE BENEFITS FROM AEROSPACE INNOVATION

5.1 METHOD

The ultimate measure of benefits from innovation is the improvement in economic and/or social welfare. Such benefits may be in the form of reduced costs or improved products. Determination of these changes in cost and benefits poses formidable though not insuperable difficulties in practice. Alternative and more easily estimated measures of benefit are changes to profits, sales, employment, trade balance, or market share.

All of these measures raise problems about who gains from the innovation. Entrepreneurs or the nation might gain in terms of profits, sales or exports but this gain may be dissipated quickly by competition and transfer of know-how. One clear relationship is that the benefits of an innovation will be related to the sales of that product. Benefits will not arise without sales. Under some circumstances the reduction in cost may be modest and the product does not change form. In other cases the product is new and its sales have an important impact on downstream industry and the eventual benefits to the consumer.

Figure 5.1 addresses the issue of evaluation in the transfer process and shows examples of the various ways in which a product, product group or service may reach final consumption eg.

- directly to the final consumer
- directly to another industrial product/process and thence to final consumer
- via an initial industrial consumer to yet another industrial consumer and thence to the final consumer

Clearly chains could be much more complex. The shaded area in the figure identifies the focus of the evaluation in this project.

In the approach followed, sales of products influenced by aerospace derived technology are used as an indication of the relative importance of the innovation in the market place. The benefits from an innovation occur over a number of years following its initial adoption. Later adaptation of the product or process mean that the original contribution is submerged in the benefits of derived products. Strictly speaking the benefits from the original R&D would have been gained by later R&D in non-aerospace industry, and therefore the benefits only last for a period of years. Rather than attempt to consider the lifetime sales that are related to the original innovation sales per year are used as the relevant measure.

Whilst sales of the product related to the innovation generate the benefits, it is also worth considering the size of the user industries/sectors (in terms of its sales). This gives some idea of the proportion of industry that is affected in some way by the aerospace innovations examined below. The sales figure in this case refers to all sales to industry or final consumers on an annual basis.

Sections 5.3 through to 5.8 detail the implementation of the procedure described below for each of the case studies: specialised glass (the materials technology example) adhesives (the process technology example), and finite element analysis (the software example). Data limitations restrict the level of resolution that can be provided on the finite element analysis example. Also included are appraisals of the wider economic benefits for Hot Isostatic Pressing (which because of its potential importance is given in reasonable detail), and then briefly, for completeness, the artificial lower limb and heat exchanger examples are included.

Figure 5.1

EVALUATION: METHOD

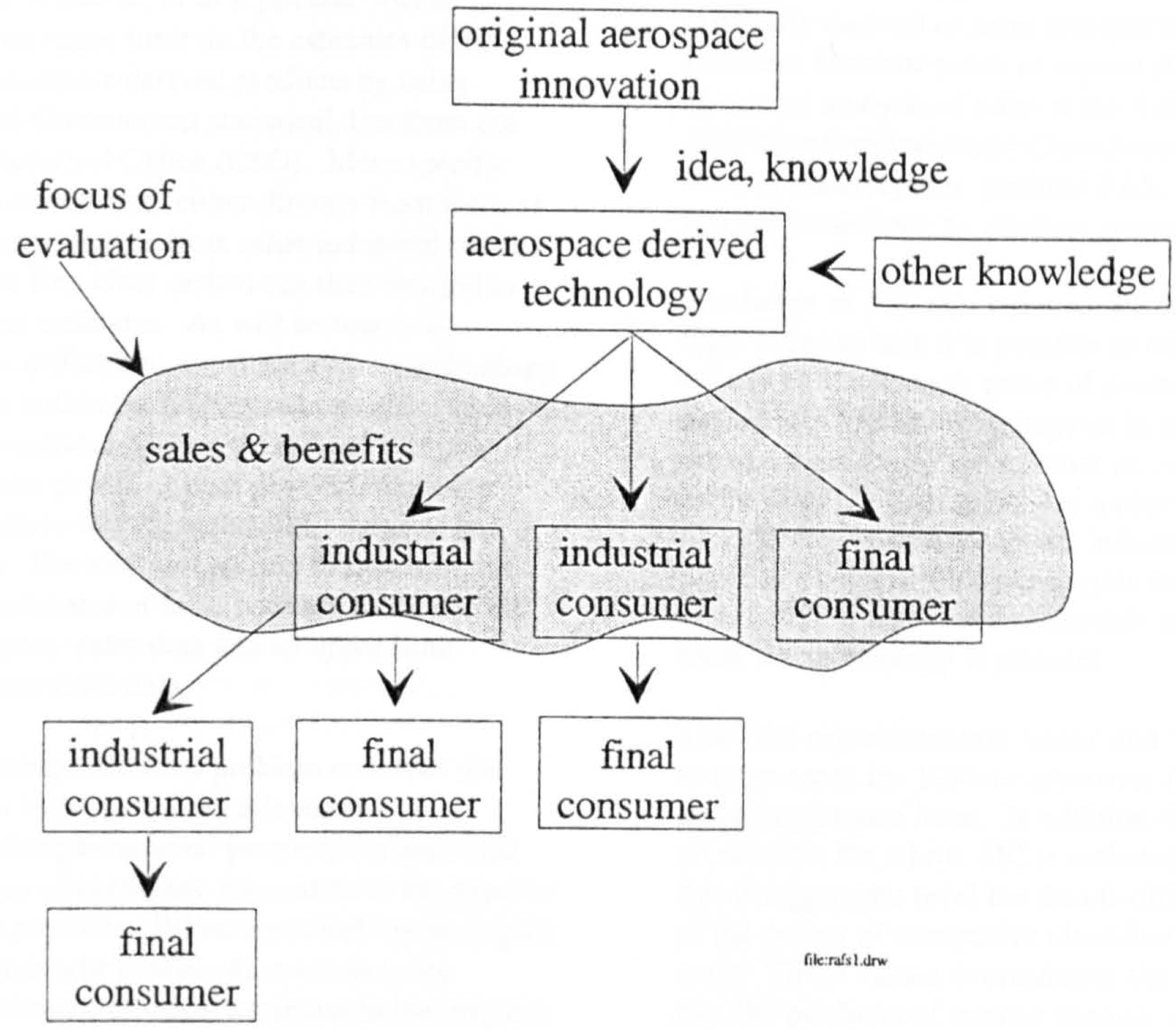
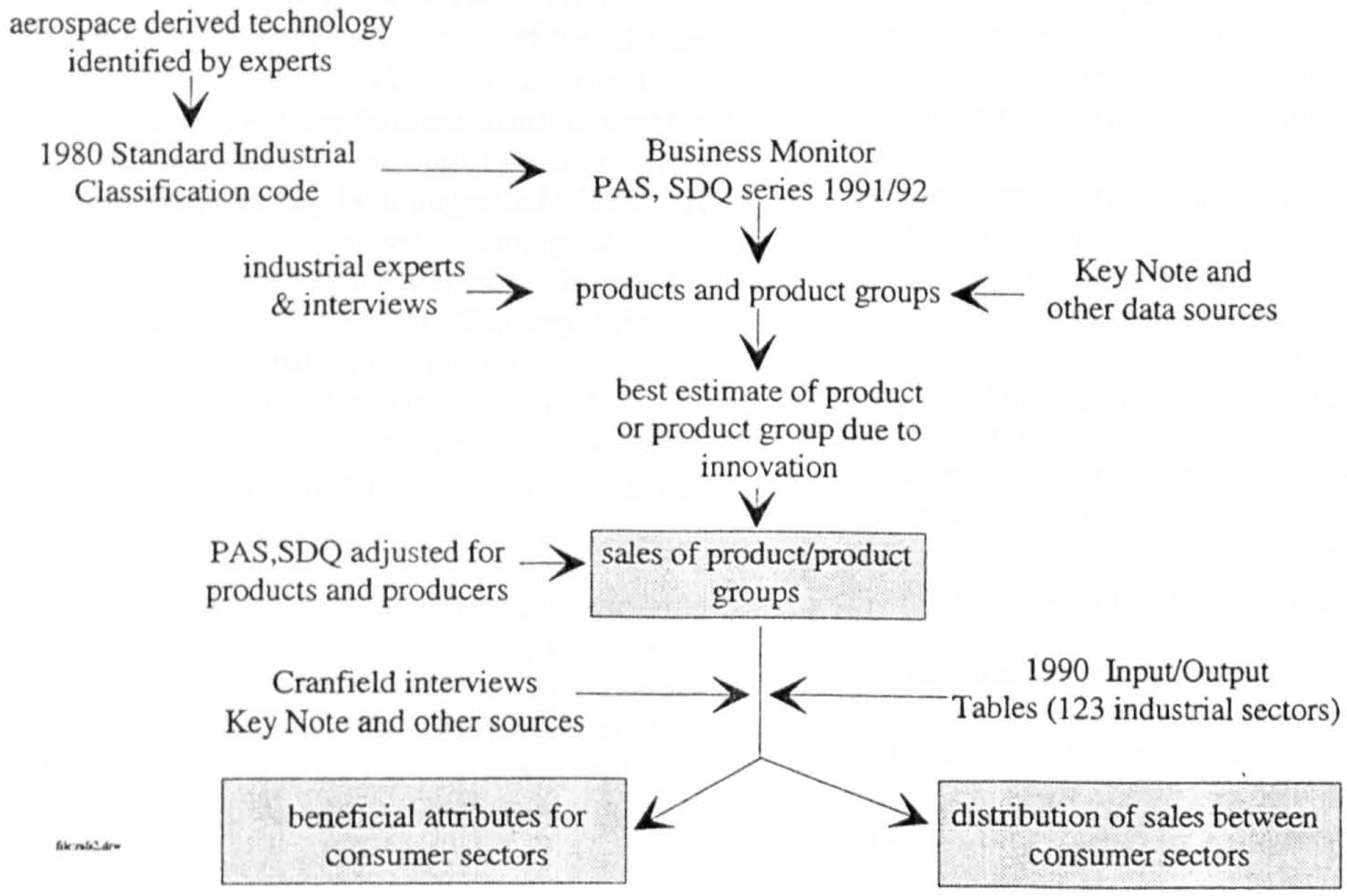


Figure 5.2

EVALUATION: PROCEDURE



5.2 PROCEDURE

The aim is to derive, in as replicable way as possible, an upper limit on the estimates of the sales of aerospace derived products by using established Government statistical data from the Central Statistical Office (CSO). More specific data from companies (either directly from them as part of this project or from other industrial survey such as the Key Note series) can then be used to refine these estimates. As will be seen it is sometimes difficult to associate a given technology or product within the CSO data at a sufficient level of disaggregation. On the other hand company data tends to give their own perspective on the overall picture which needs to be related to the CSO data. The idea is therefore to sandwich the project's estimates of sales between those derived from company sales data and an upper limit derived from CSO data.

An interesting additional problem concerns the distinction between technical/scientific and managerial/organisational perspectives about the contribution of aerospace innovation to the specific derivative products. When consulted, technologists and scientists will confine themselves to the linkages between physical attributes in the original and derived products, process or service. The business manager is more likely to include a wider range of products and processes on the grounds that these are only possible, in a business context, on the back of those derived directly from aerospace. The difference in perspectives can result in substantial differences in estimates of the relevant sales. For instance, for Adhesives, in the early parts of the project one business manager suggested a value of £600M per year while estimates derived from the relevant Key Note suggested £350M. The value derived from an expert technological identification of aerospace derived products is a maximum of £229M per year. The very different case-studies selected for this project have required a somewhat different implementation of the procedure described in detail below but generally the technological derivation has been used as the basis for valuation.

A flow diagram of the procedure used is shown in Figure 5.2. The shaded areas identify the outputs which are incorporated into the Summary Table at the end of this section. The figure shows all of the possible elements of the procedure, although for each case-study the particular elements required will vary.

The intention therefore is to identify benefits, in the form of sales, and the beneficial attributes to which users respond, at a disaggregated level in order to identify more closely the effects of technology originally derived to meet aerospace needs. The Business Monitor series of reports (CSO) includes an annual analysis of sales at the 4 digit level of the 1980 Standard Industrial Classification. Within each of these reports, prefixed PAS, is normally a further breakdown by product, process or service.

The Index of SIC lists items under each of the 4 digit codes so that it is possible to identify quite clearly within a small group of products which 4 digit codes and its disaggregates in the PAS report are associated with the relevant aerospace derived technology. Where necessary technology experts at Cranfield or in an appropriate industry have been asked to examine the disaggregate data in each relevant PAS report and to identify to which of these the technology is relevant.

The PAS reports contain 'value' and 'volume' data, in most cases for 1992 or otherwise for 1991, in this disaggregate form. In addition the total value of sales for the whole SIC is included. However, at this disaggregate level the data is offered in terms of the output of companies identified by that SIC code. These values overestimate the real value of the SIC products of interest because companies may be involved in other activities. The reports also offer, at the disaggregate level, value and volume by product, but only for companies over a certain size. However an adjustment factor (see Figure 5.2) can be calculated from the ratio of estimated total company sales to those actually disclosed by the more limited number of respondents and this adjustment factor is then applied to the disaggregate product values.

Further corroboration of actual or potential sales can be obtained from the Key Note series some of which cover relevant technologies. The Key Note reports relevant to this project use the same starting point, the PAS series of Annual Reports. In addition MINTEL, Dataquest, Datasearch, F&S and a specialist data base on materials technology, Metadex, have been scanned for relevant information. To this is added the information obtained from our interviews described in Section 4, with technology and industry experts.

The distribution of sales or potential sales among industry is estimated using the appropriate combination of the sources above. It is also possible to use the 1990 Input/Output tables (I/O) as well. These record the sales between each of the 123 economic sectors.

For each of these sectors the appropriate SIC's (at the 4 digit level) are available so that it is possible to match the SIC of the technology in question to its sector and hence to identify the relevant PAS report and disaggregate information. The I/O tables were obtained in electronic form and an edited version produced which contained the sectors of interest as columns and the 123 sectors as rows. A further row gives 'Total sales' which is an indicator of the relative size of the sector.

The sectors into which a relevant technology based product or service is sold can be estimated from our own interviews, Key Notes, MINTEL and other sources. The values in these cells are for all the sector products as a whole and they can only provide an indication of the relative shares that a technology might have between these buying sectors. None the less this is better than assuming that the distribution of the sales of a sector among all other sectors is representative of any one specific technology.

For some of the technologies identified in this report there are quite detailed market analyses from the interviews, Key Note and other sources which contain sales by type of product by consuming sector and the pertinent aspects of these have been offered in the report. It would also be possible (although not attempted within the time scale of this study) to collate all relevant PAS data for a sector and to estimate the percentage contribution by a given technology. The value of that contribution to cell values for all buying sectors could then be shown. This would assume that the distribution of the value of the technology would be the same as for the sector as a whole. A modification to this approach would be to use the other market analysis data to focus on the actual buying sectors.

The use of sales and sector size as proxies for economic and social value of aerospace derived technology suggests a greater weight be placed on understanding the nature of the benefits conferred on the buying organisations. Where these are intermediate users some attempt needs to be made to identify which attributes of the technology are influencing them and what beneficial attributes they offer buyers of their products, processes and services. A complete analysis would attempt to follow this process down to the final consumer. Within this report our own fieldwork interviews and other market analysis sources are helpful in providing some of this information and this has been noted where possible.

5.3 SPECIALISED COATINGS FOR GLASS

Relevant SIC: Glass SIC 2471 Total Sales in this SIC are £M643 of which £M106 are exports. Adjustment factor 1.24

Our case study interviews, described in Section 4.2.1, identified the strong influence of aerospace technology on the development of flat glass with low emissivity coatings and on multi-layered security glass.

There is much less disaggregation in this PAS report for 1992 which may be due in part to commercial confidentiality. 'Unclassified' products account for £M434 of the total. The data for 1991 is more explicit so this data has been used, but multiplied by the ratio of 1991//1992 gross sales (0.9) as a way of giving more disaggregate estimates of 1992 data.

There are a number of views about what proportion of specialist glass should be considered as derived from the original aerospace requirements but it is generally considered to be considerably less than the values specified as "Specialist Glass" in the PAS report although growing fast. Subject to more explicit data an estimate of 20% has been assumed. The appropriate categories in PAS 2471 and the value of sales are shown in Table 5.1.

Table 5.1 Sales of specialised glass products

Disaggregate product range	**Estimated 1992 Sales £M**
Flat glass and flat glass products Unworked etc., / cast, rolled, drawn	159
Cast/rolled etc. cut to shape Multiple walled insulating glass or units, factory made	62
Safety Glass: for all types of vehicle for all other purposes	 168 129
Total Specialised glass	**518**
of which aerospace derived (20%)	**104**

In the 1990 I/O Tables Glass is classified as Sector 18 and contains SICs:

2471/1 Flat glass not further worked
2471/2 Flat glass further worked
2478 Glass containers
2479//1 Domestic and ornamental glass

The total Glass sector was worth £M3,171 in 1990. The main sectors identified as consumers of coated/laminated glass are shown in Table 5.2.

Table 5.2 Relative distribution of markets for all glass products

Sector	Sector sales	of which all specialist glass	Total Sector value in 1990
	£M	£M	£M
Motor vehicles	212	150	38,637
Construction	461	325	93,151
Total	673	475	N/A

5.4 ADHESIVES AND ADHESIVE PRODUCTS

Relevant SIC:
- Formulated Adhesives and Sealants SIC 2562
- Adhesive Film, Cloth and Foil SIC 2569.
- Adjustment factors: PAS 2562 - 1.224: PAS 2569 - 1.388.

Total sales of all products in SIC 2562 in 1991 were £M476 of which £M91 were exports.

Our case study interviews described in Section 4. 3.1 indicate that structural bonding adhesive technology has been largely driven by aerospace technology.

An expert in the adhesives sector (Centre for Adhesive Technology) had identified which of the disaggregated product ranges listed in the PAS reports have been derived from the initial aerospace driven innovation. In addition the Key Note on Adhesives notes that:

> *'The aerospace industry, for example, was the pioneer user of advanced adhesives and has continued to provide the most testing conditions for the latest in adhesive technology'.*

The relevant selection of 'Formulated Adhesives and Sealants' is shown in Table 5.3

Table 5.3 Sales of aerospace related adhesives

Disaggregate product range	1991 Sales £M
Cross linking,	4
Casein	4
Two part Sealants	37
Urea/phenol	7
Total	52

Some indication of the main consumers of the product can be gained from the *1990 Input-Output Balance for the United Kingdom* (Economic Trends, Oct 1993, Crown Copyright). Due to the category used (Special chemicals for industry etc SIC 25)this can only yield a crude approximation. At this level of aggregation the sales for Sector 25 known to consume aerospace derived adhesives have been identified using market information from Key Note Report 016532 (1992). The value of total adhesive sales to these sectors can be estimated as £M280 per annum. Each of the sector values below are too large due to the inclusion of other Sector 25 products but the % share gives an indication of the relative importance of the markets for aerospace derived adhesives, to which is added the Retail Sector as below.

The Retail consumption of adhesives and adhesive based products has been analysed in the DIY Chemicals Market (Harvest/Mintel 1993) report and the overall markets for adhesives and adhesives based products in a Key Note report. The market information sources differ on the size of the retail market. The Mintel data suggests an aerospace derived adhesive retail market of £M70, although it is difficult to identify which of this is specifically for aerospace derived products, while the Key Note refers to a 30% market share of all adhesives as retail which implies a somewhat higher value. The sales value of £M70 has been used in Table 5.4.

Table 5.4 Relative distribution of the main markets for all adhesives

Sector	1991 Sales of all Adhesive Products £M	Share among major consumers (%)	Total value of consuming sectors £M
Consumers' Expenditure (Retail)	70	20	38,637
Motor & other Vehicles	17	5	41,718
Carpets	6	2	2,766
Timber & Furniture	60	17	14,909
Paper Products	59	17	8,862
Construction	93	26	93,151
aerospace	18	5	17,501
Other sectors	27	8	.N/A
Total	350	100	N/A

The main products and consumers benefiting from aerospace derived products are Packaging (about 33% by product volume, speed and strength giving cheaper or more reliable products), Construction (about 20% by product volume, much in laminated and particle boards, giving longer life, quicker assembly)) with the transport industries, particularly automotive, growing fast as users (through assembly speed, use of new materials of greater strength/weight ratio) Non-woven textiles are covered below in adhesive based products.

Sealants, of which the main consumer is the Construction Industry, offer benefits of a superior product yielding energy savings to the final owner of buildings and lower maintenance costs in other infrastructures e.g. roads. The main benefits of the product in use in construction is cold curing and speed thus lower construction costs. In the automotive sector reliability of seal, weather resistance, and assembly speed are the main benefits.

Adhesive Film, Cloth and Foil SIC 2569 Total sales of all products in SIC 2569 in 1991 were £M177 of which £M32 were exports.

The products are described in PAS 2569 as:

> *'Adhesive film, tape et. of plastics or cellulose, adhesive cloth and foil, including heat and solvent activated materials, with the adhesive mainly of rubber, converted self-adhesive industrial products'*

It is not clear what proportion of these products were initially derived from aerospace needs but they have been assumed to have been widely influenced by that technology and an upper limit has been assumed as the total sales of £M177.

The sales are widely diffused. The main markets are aerospace, automotive manufacturing, consumer stationery, construction, DIY, fire safety, mining, packaging, office supply etc.(Key Note). With the exception of the construction sector the distribution of sales among sectors could be assumed to be approximately as for adhesives.

5.5 FINITE ELEMENT ANALYSIS/COMPUTER AIDED DESIGN

Relevant SIC: 8394 Computer Services

Our fieldwork interviews, described in Section 4.4.1, suggested that almost all the pioneering work on Finite Element Analysis was done in the aerospace industries in the 1960's, and this work was transferred, mainly through the movement of people, into all structural and stress analysis.

FEA is a technique which is embodied in computer packages for use in Computer Aided Design (CAD)and data limitations restrict us to this level of resolution. The relevant available source of sales data for this SIC is in the quarterly analysis of Business Monitor SDQ9. The last quarter for 1991 contains disaggregate data for the whole of 1991. The appropriate sub-section is shown in Table 5.5. The relevant items in Table 5.5 are Custom software and Software products, shown in bold.

Table 5.5 Sales of Software

	1991 £M
1. Section B:- Software	
Custom software	**766**
Semi-custom software	48
Software products	**564**
Software support/maintenance	264

Table 5.6 Sales of UK CAD: Method 1

Product type	£M	CAD products min 6.2% £M	CAD products max 9.3% £M	CAD products average £M
Software products (SDQ9)	564	35	52	44
UK originating Bespoke software	766	47	71	61
Total software	**1,330**	**82**	**123**	**103**

Key Note Report (0166885) on Computer Software gives the total software market in the UK as £M5,300 in 1992 but there are few UK companies producing package software and none that are UK owned. The Report (Source-CONTEXT) gives CAD in 1992 as 2.2% by volume of sales in the UK software products market and 9.3% by value in 1992 and 6.2% by value in 1993.

Thus the minimum and maximum UK based product sales can be estimated by applying the 1992 and 1993 percentages to the 1991 Software products value of Table 5.5. This is shown in detail in Table 5.6.

However CAD may also be classified as Custom, Bespoke or part of Value Added Retail and the above may be an underestimate. A further Key Note Report, (016663) on Computer Services includes material from the Computer Services Association (CSA) which combined by them with data from SDQ9 suggests a UK Bespoke software market in 1992 of £M776, very close to the £M765 of the SDQ9 classification of Custom software. The sum of these two multiplied by the percentages provides a further, and very similar, estimate of the range of values required and is used in this report. Table 5.7 shows the method of calculation.

A report compiled for this report comments that all of the top four CAD/CAM systems in use by the worlds automotive industry have either been provided by, or have been predominantly funded by the aerospace industry.

Table 5.7 Sales of UK CAD: Method 2

	£M
Input/Output Tables for the Computing Services Industrial Sector (111)	10,560
Sum of Key Note Reports (Computer Software plus Computer services)	9,800
UK based companies produce	1,645
Ratio of UK production to all consumption 1645/9800 17%	
UK market for CAD (Cranfield Sources: Dataquest, Daratech)	580
CAD originating from the UK = 17% of £M580	**100**
Software products	**40**
Bespoke software	**60**

Our literature search also gives the breakdown of sectors buying CAD internationally and the UK distribution of sales is assumed to be similar to this data which is shown in Table 5.8.

Table 5.8 Major consumers of CAD

Sector	%
Automotive	10.6
Electrical Design/components	10.1
aerospace	9.8
Computers and Office Equipment	9.4

5.6 Hot Isostatic Pressing (HIP)

Relevant SIC: SIC 30 Metal castings etc
This contains the following sub-groups which are relevant to HIP:

3112 Non-ferrous metal foundries
3120 Forging, pressing and stamping
3138 Heat and surface treatment of metal) including sintering

Section 4.3.2 described how Hot Isostatic Pressing originated outside aerospace, but then in the 1970-80s period was fully developed by aerospace technologies and is now, as a result of the development, beginning to be widely transferred elsewhere.

The technology was not available at the time of the 1980 SIC and is therefore not directly classified in any disaggregate tables. The maximum total value of the current UK based HIP market is estimated from Cranfield interviews as £M60. HIP is, however, a current technology in the process of diffusion from high value items which are performance and safety critical to lower value items. Economies of production at lower quality is very evident. The rate of diffusion is inhibited to some extent by the lack of knowledge about the materials properties it can produce rather than costs alone and possibly the scale of plant required. The following analysis aims to identify the potential market.

The following PAS reports have been examined by a materials technology expert at Cranfield and the categories for which HIP is appropriate technically and in terms of beneficial attributes have been identified as shown below in Table 5.9.

Table 5.9 Potential market for HIP

	£M
1. PAS 3112 Non-metal foundries Total value in 1992 £M697 of which £M19 was exports Adjustment factor 1.51 Castings	
Aluminium and aluminium alloys and castings of copper	560
Brass and copper alloys	17
Other non-ferrous metals	117
Sub-total	**694**
2.1 PAS 3120 Forging, pressing and stamping Total value in 1992 £M1600 of which £M100 was exports Adjustment factor 1.63 Aluminium and aluminium alloys included in "unclassified"	
Limited application for HIP. Estimate	5
Non-ferrous metals (other than aluminium copper and their alloys	92
Sub-total	**97**
2.2. Further applications of HIP that may displace existing processes	
Hammer forging (In "unclassified"). Estimate	10
Heavy forging	27
Sub-total	**37**
3. PAS 3138 Heat and surface treatment Total value in 1992 £M652 (no export data) Adjustment factor 1.92	
Hot dip coating (other than galvanising) Research stage only	
Metal spraying	60
Other metal finishing	225
Heat treatment of iron and steel	62
Sintering of metals	19
Sub-total	**366**
Total of all potential HIP applications	**1,194**

The current value of HIP based on industrial estimates is up to £M60 out of the 1992 potential value of £M1194 for which it is an applicable technology i.e. 5%. The 1990 I/O tables gives the Metal castings and etc. sector (30) a total value of £M6578. Table 5.10 below gives the distribution of the potential value of HIP pro rata with the distribution of the largest Total value sectors, based on the ratio of HIP potential market to Total Sector 30 sales i.e. 1194/6578 (0.1878)

Table 5.10 Relative distribution of largest potential markets for HIP

Sector	Total value of Sector 30 products £M	Potential market for HIP in these sectors £M	Total value of Sectors £M
Aerospace	230	42	17,501
Metal goods	245	45	9,351
Industrial plant	183	33	5,725
Agricultural machinery	126	23	2,433
Mining equipment	182	33	6,486
Other machinery	692	126	14,761
Electrical equipment	187	34	3,515
Motor vehicles	1,585	288	38,637
Construction	687	125	93,151
Totals	**4,097**	**749**	N/A

5.7 Artificial Limbs

Relevant SIC: SIC 37 Instrument Engineering, comprising SIC 3710, 3720, 3731, 3732, 3733, 3740.

The Total sector (37) was valued at £M7489 in 1990 of which £M2331 was exports.
16% (£M1223) of the Total is to the Health sector

Of the above, SIC 3720 (Medical and surgical equipment and orthopaedic appliances) is the one which is relevant. Within this SIC sub-classification 3720/3 (Orthopaedic appliances and artificial limbs) covers this specific technology. The total value of SIC 3720 given in PAS 3720 for 1991 was £M777 of which exports were £M550. (Imports were £M441).
Adjustment factor is 1.5.

Section 4.2.2 described in detail the novel transfer processes from aerospace technology which gave rise to major product innovations in the manufacture of artificial lower limbs, and which regenerated a medium sized British company. The value of 'Artificial limbs' in 1992 was £M54 of which, based on direct sales data from companies, at least £M20 is derivative of aerospace technology.

5.8 Heat Exchangers

Relevant SIC: 3205 and disaggregate data can be found in PAS 3205.
Total sales of SIC 3205 in 1992 were £M2265 of which £M403 were export.
The adjustment factor is 1.61

Section 4 2.3 outlined the development of lighter and more reliable heat exchangers based on materials technology derived from aerospace. This section indicates the potential transfer benefits derivable from the relatively new transfer. The source of the materials technology is in the development of "composites". The application to industrial heat exchangers is a specific example of the potential of this materials technology.

Table 5.11 All sales of all heat exchangers and condensers

	£M
shell and tube	91
plate	37
other	68
Total	**196**

It is not possible within this project to identify the proportion of the £M196 which uses composites so this must be regarded as an upper limit on potential sales. A value of £M49 (25%) has been assumed for the total actual sales.

Sector 34 (Industrial plant and steelwork) comprises SIC 3204 and 3205. Total value of the sector was £M5725 and the distribution of sales of products among the largest buying sectors as follows:

Table 5.12 Relative distribution of markets for 'Composite heat exchangers'

Sector	Sector 34 Sales £M	Total value of sector £M
Oil and Gas	82	16,637
Industrial plant	422	5,725
Process machinery	103	3,790
Mining equipment	232	6,486
Other machinery	95	14,761
Construction	721	93,151
Total	**1,655**	N/A

5.9 SUMMARY

The process of identification of the value of aerospace derived technologies above is complicated because of the variability of data and the various levels of disaggregation available. The following **Summary Table** pulls together the previous sections and the nature of the benefits to users of each technology.

In addition to the estimates derived from the mainly 'technology based' evaluation it is also possible to give some indication of the 'business derived' values and of the short / medium term 'potential markets', all based on data shown in the previous sections on the six selected case studies.

- Technology based £M 562
- Business derived £M 884
- Potential market £M 2,575

SUMMARY TABLE

Innovation	Total product sales £M	Producer Industrial sector: (Sector number)): Total sales of sector £M	Main industrial consumer sectors	Value of sectors £M	Main benefits from this innovation to these sectors
Specialised glass SIC 2471			Construction	93,151	Thermal efficiency (lower cost to user),
Thermal	236	Glass (18)			security
Safety	239	£M3,171			
Total of which aerospace	475		Motor & other vehicles	38,637	Safety
	104				
Adhesives SIC 2562	52		Packaging	8,862	Speed, strength
Adhesive products		Specialised chemicals (25)	Construction	93,151	Longer life, quicker assembly, lower costs
SIC 2569	177	£M7,028	Motor & other vehicles	38,637	Assembly speed, strength/weight ratio
Total	229				
Hot Isostatic Pressing			Motor vehicles	38,637	**For all Sectors**
Current market	**up to 60**	Metal castings (30)	Other machinery	14,761	Provides a continuous range from very high
Potential market		£M6,5778	Construction	93,151	quality/high cost to very reliable quality and
SIC 3112	694		Industrial plant	5,725	lower cost.
SIC 3120	134		Mining equipment	6,486	Provides access to wider range of materials
SIC 3138	366		Agricultural machinery	2,433	and options for new designs
Total Potential market	**1,194**		Electrical equipment	3,515	
Finite Element Analysis &			Motor vehicles	38,637	**For all sectors**
Computer Aided Design		Computer Services (111)	Electrical components	9,199	More precise design; weight/strength ratios
SIC 889 sub-classes		£M10,560	aerospace	17,501	Cost savings in design process and products
Software products	40		Office machinery	16,254	Speed of design and production
Bespoke software	60				
Total	**100**				
Artificial limbs		Instrument engineering (57)	Health Services	35,577	Speed of delivery, shorter time of doctors,
SIC 3720 subclass:		£M7,489			lighter and more mobility for patient
Artificial limbs	**20**				
Heat Exchangers		Industrial plant and	Oil & gas	16,637	**For all sectors**
SIC 3205	196	steelwork (34) £M5,725	Industrial plant	5,725	Radical reduction in space and weight
of which Aeorospace	49		Process machinery	3,790	Improved reliability in hostile environments
			Mining equipment	6,486	
			Other machinery	14,761	
			Construction	93,151	

6. CONCLUSIONS

In summary, our main conclusions are:

i) Our interviews have indicated that there has been extensive technology transfer in the main case study areas of specialised glass coatings, adhesives and finite element analysis (FEA). In the subsidiary case study examples, hot isostatic pressing and simulators, there is evidence of rapidly growing transfer and, in the first of those, this may extend into many important industrial sectors.

ii) Technology transfer in these specified areas has contributed to benefits in the form of improved products (often in the form of better quality, reliability or longer life), reduced costs of assembly (use of adhesives decreasing assembly time, 'hipped' products needing less machining) and reduced weight (use of FEA in structural optimisation). These benefits have been transmitted to the economy through product sales of as much as a billion pounds per annum, and they apply to a wide range of industries.

iii) In most cases, the technology transfer involved significant adaptation to modify the stringency of the aerospace standards and to reduce costs. It was frequently expressed in the interviews that the aerospace applications had considerably reduced the RTD risk and the adaptation costs were unequivocally worthwhile in the areas cited.

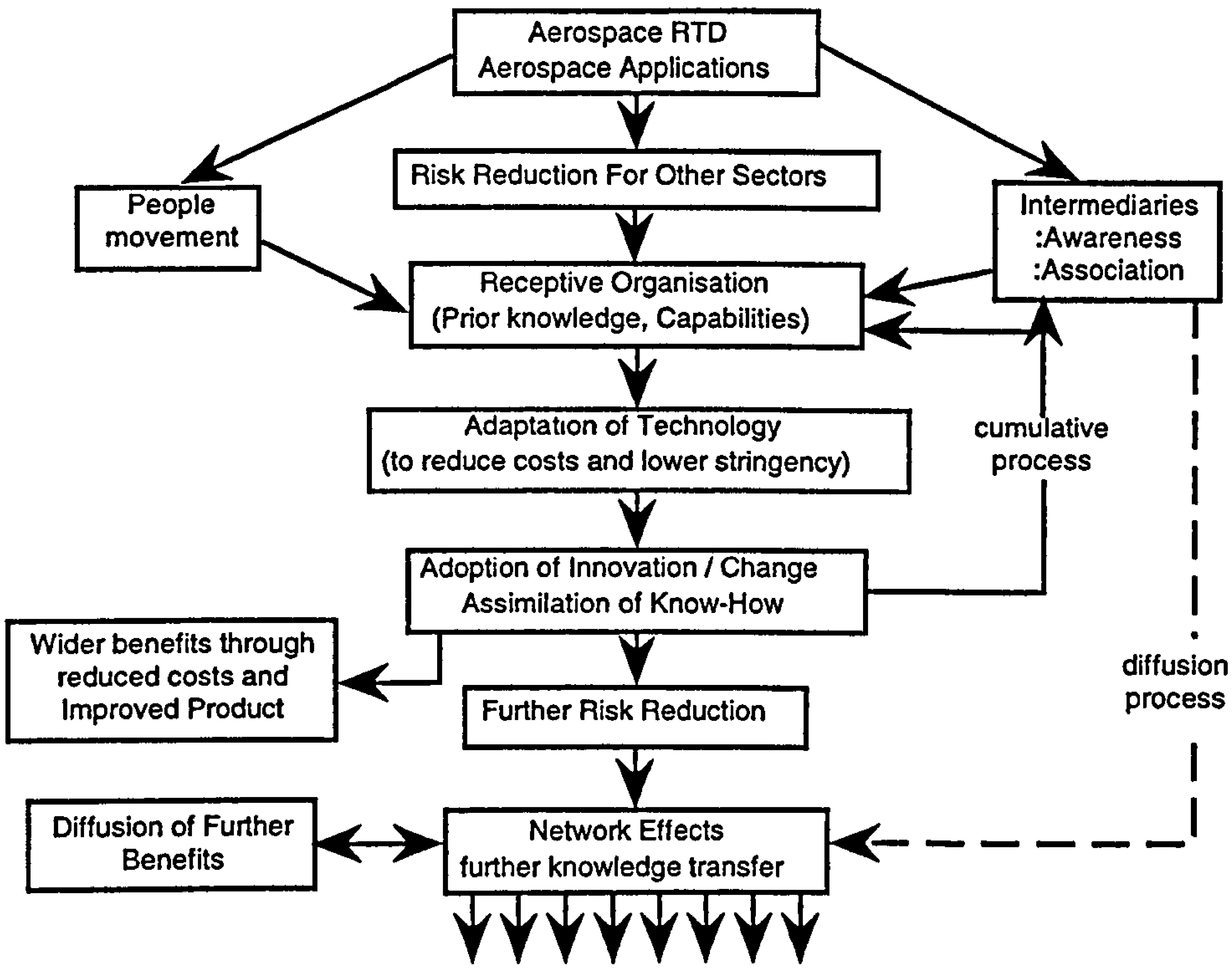
iv) The successful examples of identified technology transfer in the UK often involved companies recognising the importance of scanning for new ideas/technology, sometimes using an intermediary organisation, often stimulated by the need for diversification and frequently benefiting from the inward movement of people with knowledge from the aerospace industries. An impression was gained that there were also very strong network effects, with those companies tuned into that network being exceptionally good at technology transfer. We also perceived that significant useful knowledge transfer was flowing through the networks with major, but less detectable, benefits. These knowledge and technology transfer processes appear to be cumulative, with one success leading to another whilst other less receptive industries are not locked-in to this learning process.

v) There is also considerable latent potential for technology transfer that is unfulfilled, particularly in the areas of composite materials bonded by synthetic adhesives, where it was said that, in the construction and transport sectors, examples in Japan and some parts of Europe outnumber those in the UK by ten to one. Opportunities appear to exist here for knowledge transfer and supply chain innovation. The case study on artificial lower limbs usefully illustrates the potential of materials technology transfer.

Figure 6.1 (see overleaf) integrates conceptually these findings into an interactive process model of technology and knowledge transfer from the aerospace industries into wider use. It also contains further concepts derived from our earlier research on the development and application of interactive models of industrial technology transfer (Seaton and Cordey-Hayes, 1993)[2] and inward technology transfer as an interactive process (Trott, Cordey-Hayes and Seaton, 1995)[3].

[2]Development and application of interactive models of industrial technology transfer, Technovation 13, 45-63, 1993.
[3]Inward technology transfer as an interactive process, Technovation 15, 25-43, 1995.

Figure 6.1



Aerospace RTD
Aerospace Applications
Risk Reduction For Other Sectors
People movement
Intermediaries :Awareness :Association
Receptive Organisation (Prior knowledge, Capabilities)
Adaptation of Technology (to reduce costs and lower stringency)
cumulative process
Adoption of Innovation / Change Assimilation of Know-How
Wider benefits through reduced costs and Improved Product
Further Risk Reduction
diffusion process
Diffusion of Further Benefits
Network Effects further knowledge transfer

APPENDIX: CASE STUDY INTERVIEWS

A.1 AGENDA OF QUESTIONS FOR STAGE (II)

Section 2 outlined broadly the intention of the various steps of the study. This appendix now describes in more detail the agenda of questions addressed in the interviews of recipients of technology originating in the UK aerospace industries. It was not expected that this agenda of questions could be covered by a single individual in the recipient organisations and it turned out that typically a chain of three or four individuals in each organisation needed to be consulted. The agenda of questions for stage (ii) broadly addressed the following:-

<u>How did the technology come to the notice of the recipient company?</u>
Was it by chance, routine search or a positive search
When was this
Who in the company brought it to the attention of whom
Why did they think it was potentially of interest
What contacts outside the company were involved in making the company aware
What implicit or explicit criteria were being used at that time
What were the main business development pre-occupations of the company at the time?

<u>Where was the technology?</u>
owned by who
used by who
for what purpose
from whom was it available
was it ready to use as a produce or process?

<u>How was it made available; by what process and events was it acquired?</u>
who was involved in these events; in the company; in other companies or agencies
what was the nature of the 'deal' by which transfer took place
what, at that stage, was its purpose as far as the company was concerned
what was it intended to do for the company?

<u>What, if any formal evaluation was made of the technology prior to acquisition?</u>
what was the nature of any evaluation, investment appraisal, risk analysis
what in this company have been the overall costs in terms of finance; manpower, management, training; development; other adjustments to the organisation:

<u>What are the benefits to the company in terms of</u>
reduced costs of production
increase quality or standards
new product and widen or diversify product range
increase speed to market
access to new markets
increased customer service?

<u>What would have been the equivalent cost if the company had developed the technology from its own resources</u> R&D; with other companies; with R&D institutes or universities
could it actually have done this if not, what factors would have made it difficult or impossible(knowledge base, expertise, finance)
what would have been the risks (costs, production, speed to market etc.) of doing that
has external acquisition reduced risks (financial, revenue etc)
by how much in financial terms
has external acquisition reduced the scale of investment required
have any other aerospace related technologies been considered; if so what; why not adopted
what other sources of technology have actually been used in the last few years
what technologies?

<u>Are there any benefits or costs to companies in the supply chain?</u>
which companies; what benefits; what costs?

<u>How receptive to new technology are companies in general in that sector</u>
how receptive is the sector to technology derived from aerospace needs or technology

<u>What have competitor companies done in terms of technology changes</u>
what effects have these had in the sector
what effects in the markets
which of these derive from aerospace demands or technology
has it changed the structure of the sector?

<u>What proportion of the total market for that product/process was influenced by the identified transfer?</u>
what share of the market does the company have
what proportion of company turnover is accounted for by the identified product/process transferred
what sectors or customers are served with this product/process in the UK?

A.2 The Interviews

Unlike the adoption of a totally open approach, as used in tapping the knowledge base, a set of questions was prepared for the industrial contacts. Two forms of these questions were prepared, one that had prompts for use by the interviewer and the other that was without prompts, which could be given in advance of the questioning. However, at each interview the respondents were encouraged to begin in a spontaneous way; to discuss their ideas and views about this kind of technology transfer. In practice, many of the pre-prepared questions were covered by this approach. The discussion in each case focused upon a specific technology transfer which was agreed at the beginning of the interview:-

Materials Technology
Specialised glass coatings
Lower limb prosthesis

Process Technology
Adhesives applications
Hot isostatic pressing (HIP)

Avionics/Software
Simulation/FEA

Although a focus was maintained throughout the interviews there was a strong tendency for respondents to emphasise future transfer of aerospace-based technologies, and in each case they had to be brought back to the brief of past and current applications only. Where significant future applications were identified these have been recorded and included in the network of transfer channels, see Figure 3.1.

Interview contact varied from around 20 minutes on the telephone, where the lead was proving less fruitful, to over 4 hours of face-to-face discussion. The list below gives the contacts used in finding and developing the case study material.

Dr R Baker	Director R&D British Steel Rotherham
Mr M Banks	Director Engineering Landice Lund Keighley
Mr J Birch	Manager Marketing and Planning Pilkington Plc St Helens
Mr T Bonnington	Director Marketing Ciba Geigy Plc Duxford
Mr R S Bruce	Technical Director Pilkington Aerospace
Ms S Duncanton	General Manager TWI Abington
Dr J Eddington	Director Engineering British Steels
Dr T Ellis	Director Pilkington Plc London
Mr A Espie	Senior Project Engineer (Adhesives) TWI Abington
Mr A Evans	Technologist Blatchford & Sons Basingstoke
Dr J Fowler	MD Rolls-Laval
Mr C Guest	Manager R&D Union Carbide
Mr M Jenkins	Director Pilkington Plc London
Dr S Jones	Manager Technology Transfer TWI Abington
Dr S King	Manager HIP Chesterfield
Mr R Langham	Manager Thompson Training Simulation Crawley
Dr G McGrath	Manager Adhesives Technology TWI Abington
Sir R Nicholson	Executive Director Pilkington Plc London
Mr T Nordbery	Manager Thompson Training Simulation Crawley
Mr N October	Manager Polymers Ciba Geigy Duxford
Dr B A Rickinson	MD HIP Chesterfield
Mr P Spence	Manager Thompson Training Simulation Lancing
Mr J J Shorter	MD Blatchford & Sons Basingstoke
Mr I White	Applied Technology Lucas Solihull

The interviews done to tap a knowledge base at Cranfield University were, apart from one, conducted face-to-face and in most cases were for just over one hour and in some cases up to two hours. The list below gives the names of these contacts.

School of Mechanical Engineering (SME)
Professor R L Eder
Professor R Singh

School of Industrial and Manufacturing Science (SIMS)
Professor C Bucknall
Professor J Corbett
Mr M Craig
Professor P Irving
Professor J Kay
Dr M W Lock
Dr I Partridge
Dr D J Stephenson

College of Aeronautics (COA)
Professor D J Allerton
Professor J Fielding
Professor A J Morris (by telephone)

Cranfield Precision Engineering Ltd (CPE)
Dr W Wills-Moren

Cranfield Computer Centre
Dr B J Robertson

Gilbert M., Seaton R. and Cordey-Hayes M. (1997) "Innovation and Instrumental and Developmental Knowledge Dynamics". Proc. Sixth International Conference on Management of Technology - MOT 97, June 97, Goteborg, Sweden

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INNOVATION AND INSTRUMENTAL AND DEVELOPMENTAL KNOWLEDGE DYNAMICS

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Paper is suitable for either oral or poster presentation
Suggested Topic is H, Category 2.

Keywords are : Innovation, Knowledge, Dynamics, Learning, Complexity, Organizations

ABSTRACT

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This paper presents a dynamic model of the complex processes of knowledge acquisition and assimilation in organisations. It is a human-centred model and can be articulated in terms of both models of learning and complex systems thinking. It has been used to underpin research for British Telecom on knowledge dynamics and taxonomies of knowledge in organisations. The model has been developed on the basis of empirical work undertaken within two organisations and has been verified by the management involved. The studies were concerned with technology transfer within a technological organisation and technological innovation within a service organisation. However such a model requires adaptation in the way that it is communicated to practitioners in both strategic and operational management. The current activity which is being undertaken is to identify and formalise the nature of response of managers when exposed to this model. This in itself can be seen as an example of knowledge transfer from the theoretical and conceptual domain to the applied domain. The proposed paper describes the model and its derivation in terms of learning and complexity and then presents the results of the responses of a number of managers. Two different forms of knowledge are identified, instrumental : knowledge necessary to undertake a particular function or task and developmental : knowledge related to areas of personal development. The model described extends the features of double-loop models by focusing on the emergent knowledge properties of the nested hierarchy within which knowledge dynamics are located.

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INTRODUCTION

Organisations today are becoming increasingly concerned with their ability to innovate and to take advantage of the vast amount of information that is becoming available from a multiplicity of sources. How knowledge is managed is crucial to the innovation process and the ability of the organisation to respond to change. This paper presents a dynamic model of the complex processes of knowledge acquisition and assimilation in organisations. It is a people focused model and may be articulated in terms of both models of learning and complex systems thinking. It is important to state at the outset that this model, whilst based on strong conceptual frameworks was developed from two empirical pieces of field research studying knowledge and knowledge transfer in organisations and in both cases, the model was verified by the managers concerned (Trott, 1993 and Gilbert, 1995). The aim of this paper and the further research to be undertaken is to explore the value of the model to managers in order to enable them to better manage the processes of knowledge transfer and the issues of complexity and uncertainty. The paper describes the model in terms of learning and complex systems. Once such a model has been developed it must be communicated, translated and interpreted into a language that is understood by business. The model has been used to underpin research for British Telecommunications (BT) on knowledge dynamics and taxonomies of knowledge in organisations. The paper continues by exploring the way in which such complicated and complex non-textual information may be presented to managers and the response of a number of managers to the model.

THE MODEL - KNOWLEDGE ACQUISITION AND ASSIMILATION IN ORGANISATIONS

Background

The two studies from which the conceptual model (Fig.1) was developed had a slightly different focus. The first was undertaken within ICI (Trott, 1993), a high technology production organisation, and was designed to map and gain greater understanding of the processes enabling technology transfer within the organisation. The second study explored the knowledge processes involved in the introduction of new technology and associated organisational processes within an area of Lloyds Bank. The two studies used similar research methods which involved a series of interviews with a cross-section of staff within each company. The results and analysis of the interviews were expressed in a series of maps and discussed with and validated by the interviewees (Cordey-Hayes, Gilbert & Trott, 1995). Both studies confirmed that the ability to manage and transfer knowledge was crucial to the ability of the organization to innovate and change. Further work was undertaken which has resulted in the development of a conceptual model based on the understanding of the processes of knowledge transfer that were achieved from the fieldwork.

A number of stages were identified that must be undertaken if the process of knowledge transfer and thus organisational learning is to be complete :

The first step is that of acquisition, before it is able to be transferred, knowledge must be acquired. The organization might learn from its past, by doing, by 'borrowing', by acquiring individuals with new knowledge and by a continuous process of searching or scanning. A major influence is 'congenital learning'. The very essence of an organization is profoundly influenced by its founders (Schein, 1991). The prior knowledge held at the inception or birth of an organization will direct and determine how it moves forward, what it searches for, what it finds and how it interprets knowledge acquired. Whilst Fig.2 identifies the processes of knowledge acquisition, the type of knowledge acquired will be differentiated by these constructs that will influence the source of the knowledge.

The second step is the communication of knowledge once it is acquired. Communication may be written or verbal. This process of distributing the knowledge acquired in organizations has been well researched. The organization must be aware of the possible barriers to the dissemination of information if it is its intention to encourage knowledge transfer. The model requires that the communication mechanisms are developed so that the opportunities for transferring knowledge effectively are both present and encouraged.

The knowledge acquired and communicated must then be applied for it to be retained. It is the results of the application of the knowledge that enables the organization to learn rather than the knowledge itself.

The key to the process of knowledge transfer is the assimilation of the results and effects of applying knowledge gained. This requires the transfer of the results of history into the routines of the organization.

The empirical work explores the point at which the knowledge is transferred from the individual, to the group and thence to the organisation. In order for the organisation to learn the knowledge must be assimilated into the core routines of the organisation. Therefore the knowledge acquired by the work group, having been adopted, must be applied. Knowledge transfers from the individual to the organisation at that point. The studies showed that there is a stage before this knowledge gained by application can be assimilated into the core routines of the organisation. This stage is acceptance, indeed it was shown that successful technological and organisational change can be achieved at the acceptance stage yet the organisation has not gone through the full learning cycle and this knowledge is not completely transferred into the core routines. Thus the model may be redrawn, as Fig.3, on the basis of the fieldwork to reflect this addition.

Organisations must develop and encourage an environment that allows completion of the cycles if learning is to occur.

INSTRUMENTAL AND DEVELOPMENTAL KNOWLEDGE

It became clear from the fieldwork and study of current literature that there is considerable confusion in the way in which the term knowledge is used[1]. However, two distinct types of knowledge emerged from the fieldwork and it became clear that these were fundamental to understanding the processes of knowledge transfer and thereby of knowledge management. These were distinctions between instrumental and developmental knowledge.

Instrumental knowledge, the knowledge that is necessary to be able to do the job

Developmental knowledge which enriches and enhances the instrumental knowledge. includes the field of personal and organisational development and embodies the processes of innovation and creativity.

Knowledge that is held by an individual only and not shared is of no value in the learning process. It is not transferred therefore it cannot become assimilated into the core routines of the organization [Gilbert and Cordey-Hayes, 1996]. Most organisations are good at creating channels and opportunities to transfer instrumental knowledge but in order to progress and develop they must learn how to manage developmental knowledge. Table 1 illustrates some of the distinctions that were identified in the Lloyds Bank study between opportunities to acquire different types of knowledge. Many opportunities to acquire developmental knowledge do arise out of opportunities created for the transfer of instrumental knowledge but this process is too serendipitous, for an organisation to take advantage of this knowledge a more proactive process is required.

Organisations, or parts of organisations, may be described in terms of their knowledge requirements between instrumental and developmental knowledge. Fig 4, from the Lloyds Bank study illustrates the way this may be used.

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1 There is an important and continuing debate on what, precisely is meant by the term knowledge, it began with the Greek Sophists in 450BC and continues today. It is becoming increasingly necessary that distinctions between terms such as knowledge and information have commonality of understanding. This paper recognises the importance of making such distinctions but equally recognises that the debate must be continued elsewhere.

TABLE 1 : EXAMPLES OF OPPORTUNITIES TO ACQUIRE KNOWLEDGE WITHIN DAILY WORKING LIFE		
INSTRUMENTAL	DEVELOPMENTAL	INSTRUMENTAL AND DEVELOPMENTAL
newsletters, circulars in-house newspapers	visits to Chief Office - brought in people app. 5 at a time - to look at International products/systems	visits to clients, clients visiting office, telephone contact with clients
conditions of employment, benefits, ,	social contact i.e. occasional office parties, outings, lunch	sending out questionnaires to clients feedback from : research about company and image, from client questionnaires, from staff visits
notification of changes in employee benefits	questionnaire to own office colleagues on level of service being provided	visits to Chief Office, Regional Office, Technology project, business centres
health and safety material	attending conferences	visits from Chief Office, Regional Manager, Technology Project Team, Service Excellence Team
audio tapes, video material	monitoring own performance	internal and external training
letter or telephone contact with Chief Office	open plan office encourages teamwork - multi-floor acts as barrier	meetings with manager - varies with size of office, rarely for junior staff in larger offices
telephone contact with Chief Office, regional manager	personal contact with people in other offices through own networking, almost no formal contact	investment manager meetings, including people from investment unit - regional 2-3 times a year - not common to all regions

THE MODEL IN LEARNING TERMS

The relationship between knowledge transfer between individuals into groups and between groups and then into whole organisations may be expressed as two interlinked systems, in the manner of double loop learning (Argyris, 1977) see Fig. 1. The learning process identified forms a loop transferring the knowledge of the individual into the group. The assimilation and adoption of this new knowledge move the knowledge into the wider environment and thus into the loop of organisational learning. The role of assimilation is slightly different within the individual loops. Assimilation in the individual and group learning cycle refers to assimilation of knowledge from an external source which may then be applied within the company. Assimilation in the wider cycle relates to the assimilation into the core routines of the organisation and is evidenced by a behaviour change within the organisation.

The model as illustrated in Fig.1. is an amalgamation, it illustrates a first step in linking together two pieces of research which each contribute significantly to our understanding of the processes of knowledge transfer in organisations. Yet it is clear that there are considerable difficulties in translating the two into a whole. There are, indeed a number of initial issues associated with first exploring the model, for each term used describes a complex process in its own right with all its underlying assumptions and definitions. The primary difficulty occurs where the sub-systems, that of the individual or group and the organisational meet. The problem is not that it is difficult to see where they link together but rather that the processes within each system, whilst still described with the same terminology and indeed identifying the same process are in fact somewhat different within each level of the hierarchy. Thus the understanding of the processes linking the two is unclear.

The differences experienced in linking the different levels provide a practical consequence of the emergent properties of systems. To explore this further, it is possible, to redraw Fig.1 in rather less complex form (see Fig.5), this illustrates very simply the relationship between the knowledge transfer processes at different hierarchical levels using a number of control loops. Whilst this illustration shows very clearly that the transfer of knowledge through the hierarchy shows that the experience of the process of assimilation at one level is a necessary precondition for acquisition at the next level. What it totally fails to do is to identify that the characteristics and outputs of the processes at different levels are quite different because of the effect of the emergent properties of each system on the linked system. We cannot begin to understand knowledge dynamics in organisations nor the way knowledge is transferred between hierarchies without understanding the effect of emergence.

Emergence

The concept of emergence[2], whether looking at emergent systems or emergent properties is important simply because we cannot ignore the unexpected and the unpredictable if we are ever to attempt to manage our future. We must be aware of the potential for unpredictability.

Checkland identifies "emergence" as one of the fundamental ideas of systems thinking:

"It is the concept of organised complexity which became the subject matter of the new discipline 'systems'; and the general model of organised complexity is that there exists a hierarchy of levels of organisations, each more complex than the one below, a level being characterised by emergent properties which do not exist at the lower level" (Checkland, 1981).

2 See Hadfield, 1996 for theoretical review of concept of emergence

Morgan, 1933 suggests that each level of the hierarchy may be considered to be playing the same game but within each level a new set of rules comes into play which cannot be predicted from the games that went before. This approach is explored by Allen (1995) who suggests that identifying components of a system and their interactions thereby identifying causal relationships may only be predictive if the structure of the system stays the same. Fig.5 may be viewed as depicting a system with three identified sub-systems however the behaviour of each subsystem whilst appearing initially to be the same may be quite different and cannot be predicted by the behaviour of the other sub-systems.

VALUE OF CONCEPTUAL MODELS TO THE END-USER

There is an identified need to bring closer together the infrastructure of knowledge and links between researchers and users[3]. It is vital to convert the knowledge within conceptual models into something useful on behalf of end-users. The questions 'what does this mean for my company' or 'how do I use this for competitive advantage' are justifiably asked by managers. It must not be assumed that managers automatically recognise the value of such models and the impact of changes inside and outside their environment on their organisation. Management is about intervention and this understanding may be used to plan how and where intervention is needed to make the most effective use of knowledge in the organisation. The value of the conceptual model described is that it is an empirical model, rooted in reality, based on field research and validated by the managers who took part in the study. Current and continuing research within IERC at Cranfield University is exploring the use of this model and others as management tools.

Response of Managers

The most effective use of the model so far has been to use it as a framework for exploring the complex interactive processes that enable knowledge transfer to occur. The use of a this model which explores organisational processes in terms of learning and systems thinking is for most managers a novel approach which stimulates creativity. Following its development from the studies described the conceptual model has now been used with a number of groups of managers[4]. The work has been undertaken both individually and in groups with managers at different levels where the model has been used as a tool or framework for the individual to explore the way knowledge flows occur in their organisation and for their particular job function. The approach taken follows a number of stages in which individuals are exposed to the idea of process models before meeting with the researcher. A semi-structured interview with the manager develops the discussion of process models and uses the conceptual model to track knowledge flows, analysed in terms of instrumental and developmental knowledge. A set of

[3] ESRC research programmes and Technology Foresight Initiative

[4] Participating groups have included RSA working groups, RAF and BT

maps are drawn from the interview and these are returned to the interviewees for discussion. One or more group meetings follow in which the participants discuss with their colleagues their own maps and develop group maps of knowledge flows within the organisation. The barriers to knowledge flow and knowledge management may then be identified and mechanisms for removing and improving knowledge management are developed within the group. This approach has raised a number of important issues :

1. Most managers are not used to seeing process models in this form.

2. Time is needed to assimilate the ideas and the use of a number of sessions, mixing groups and individuals are essential

3.

4. Managers find the distinctions that are made between developmental and instrumental knowledge to be a useful tool in analysing knowledge.

5. Use of the model in this way has provided, as a by-product of this exploration, considerable, if not comprehensive understanding of the organization in the area under study.

Perhaps the most important result of the studies so far is that the model has proved to be a useful framework for exploration and a tool for creative thinking. It is clear that using a process model in this way requires developmental knowledge and managers may need time to acquire this knowledge. This simple conceptual framework encompasses within it a number of emergent systems. In order to be able to manage these systems managers must be aware of their existence. Seaton (1996) suggests that the whole system cannot itself be managed but that we must manage the component sub-systems which generate the outcomes. The management must, however, be undertaken at the level above which the emergent effect is observed. Tackling the problem at the level of emergence is tackling the symptoms but not the root cause which occurs as an output of the system above. Management is far from simple because emergence may, as identified above, not be predicted but may only be recognised with hindsight. Thus management of emergent systems may be defined as a continuous, flexible, creative learning process in itself based only on the consequences of attempts to manage the effects of the previous intervention.

One illustration of managing emergent properties faces managers when attempting to manage the behaviour and knowledge transfer of staff who are at a different hierarchical level to themselves. Unless there is recognition that they need to be managing a set of emergent properties generated by those whom they are managing which are different to those generated by themselves they will not only be less effective but considerable confusion may ensue. They must not only know what emergent properties they want to manage but must also be aware of the necessary attribute sets and decision spaces that give rise to the emergent properties in the level down.

Current and Future Research

Research is continuing within IERC at Cranfield University into the way in which this model, and other process models may be used to benefit management in organisations. A number of strands of research are being undertaken within industry and commerce using the model in different ways. Within BT, where research is being undertaken to develop a taxonomy of organisations based on their knowledge requirements in terms of the balance between instrumental and developmental knowledge. Within BT and other organisations, exploring the way in which the model may be used most effectively as a tool for managing knowledge. With DERA (Cordey-Hayes and Longhurst, 1996) using models as process tools to explore how to develop effective methods of technology transfer. In parallel with these studies is a developing research interest in understanding whether exposure to models of this type does enable an individual to be more able to cope with managing uncertainty within a climate of continuous change.

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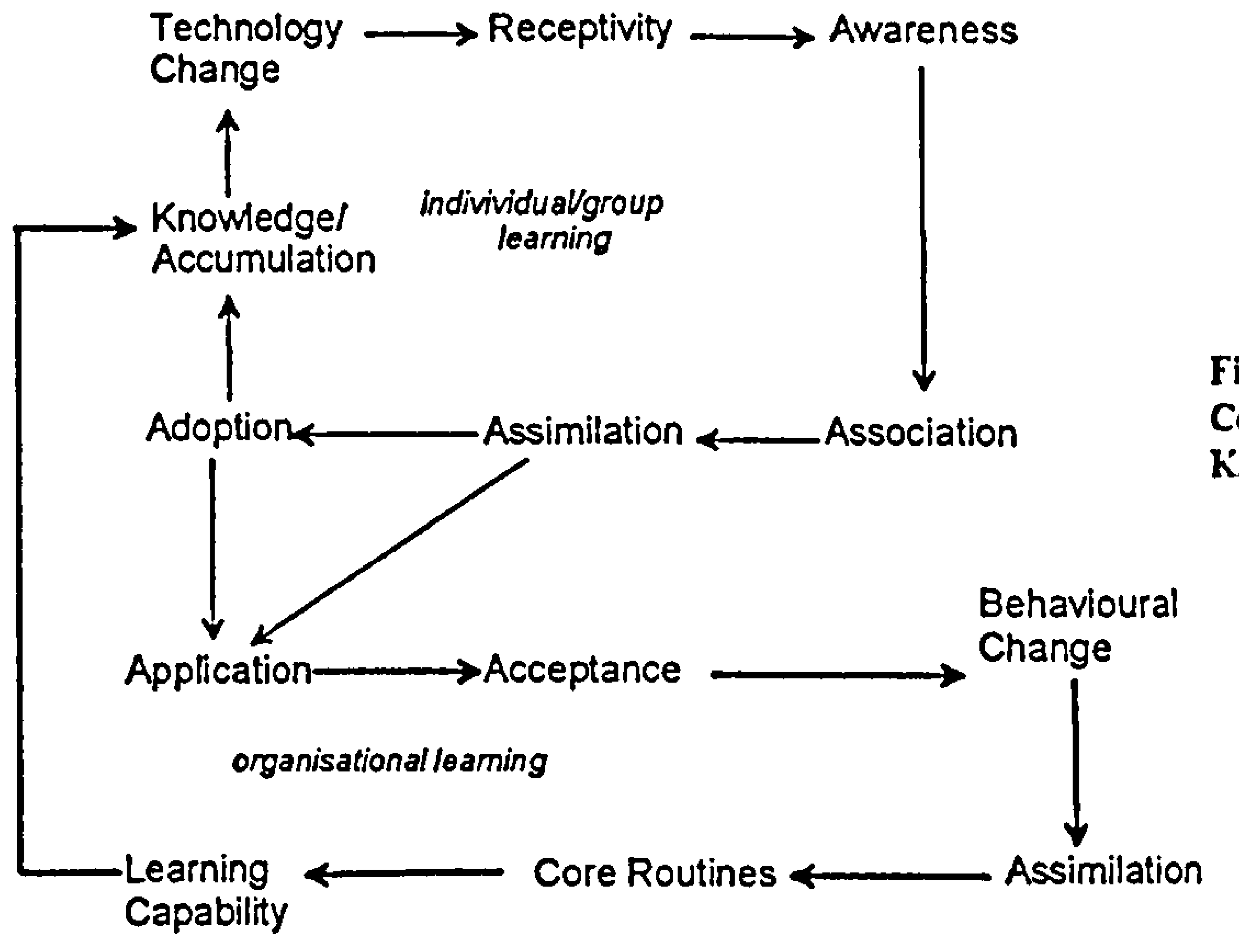

Fig.1
Conceptual Model - Knowledge Transfer

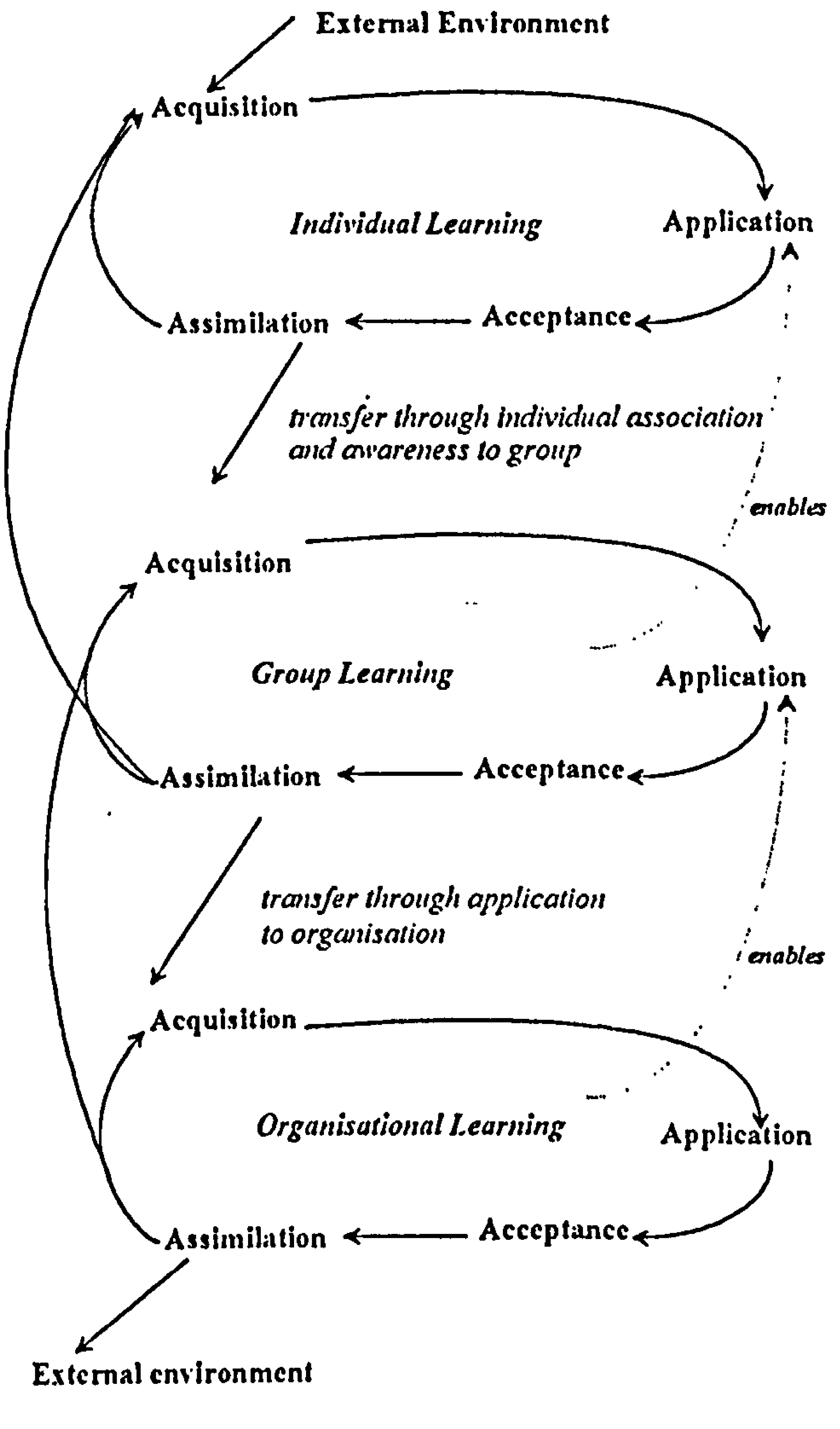

Fig 5 - Simplified Model to Illustrate Learning

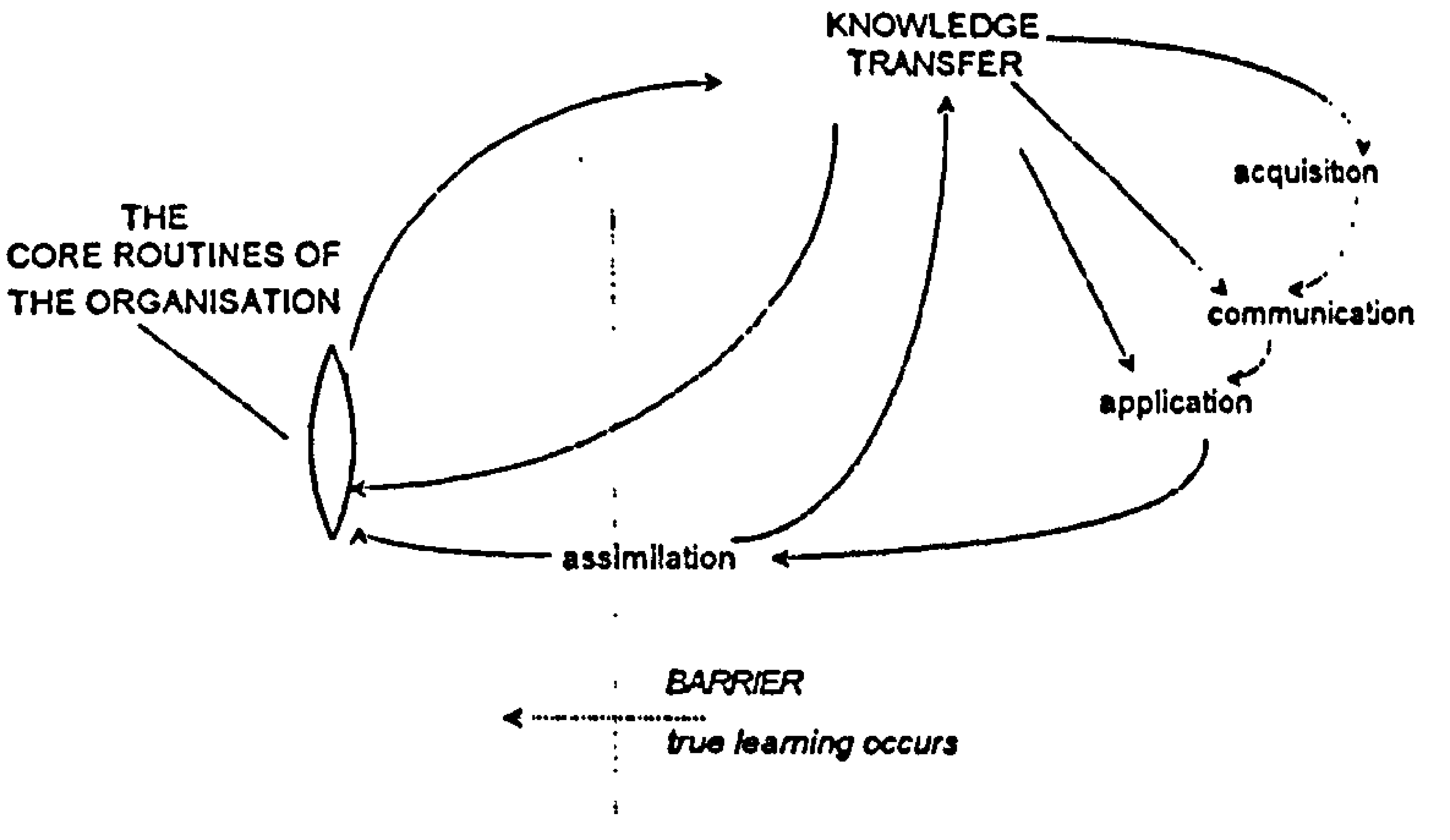

Fig.2 - Conceptual Framework for Knowledge Transfer

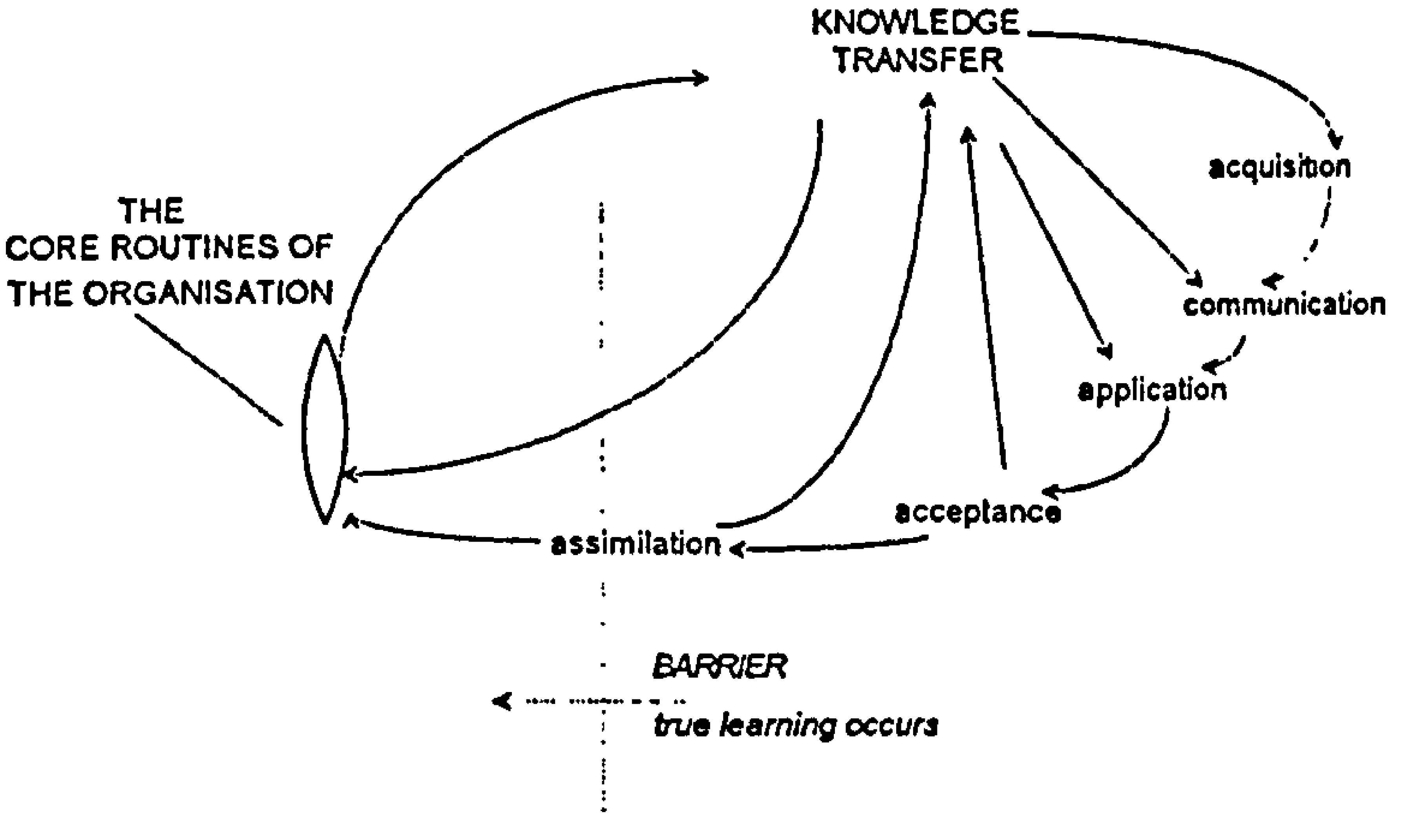

FIG. 3 THE FIVE STAGE MODEL

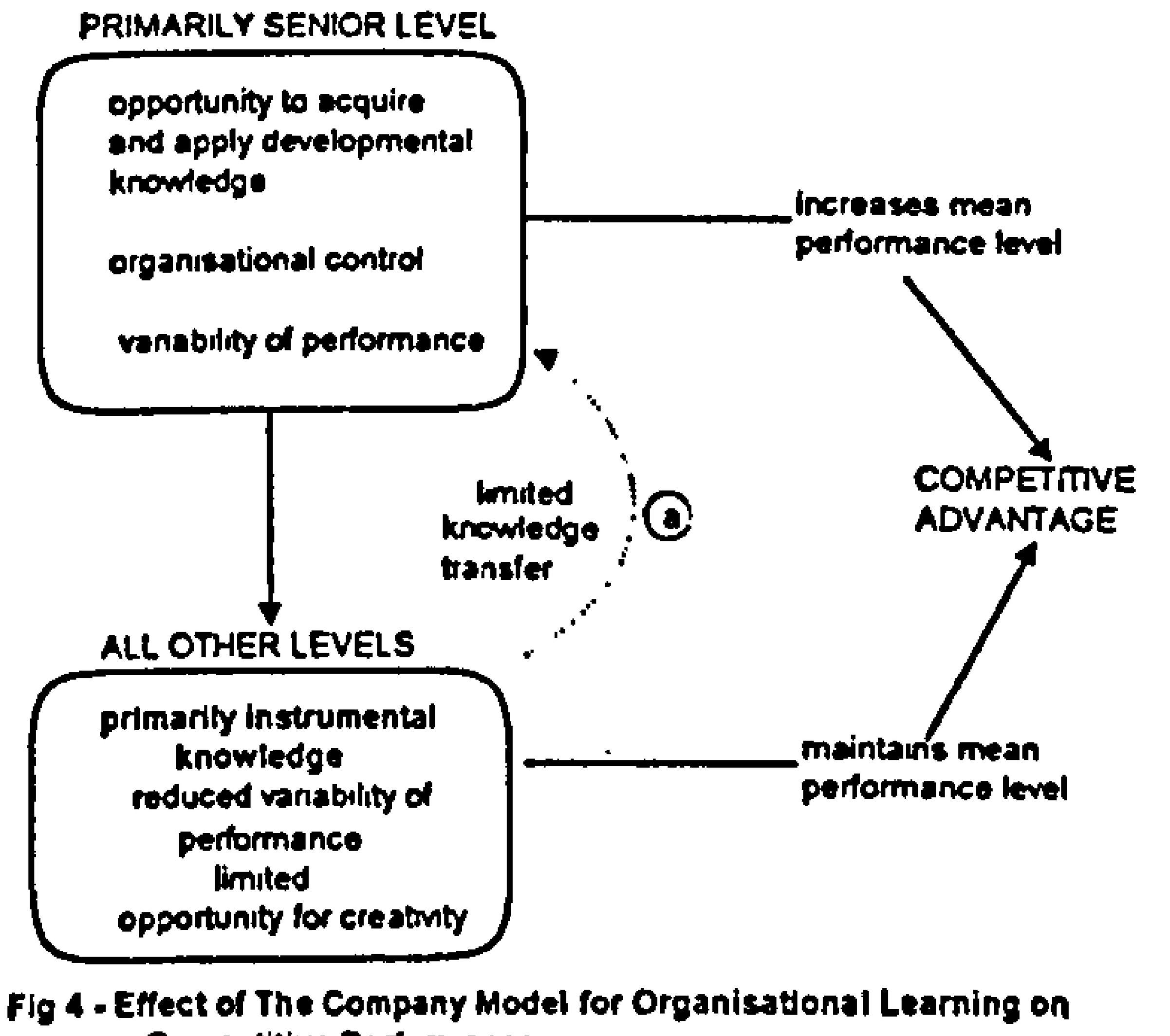

Fig 4 - Effect of The Company Model for Organisational Learning on Competitive Performance

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Integrative Research and Sustainable Agriculture

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ABSTRACT

Sustainability is a term which is increasingly being used by researchers, politicians and informed members of the public. However, criteria for carrying out research within a sustainable systems framework are either ill-defined or non-existent. As an aid to this process the concept of sustainable pathways and viability space are introduced and interpreted as the need to maintain adaptive capacity, and therefore options within production systems that interact with the natural environment.

A research approach is required which takes account of ecological, economic and social aspects of change and that is able to interpret and synthesise information, generated from a range of sources, in a manner which is policy relevant. This requires the construction of interfaces which link activities across a range of disciplines. A research project designed to assess the potential of alternative cropping systems is used to illustrate a series of interfaces. It is argued that demonstrating and developing the connections between the concept of sustainability and decision making processes provides an immediate challenge to those undertaking methodological research.

INTRODUCTION

Over the last 50 years the productivity of UK agriculture has increased considerably, with a drive towards self-sufficiency in many products

(Sturgess, 1992). Farmers have adapted and used a wide variety of technological innovations in agricultural production (O'Callaghan, 1992). However the economic and environmental cost of this success is increasingly being questioned by politicians, the public, researchers and the farmers themselves. As people have become more involved with the rural environment the farming community has received a considerable amount of publicity, much of this unfavourable. Farming has been under the economic spotlight with regard to the CAP (Common Agricultural Policy) reforms and the GATT (General Agreement on Tariffs and Trade) negotiations (Sturgess, 1991; Ackerill, 1992) Modern farming methods are blamed for destruction of the countryside (Shoard, 1980), pollution (Conway and Pretty, 1991) and the degradation of the soil itself (Pimentel *et al.*, 1987). The reliance of farming on fuels, fertilisers and chemicals all of which depend on non-renewable resources in their manufacture also raises concern (Pimentel, 1984).

In response, a wealth of research information exists concerning the possibilities for change, the options available and the likely effects of a range of land use practices and strategies. However, it is less clear how this information is of use to, or can be filtered into, decision-making processes. At a time when the term 'sustainability' provides a backcloth for a variety of agriculturally related research, and is a term found in many funding proposals, there appears to be a gap between this important concept and the notion of policy relevant research.

This paper argues the need for policy relevant research in the context of the debate surrounding the concept of sustainability. A discipline specific approach is not usually applicable to policy analysis and therefore may not be appropriate unless incorporated within a wider sustainable systems framework. It is suggested that the results of research need to be both relevant and accessible to the decision making process (at a policy level) if change within a system is to be encouraged to follow sustainable pathways. Sustainable pathways are described in terms of desirability and viability space which accounts for the need of change to be both economically beneficial in the short-term and ecologically sound over longer time periods. Progress along sustainable pathways requires an understanding of the vertical and horizontal integration between and within a variety of production systems that interact with the natural environment. The paper argues that this integration can be demonstrated via a series of interfaces which link the concept of sustainability to policy relevant research. A project designed to assess the possible uptake of silvoarable agroforestry in the UK is used to demonstrate a series of interfaces, via a variety of research activities in several disciplines. The paper concludes with the implications of this type of integrative design for both policy and research.

DECISION MAKING AND THE NEED FOR POLICY RELEVANT RESEARCH

The future is inherently uncertain, although our inability to predict the future does not release us of our responsibility for thinking about it (Spedding, 1991). Yet despite the desirability for explicit definition of objectives in land use decision making (Stomph *et al.*, 1994), agricultural policy appears to lack any long-term positive goals toward which the industry can develop. For instance, current policy encourages the cutting back of production and the setting aside of land. Constant change and uncertainty is forcing the farming community to follow the ebb and flow of political and economic debate rather than to fit in with the social and biophysical systems in which it operates. This has meant that farming systems have become determined by a narrow economic agenda in which many farms have become very specialised and highly capitalised units which are increasingly inflexible to change (Clunies-Ross & Hilyard, 1992).

There are three important issues which need to be addressed in agricultural research in order to provide a more effective contribution to this situation:

(1) The broadening and integrating of research so that more relevant information can be made available to the decision making process.
(2) The operationalisation and maintenance of flexibility and adaptability and identification of the types of policy that enable increased options in the future.
(3) The identification of longer-term attributes (as opposed to narrowly defined states), toward which it would be desirable for systems to evolve.

The provision of information for the decision making process requires methodologies for synthesising research and data from a range of disciplines. This paper offers an interpretation of how information can be synthesised. No attempt is made to suggest that there is a single method of carrying out research toward a sustainable systems framework. However, it is necessary to have a person or a team that are capable of conceptualising linkages and interfaces in addition to those who prefer to work within disciplinary specialisms. Bonnen (1986) comments on the lessons for science policy with respect to American agriculture. He is critical of many colleges that have become collections of independent disciplinary researchers who are unable or unwilling to address the problems of future agriculture effectively. He sees part of the role of social science research as providing an integrated focus upon the agenda of science and that of the problems in agriculture. This supports the arguments of Newby (1992) that social science is integral and not merely marginal in the understanding of how scientific excellence and technological innovation may lead to economic and social well-being.

Often when attempts are made to present scientific research (and thus the data and output from it) into a wider social, economic and cultural framework, the latter is seen as a 'bolt on' part of the research design rather than an integral part of it. Therefore the primary aim of a considerable amount of scientifically orientated research is not in the presentation of policy relevant information. Other agendas for this research, i.e. testing theories, etc, provide the main driving force, which means that even if results do have relevance to policy they are not necessarily presented or communicated in a useful manner.

The construction of research interfaces enables the presentation and interpretation of information derived from scientific or fieldwork at various decision making levels. The integrative research approach adopted in this paper demonstrates linkages between several disciplines, referred to as horizontal integration, and provides vertical integration between science and policy. The disciplines that form the basis for this integrated research approach are only one combination which demonstrate a methodology for linking the concept of sustainability to the need for policy relevant information. Lockeretz (1991) provides an overview of the use of multidisciplinary research in sustainable agriculture, and states that, 'an overly narrow range of disciplines is easier to change than an overly narrow scientific imagination.' This suggests that it is the ability to conceptualise and synthesise new viewpoints that is as important, if not more so, than the range or mix of disciplines that are associated with a research project. The disciplines with which the research described in this paper is associated have not been chosen because they are seen as necessary for research toward a sustainable systems framework, but because their integration was thought to enable the demonstration of the interfaces discussed earlier. Larger research projects are exploring similar approaches. For instance, the EC Archaeomedes Desertification research project concerns the threat to the sustainability of fragile ecosystems, integrating research on the biophysical aspects of sustainability, farmers perceptions of change and the relevance of this information to the decision making process at a policy level.

RESEARCH AND THE SUSTAINABILITY DEBATE

Sustainability is a complex concept which is generally seen as human centred, long-term and involving interaction with natural systems. Whereas it can be argued that all production systems are associated with natural systems to some degree, this paper focuses on land based production because of the irrefutable importance of food as a basic necessity. Many previous attempts have been made to define sustainability in the context of global issues (Brown *et al.*, 1987; Liverman *et al.*, 1988), although O'Riordan (1985) warns of the dangers, describing its definition as 'an exploration into a tangled conceptual jungle where watchful eyes lurk at every bend'.

However, despite the ambiguity associated with the definition there appears to be global consensus about the need for human actions to be sustainable, (Earth Summit, 1992; Bruntland Commission, 1987). Despite, or perhaps because of its ambiguity, the concept has been the subject of considerable research and debate. The conceptual foundation on which many definitions of sustainability are based differ considerably, often dependent upon the underlying conceptual models derived from traditions of relevant disciplines. Murdoch (1993) suggests that at a conceptual level sustainability clearly poses a challenge to the maintenance of traditional disciplinary boundaries both within social science and also between social and natural sciences.

In the agricultural context, since the adoption of a sedentary lifestyle some 10,000 years ago (Conway, 1987), human intervention has changed the evolutionary patterns of ecosystems, and continues to do so. The sustainability of agriculture is inexorably linked with this process of change and is closely associated with the dynamics of ecological and socio-economic change. Harwood (1990) takes account of this continuous change, defining sustainable agriculture as a system that can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment which is favourable to humans and most other species. Human utility in itself is a very subjective concept based on the systems and surroundings in which we live today. In reality, although quite accurate speculation may be undertaken with regard to what humans may find useful in a single year's time, these predictions can be extremely inaccurate over longer time periods. There is concern that the farming methods used today are having a negative impact on our ability to farm and produce food in the future, reducing the options available for following generations to utilise the land for productive purposes. This does not necessarily mean that they will not be able to produce food at any given point in time, only that their options for selecting different futures at a given instant may be reduced. Thus, the adaptability of farming systems is being diminished. Sustainability in this context can be viewed as a maintenance of the adaptive capacity of farming systems. This adaptability is alluded to by Pearce *et al.* (1990) who suggest that sustainable development within a given vector should allow development characteristics, which are open to ethical debate, to be non-decreasing overtime.

If agriculture is the vector in their definition and the development characteristics are the options available in the future then this reflection on sustainable agricultural development may seem to be a useful progression. However, development to many implies growth, which in western society infers economic growth. Daly and Cobb (1989) highlight the important difference between growth and development, as continued economic growth on a finite world resource base is unlikely to be sustainable. This links with the debate which suggests that change must be economically viable if it is to be successful. However, agricultural change can be economically viable in the short-term but non-viable over longer periods of time because it impinges on the ecological or natural functioning of the agroecosystem. Giampietro *et al.* (1992) note that production systems optimised through economic indicators ignore the fact that human managed systems may be degrading environmental resources, i.e. by consuming non-renewable resources and reducing the capacity of some parts of the natural systems to renew or recycle. Economic assessment of new technology should not be ignored, but used in combination with information indicative of the longer-term effects of change. This is recognised by Adams *et al.* (1992) who highlight the need for linkages between economic and ecological indicators of change in land use. In this sense increasingly sustainable land based production may be achieved by the identification and discouragement of innovations which are economically viable in the short-term but lead to the decreasing sustainability of agriculture in the long-term. However this process is often complicated by the indirect effect of some actions. For instance, in some cases, the increased use of heavier and more powerful machinery in the US has led to the removal of shelter belts, hedges and has reduced contour planting. These changes have increased soil erosion (OTA, 1982), which is likely to compromise and increase the economic cost of food production in the future (Pimentel *et al.*, 1987).

Whether or not change is deemed to be increasing the degree of sustainability will depend on the current state of the system, reducing considerably the generalisations that can be made from one site/region to another and complicating decision making processes.

Decision making is complicated further because the results of research in a variety of disciplines cannot be easily interpreted at the decision making level, and therefore cannot sufficiently inform the change process. Thus, although the introduction of the term 'sustainable' into planning is not new, disciplinary research has emphasised convenient end states rather than processes. For instance, within the fishing industry the notion of maximum sustainable yields have been pursued for several decades, yet experience has shown that the diverse issues surrounding the managing of a resource industry, which is embedded in a number of economic and social strata, is a complex problem requiring enquiry in many disciplines (Allen & McGlade, 1987).

Similarly the Forestry Industry has utilised the concept of maximum sustainable yield to control the over-exploitation of timber reserves. Unfortunately, the incomplete knowledge on which these estimates are based makes the adoption of such guide-lines extremely risky. Even when recommendations are made, little thought is given to the processes associated with controlled implementation. For Sarawak in Malaysia the International Timber Trade Organisation (ITTO) estimated a sustainable yield of 9·2 million cubic metres for forest extraction. Estimates of extraction by legal operations were estimated to be 18 million cubic metres in 1991, with a further 7 million cubic metres being removed illegally. Similarly in the forests of New Brunswick the logging industry first selectively harvested the largest pine and spruce trees, but as the rate of harvest far exceeded the pace of natural replacement so smaller trees were harvested. Technological development allowed the harvesting of even smaller trees accommodating the change in the qualitative nature of the resource. Although the industry was sustained for over 200 years it was eventually lost (Regier & Baskerville, 1986), suggesting that concepts such as sustainable yields are dynamic with respect to economic, social and ecological conditions. These examples raise two fundamental questions for research relating to sustainability:

(1) How can research be undertaken which assists the planning of desirable and viable futures?
(2) How can research be made more relevant and accessible to policy formulation and implementation?

SUSTAINABLE PATHWAYS: DESIRABLE AND VIABLE FUTURES

The concept of sustainability is driving an emergent philosophy in which there is an awareness today of the needs of future generations. This inevitably means that planning within a sustainable systems framework requires some estimation of the needs of future generations. However, there are clearly dangers in predicting the future and then planning for it (Ackoff, 1983), as those systems which are seen as sustainable today may be undesirable a decade into the future. This suggests that the capacity and ability to respond to continually changing 'desirable goals' may be more important than aiming for set end states at a particular moment in time. In the words of Fresco and Kroonenburg (1992), '...in order to be sustainable, land use must display a dynamic response to changing ecological and socio-economic conditions.'

Future planning may therefore need to change qualitatively from attempts to achieve measurable end states toward goals that reflect the attributes and abilities of technological and natural/human activities. In this situation the maintenance of an adaptive capacity within a production system becomes important. For instance, in terms of an agricultural system this may mean that soil erosion will reduce the options available for food production at some point in the future. However, the human action that causes soil erosion in one area may actually be beneficial in another. For example, soil removed in erosion processes may denude upland areas but improve soils on lowland flood plains. Similarly, the adoption of spring instead of winter cropping may have benefits in terms of reduced machinery requirements due to weathering on some soils, whereas on other soils the maintenance of a bare surface over the winter period can lead to water and wind erosion. This example suggests the need to exercise caution before attempts are made to categorise one method of production as more sustainable than another. However, an assessment framework can be envisaged that draws on the concept of sustainability so long as criteria can be put in place to assess possible short- and long-term repercussions of change. On the basis of these criteria and knowledge of the current situation, questions need asking about the effects of a given change in land use on the options available for food production in the future, and whether this change is following broadly desirable dynamic pathways.

These dynamic pathways should maintain, and hopefully increase, the adaptability within a given production system, maintaining a direction which can fulfil both short-term needs, i.e. be viable, and long-term objectives, i.e. be sustainable. Figure 1 introduces the concept of sustainable pathways and viability space associated with farming systems.

To develop along sustainable pathways, changes in land based production need to be assessed and monitored to provide policy makers with information upon which to base their decisions. This requires research approaches which vertically integrate both physical and natural systems investigation with social and economic enquiry which identify:

(1) the nature of sustainable pathways;
(2) mechanisms which may be used to encourage change along these pathways.

In effect from the policy perspective this can be seen as a requirement to map viability and sustainability space onto each other. Viability space can

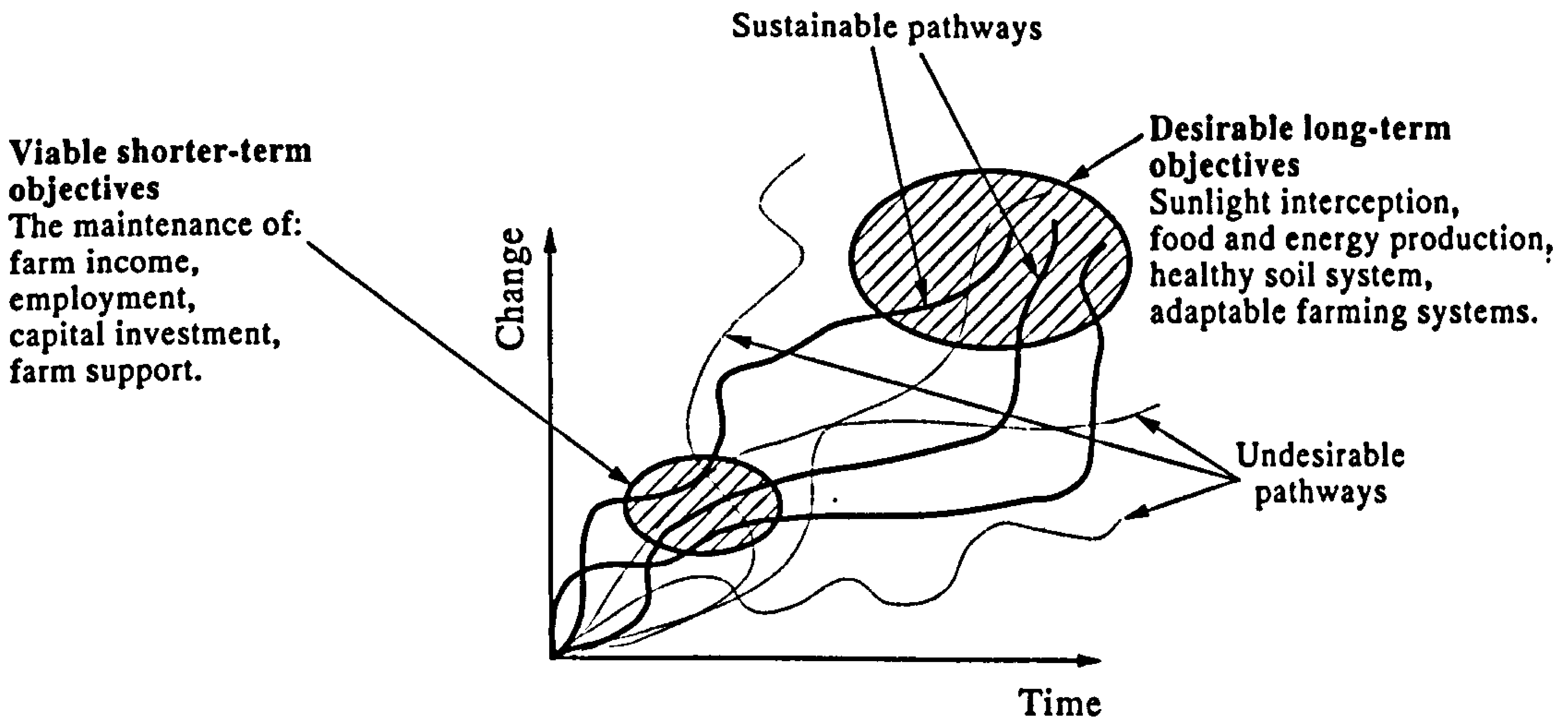

Fig. 1. Sustainable pathways and viability space.

be viewed as a much more malleable entity which can be manipulated via policy and through economic levers. Sustainability space, although being responsive to policy, has a robust core based upon biogeophysical processes which are inherently long-term and often outside the control (at least in the short-term) of human activity. The aim of policy with respect to the concept of sustainability is to ensure that a system develops along pathways which are within both the viability and sustainability space of that system.

However, the interconnectivity between production systems makes the identification of sustainable pathways more difficult. For example, agricultural and potable water systems are intrinsically linked, yet one system can interact adversely with the other. This suggests that research towards a sustainable systems framework necessarily recognises both vertical and horizontal systems interactions, see Fig. 2.

AN INTEGRATIVE APPROACH: THE NEED FOR POLICY RELEVANT RESEARCH

Budyko (1986) considers that the ever increasing volume of information in every field of science promotes specialisation within specific branches of science. This limits the possibility of developing a synthesis of data from many lines of research. The term 'multidisciplinary' is often a bedfellow in discussions involving sustainable agriculture (Gliessman, 1987; Macrae *et al.*, 1990). Lockeretz (1991) focuses on multidisciplinary research and sustainable agriculture, analysing the degree to which component disciplines interact. He describes several different types of multidisciplinary

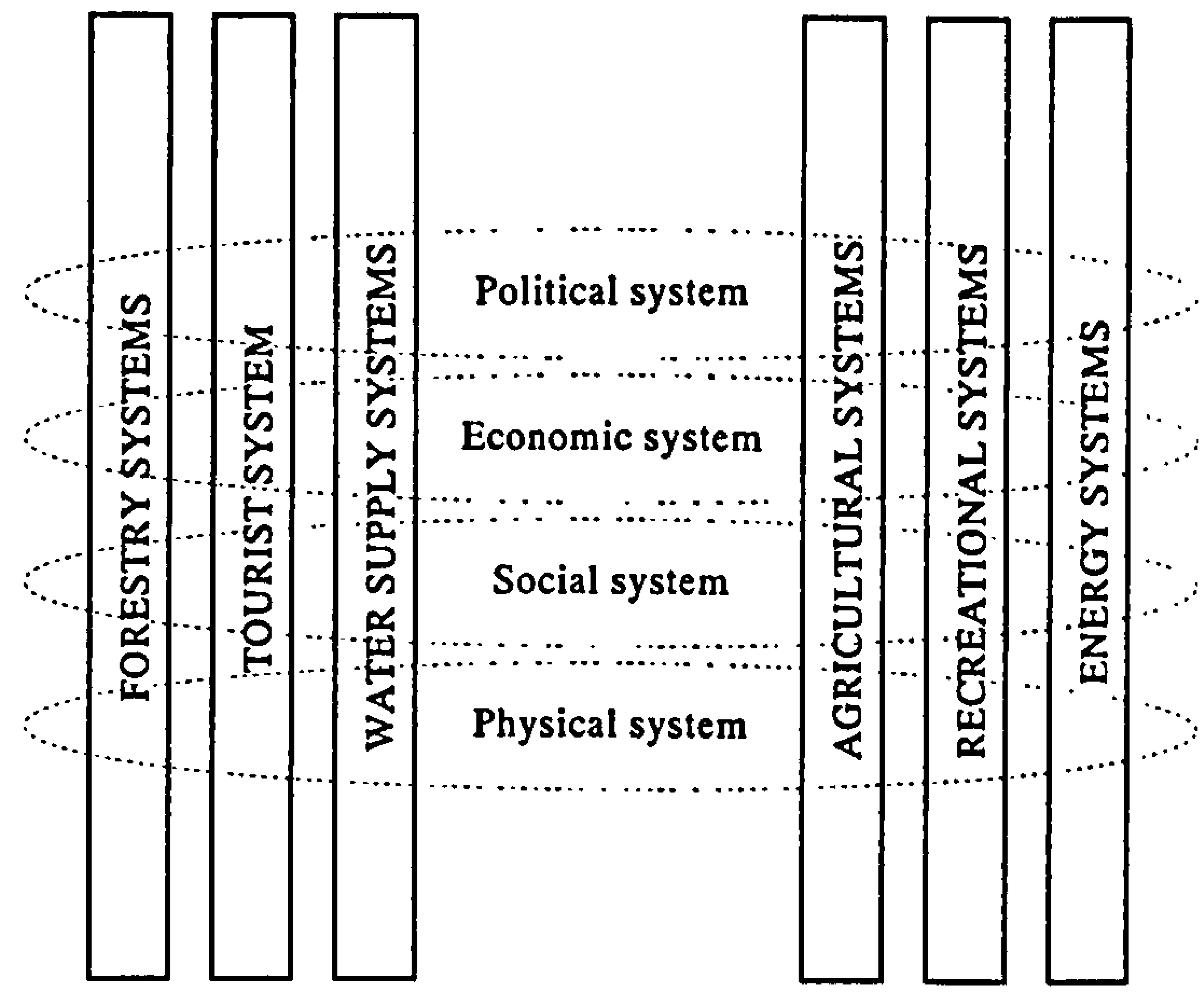

Fig. 2. Vertical and horizontal systems integration.

research, defining an integrative approach as one which divides the topic into disciplinary components, but gives special attention to the linkages among them and to the questions that either overlap or fall between different disciplinary domains.

This can be achieved by either a team of people from several disciplines or individuals who have the ability to communicate, visualise links and to step outside their own discipline. Research towards a sustainable systems framework requires these links to be made between scientific and socio-economic theory, and for information to be presented in a manner which is accessible to the policy formulation and decision making process. Figure 3 provides a diagrammatic representation of an integrative research approach which was used to question whether the introduction of an alternative cropping system. i.e. silvoarable agroforestry, would lead to development along sustainable pathways.

Such an approach inevitably raises questions about the way in which research should be designed so that information from both the physical/natural systems and the social, economic and cultural systems can be combined. Research frameworks need to demonstrate the connections between a variety of investigative activities and policy. In terms of decision making these connections can be as important as the research activities themselves. A variety of research activities can be mapped onto this framework, although it is the manner in which these are integrated and interpreted that determines their relevance to policy making. This integration is achieved via a series of interfaces that link the concept of sustainability to information relevant to policy.

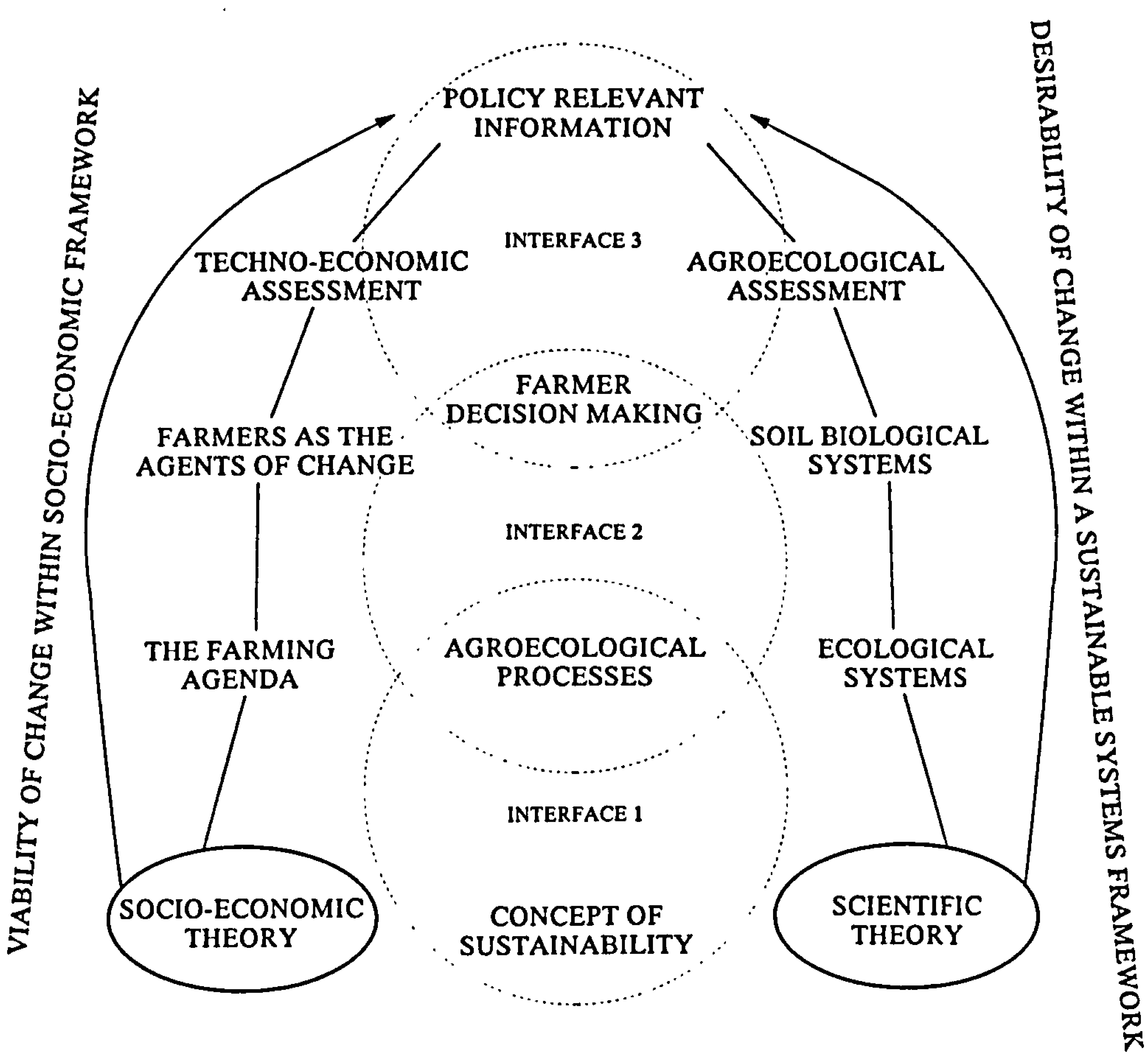

Fig. 3. An example of a integrated research approach.

Interface I: The interpretation of the concept of sustainability at an ecological level

In production systems that interact with the natural environment there is usually considerable scope for human intervention in ecological processes. For instance, agriculture can significantly effect decomposition processes in the soil, and the water industry can impact on eutrophication of lakes, water courses, rivers and seas.

A primary task for research within a sustainable systems framework is to identify key variables which are relevant and measurable in time and space. A shortfall in some research is that methods suggested for monitoring are either too expensive to undertake widely, and often do not link to fundamental ecological processes or are not easy to interpret. Additionally, research 'cycles' and funding seldom equate with political and decision-making time scales. Thus, if research is to be relevant to policy making processes there is a place for more responsive (and consequently cruder) methods to be undertaken in conjunction with more traditional scientific investigation. Figure 4 provides an example of how relatively crude data can be used to supply information on the vulnerability of soils to depletion of soil carbon.

Soil carbon, in the form of organic matter, is an important component of soil and agroecosystem processes. It influences the water holding properties, the cation exchange capacity and nutrient supply within the soil (Johnson, 1986). It can also act as a binding agent thus influencing erosion processes (Pimentel *et al.*, 1987). The map was generated from point measurements of soil carbon, acidity, temperature, soil moisture

O Areas of high soil carbon vulnerability, (i.e.low levels of existing soil carbon and potential for high turnover rates.)

Fig. 4. Carbon vulnerability map generated from the LandIS database.

deficit and altitude, each pixel representing 5 km^2. Data were supplied from the LandIS data base (Avery, 1987). The map indicates areas of both low soil carbon levels and those with potentially high carbon turnover rates. As the maintenance of soil organic matter is of importance to long-term soil productivity (Pimentel *et al.*, 1987; Agren & Bosatta, 1987), this type of mapping technique can provide one tool for informing the decision making process by facilitating the monitoring of wide geographic areas through time. This may help to target further research or action in specific areas. For instance it may be beneficial to target research on alternative farming systems in areas of high soil carbon vulnerability.

Interface II: The linking of ecological processes to the attitudes and behaviours of the agents of change

Having identified important variables associated with a production system it is necessary to recognise key agents of change and how their activities can influence these variables. Some ecological variables change relatively slowly with time, this being at odds with the nature of research funding. In terms of ecological variables the use of models has meant that results of experiments can be extrapolated to either predict likely effects of change or to explore ranges of scenarios. Such models can provide useful information for the decision making process. However, as the sophistication of these tools increases, the mechanisms they represent become inaccessible to decision makers. There is also a danger that quantitative models are used exclusively as output from research when, in effect, they may not be the most appropriate form of output, or could be better exploited as one of a suite of tools used to provide policy relevant information. Figure 5 illustrates output from a simple model which explores the movement and decomposition of organic matter in UK arable soils under a range of farming activities (Park, 1993).

The model output suggests that in UK soils that contain approximately 3% organic matter continuous cereal cropping, with the removal of straw will gradually deplete organic matter levels further. In contrast, a rotation (winter wheat, winter wheat, winter barley, oilseed rape, 4 year grass ley) involving increased return of plant debris to the soil, and a period of perennial cropping can maintain and possibly increase soil organic levels. This effect has been demonstrated experimentally and via modelling (Cooke 1967; Allison, 1973; van Veen & Paul, 1981). However if the effects of a more innovative cropping practice were to be explored using the model, it may take a considerable time period to substantiate the output experimentally.

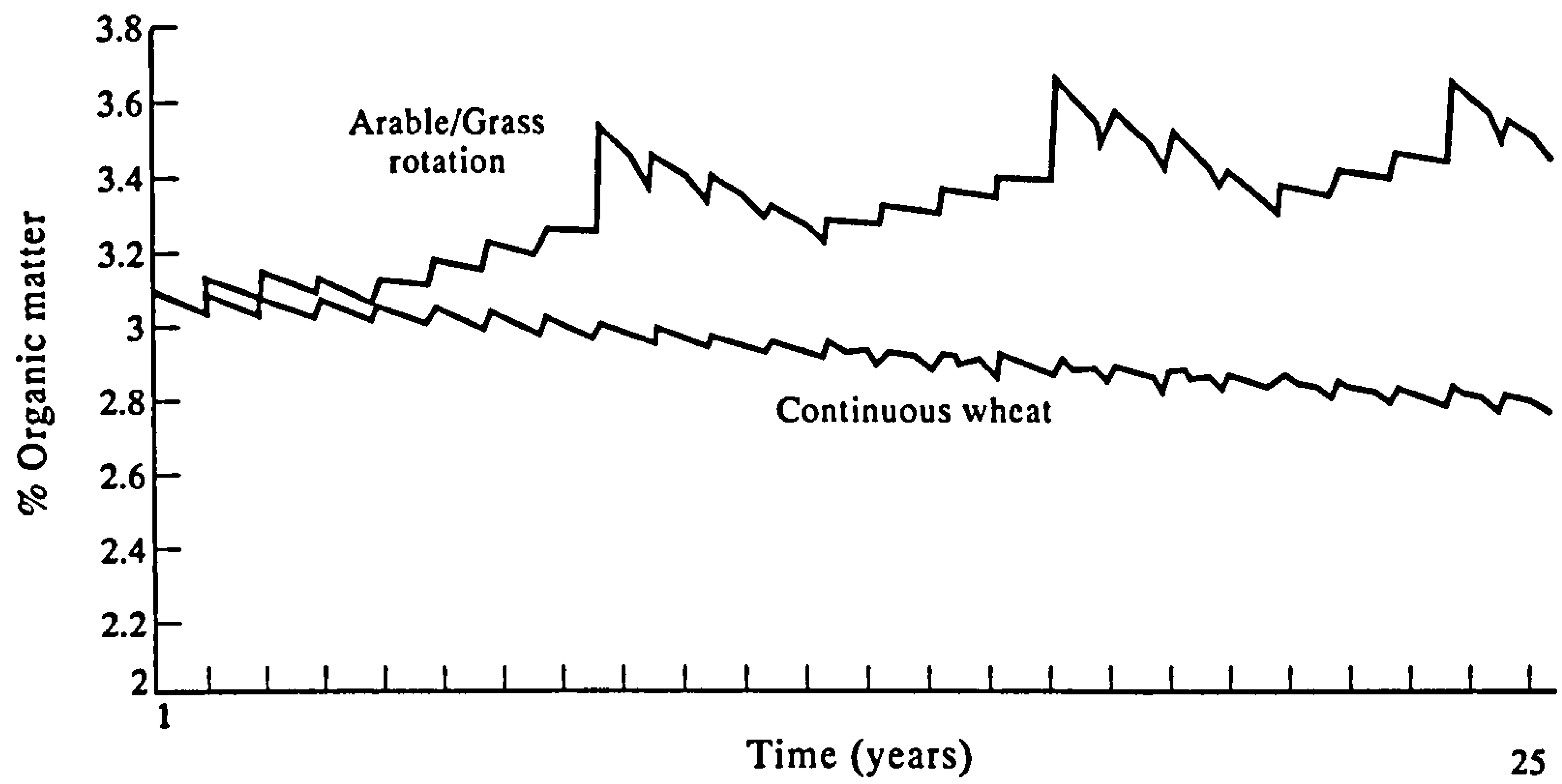

Fig. 5. Model output demonstrating the effect on soil organic matter of the inclusion of a perennial crop in an arable rotation.

In situations involving slower ecological processes it may be necessary to identify suitable proxy measures or indicators of change which can be used in combination with model output to provide quicker, more reliable feedback. For instance there is considerable interest in the use of bioindicators to monitor soils and wider ecological change (Holloway & Stork, 1991; Paoletti *et al.*, 1991). To explore the use of the mass of soil invertebrates as a simple proxy measure of agroecosystem health the Broadbalk Winter Wheat plots at Rothamsted were sampled in 1992 (AFRC, 1991; Park, 1993). Figure 6 illustrates the cumulative bodymass of the phylum arthropoda in the soil under a variety of land use practices on these plots. Four fertilisation treatments under a continuous wheat regime and the wilderness area were sampled for invertebrate populations, individual size and bodymass. Soil animals can act as a sensitive indicator of the states of soils and the impacts of environmental changes (Hole, 1981). Further in energetic terms it is the bodymass per square metre and the mass at a given size which are important measures of function (Cousins, 1995).

The differences in Fig. 6 suggest that these types of indicators may provide a proxy measure to evaluate the effects of changes in cropping practice over short periods of time. However within a sustainable systems framework there is a need for these types of measurement to be relevant to the decision making process, and not for research to be side tracked into proving obscure ecological hypothesis. The desirable characteristics of such measurements are simplicity, replicability, financial and physical feasibility and broad applicability as well as being relatively understandable by the non-scientist.

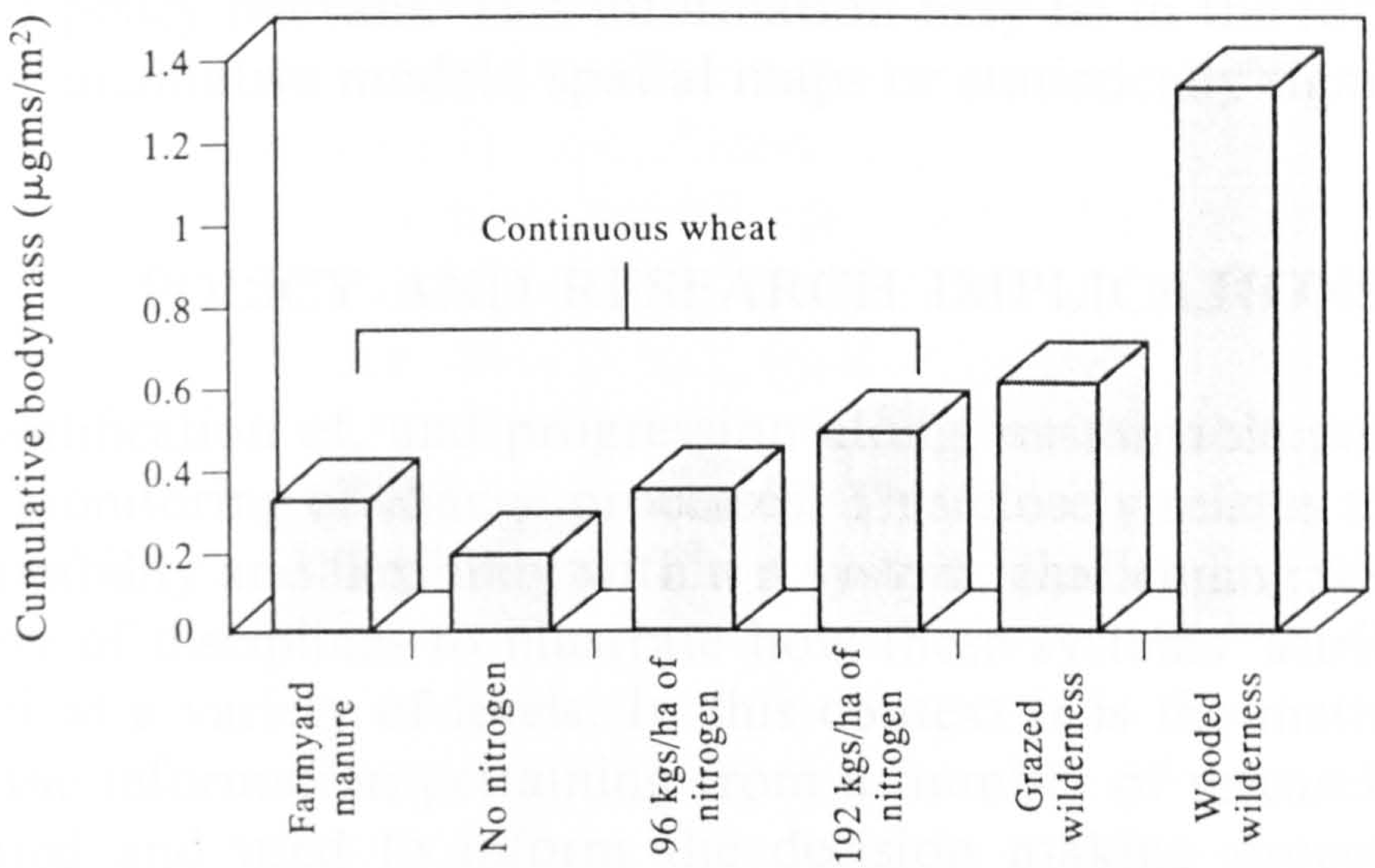

Fig. 6. Cumulative bodymass of arthropoda on soils under different land use practices on the Broadbalk plots, Rothamsted.

Interface III: Linking actions and perceptions of the agents of change to policy issues

Exploring the effects on ecological processes by the actions of agents of change is of limited value unless an understanding can be gained of how these agents of change respond to a variety of policy instruments and mechanisms. A considerable amount of policy research assumes that if a change can be shown to be profitable or financially viable, then it will take place. Using the introduction of tree–crop mixtures as an example, agroforestry systems have been shown to be highly productive and economically viable (Newman *et al.*, 1991; Thomas *et al.*, 1992) and to have benefits with respect to soil biological properties (Park *et al.*, 1994). However, discussions with farmers suggest that the potential uptake of these systems would be very limited without significant changes in agricultural policy.

The farming agenda is known to be complex (Lemon & Park, 1993), suggesting that more research is required which can evaluate the interconnectivity between system components. This questions the justification for devoting more attention to one component of a complex process before it can be said confidently how strongly the components are linked (Lockeretz, 1990). This has implications for the methods used to gather information about the possible effects of policy and how this can be interpreted and presented. In this context qualitative maps and models (Madu & Jacobs, 1991), may be as useful as statistically significant data generated from structured questionnaires. As with the interfaces discussed earlier the emphasis must be on the presentation of a range of information in a manner which is policy relevant. This information may be in the form of quantitative or qualitative models, spatial maps or statistically significant data.

POLICY AND RESEARCH IMPLICATIONS

The identification of, and progression along, sustainable pathways relies on the monitoring of change processes. This closely relates to the notions of adaptability and flexibility within a system, challenging research across a variety of disciplines to illustrate how these systems' attributes can be assessed at a variety of levels. In this context it is the methods through which the information pertaining from a number of research activities is integrated and used to inform the decision making process that is of importance. However, the overall picture produced from this approach may actually complicate the decision making process.

For instance, the experimental work and theoretical analysis of silvoarable agroforestry suggested that it could increase the ecological diversity and maintain options into the future with respect to soil productivity and energy interception. However, at an operational level the farmers themselves thought these systems could actually reduce flexibility because of the longer-term production cycles associated with trees, making it difficult for them to adapt sufficiently rapidly to an ever changing policy environment. This scepticism was not voiced simply because the farmers thought planning over the long-term was inherently wrong, only that the current policy regime, based on short-term economic criteria and a very volatile support framework, made any long-term commitment extremely risky.

Thus, it could be argued that current agricultural policy is actually at odds with a sustainable system philosophy. Of equal concern is the increasing degree of specialisation that current policy is engendering as the industry strives to minimise fixed costs. This not only means that the general infrastructure of farms becomes less accommodating of change, but suggests that the knowledge base of individual farmers is becoming more specialised.

In the context of agricultural sustainability this raises questions about the hierarchical level at which adaptability needs to be maintained, i.e. soil, field, farm, nation, etc. It is unlikely that adaptability at the level of agroecosystem processes can be maintained unless the farmers themselves have the ability to demonstrate adaptive behaviour. This, in itself, is governed to a large degree by the policy framework in which they operate and raises questions about how policy mechanisms can allow for or encourage adaptive behaviour within farming systems.

Within the agricultural industry many of the aims of current policy appear contradictory and confusing not only to farmers but for those involved in the development of the industry, i.e. researchers and decision makers. This has led to debates elsewhere about the need for long-term objectives or strategies to be set. These objectives could form part of a wider national land use strategy (Green, 1993). Unfortunately, this is in contrast to the current political philosophy, but he argues that because of the likelihood that agriculture will need continued support, the need to equate ecological and environmental management with economic efficiency may conspire to favour such objectives.

If such objectives are to be set these should be based upon desirable attributes and not desired states. These attributes should be related to long-term resource efficiency, particularly the rates of use of non-renewable resources, and not purely related to economic efficiency. However, research initially needs reorienting from an approach which assumes what a desirable pathway is and concentrates research around it, to a research approach which identifies what the possible pathways are. These pathways are linked to a desire to maintain options into the future so that a given system can remain responsive to change.

It could be argued that before large research projects are initiated there is a need for smaller exploratory projects to investigate both the physical and social systems to identify attributes associated with desirable pathways and to isolate mechanisms for recording and monitoring these attributes. This will target the main research and allow the collection and interpretation of data which can be used effectively to inform the decision making process. Further research work could be usefully undertaken to explore the handling, interpretation and presentation of data from a range of sources in a manner which can usefully inform the decision making process. This will involve the integration of quantitative and qualitative information arising from both physical and social systems research.

Finally, research associated with the concept of sustainability should highlight possible pathways into the future and identify the types of change which are conducive to these pathways and which maintain flexibility and adaptability within the system. If more information arising from this research is to be filtered into the decision making process it may be necessary to direct a greater proportion of funding at proposals in which the linking of scientific research to policy is an integral part of their design.

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Agricultural policy and desertification
A case study of the Argolid (SE Peloponnese, Greece)

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Agricultural policy and desertification
A case study of the Argolid (SE Peloponnese, Greece)

This paper presents an outline of part of the work undertaken by one of the teams within the ARCHAEOMEDES project. The team consists of two groups of researchers, one around Prof. A. Poulovassilis in the Agricultural University of Athens (AUA) and another around Prof. P.M. Allen of the International Ecotechnology Research Centre (IERC) at Cranfield University. The design and implementation of the qualitative research reported here has involved extensive fieldwork in Greece which has been undertaken by Dr. M. Lemon, (IERC) in close collaboration with Ms N Blatsou and Mr N Calamares and with the co-operation of AUA and local experts. Mr R Seaton (IERC) has collaborated on the policy related aspects of this work and Dr S. Green (University of Cambridge) has advised on the socio-cultural context.

Aims of the project

The underlying premise for this paper, and the work to which it refers, is that the natural environment is significantly affected by human activity. Any attempt to manage these affects must be based upon an appropriate understanding of what determines human activity. Therefore, information for decision making about land use must incorporate knowledge about the way people perceive and manage at the local level and how these perceptions relate to physical change. It is only through developments in the acquisition of such information, and the acceptance that the context from which is obtained is invariably "noisy and messy", that more informed understanding can be achieved about:

- who is involved in the relevant decision making processes and at what level.
- the information required to support decisions about current practice and future options.
- the impact of man made systems (technology and organisations) on natural resources
- the appropriate spatial scales of decision making e.g. administrative, farming, water systems.
- the different time scales within and between natural and social processes.

It is the aim of this particular study to contribute towards the development of more policy relevant research methods by formally integrating data about social, economic and physical processes and the various configurations of these which impact upon the natural environment.

This paper therefore focuses on a study in Southern Greece which is investigating the processes surrounding agricultural change and the degradation of the water and soils and the policies influencing those processes. It is argued that by investigating through the eyes of those who are actively involved more policy relevant information is obtained. Policy relevance in this sense will be taken to mean not only the appropriateness of the instruments employed for specific objectives but the mechanisms put in place for their implementation. The adoption of policies that emphasise production and economic efficiency can be seen to constrain the farming community into a pathway of intensive practice that ultimately may jeopardise natural resources, and the viability of the social system.

The implications of the study for policy relevant research

Recent research in technology policy (Seaton and Cordey-Hayes 1993) suggests the following limitations or deficiencies in many policies:

- Failure to recognise adequately the significance of recipients needs and therefore failure to address service delivery aspects of policy. Mechanisms tend to be judged by various criteria of efficiency rather than their ability to diagnose and respond to the changing needs of the intended recipients.

- Policy formulation focuses on technical and economic attributes of a production system and as such fails to consider the range of opportunities and threats generated by change and faced by the recipient of policy.

- The underestimation of the importance of the interactive processes and mechanisms between the policy body and the recipients, and the range of recipients affected by policy. The management of change is a dialogue between a variety of actors involving continuous interaction at varying levels of intensity.

- The assumption that the policy issue in these technical and economic terms is relevant to the recipients without adequate information as to whether this is actually the case.

The tendency of scientists to see policy making and planning as a rational science which lends itself to technical decision making ignores the complexity of the systems for which change is intended and perhaps more fundamentally the fact that it is uncertainty arising from complexity that provides the driving force for change. What is needed is a focus on "diversity" and the agendas for change of individuals and groups in the context of community, as well as those of the policy formulating system. This raises a number of issues about "scale" and the generalisability of policies as well as the methodological implications for providing relevant information about different local configurations of natural and human phenomena based on the perceived responses of the population.

"Scale" problems

The issue of "scale" is fundamental to an understanding of the difficulties of policy formulation. In other fields of study a similar concept occurs and may be known as "aggregation" in geography or "variety reduction and amplification" as in cybernetic models of organisations. A more detailed treatment of the concept as it arises from archaeology (for which subject temporal and spatial scales are central) can be found in a paper in this publication by van de Leeuw, and in ecology, by Fresco and Kroonenberg (1992). However a brief summary of the main points of relevant to this particular paper are offered below.

The difficulty of different scales of analysis and conceptualisation is that information relevant at one scale is ignored at another. Thus, treating the Argolid as a whole (regional scale) would present a (statistical) picture in which the predominance of orange growing was clear, but in which the perceptual differences would remain unremarked. Actual location needs to be taken into account rather than interpreting space as a statistical quantity (i.e. as zones which cover a percentage of the whole area). What is important is the diversity of the interactions between the physical and natural world and the social, cultural and economic attributes within a particular geographical or administrative region.

A similar argument can be made about temporal scales. Each location has a different natural balance between continuity and change, and thus its own set of "temporalités". Much of the structure and behaviour of any complex situation is determined by the temporal relationships between the different components, and the ways in which these change. Temporal scale problems are indeed as important as spatial ones.

It is for this reason that we have elected to use a "bottom up" approach in a way which allows the development of formal linkages with the "top down" approach which characterises most policy formulation.

Background

Figure 1 shows a thematic map of the area in Greece which is the focus of the project reported in this paper. The Argolid is a plain around the towns of Argos and Nafplion bounded in the north by Mykenes. The total catchment area (c. 1100 sq. km.) comprises 13 watersheds, and is divided into 38,600 ha. mountains, 26,500 ha. hills, 42,000 ha. valley bottom. The valley itself is subdivided into 29,500 ha. cultivated area, 7,800 ha. pastures, 3.000 ha urban surface and 1,750 ha. uncultivated land. All the streams feed at the edge of the valleys into the underground aquifers. The soils are generally stony on the hillsides and of poor irrigability. Deep soils (silt, loam and clay) make up the large majority of the irrigable area (120 sq. km.).

Land use is dominated by farming and in particular fruit growing. Agriculture of the area has changed from predominantly the dry farming of cereals and olives alongside some vegetable growing and sheep/goat herding, to the predominance of fruit production, in particular oranges. (See Figure 2)

The history of the area over the past four decades has therefore been one in which the availability of improved technology has enabled the expansion of irrigated food production. The introduction of more powerful water pumps, from hand, through horse to electrically driven pumps has enabled water to be obtained from a depth in excess of 400 metres. (See Figure 3)

Consequently the landscape has undergone dramatic transformation. This transformation has occurred over the last thirty to forty years and has involved increased irrigation. Before the 1939-45 war 40,000 stremmata (10 stremmata = approximately 1 hectare) were irrigated throughout the Argolid as a whole, this has now risen to more than 200,000 stremmata. Water for irrigation has been obtained from wells and bore holes (currently 95-125 million cubic metres per annum) and more recently from springs via specially constructed pumping plants and aqueducts (25 million cubic metres per annum). A wider ranging review of the structural weaknesses in Greek agriculture and the policy implications can be found in Spanopouplu (1990).

This intensification of agriculture, with the increase in mechanisation, fertiliser and pesticide use, and improved plant varieties has led to a critical level of degradation in the quality (salination) and availability of water, and the progressive degradation of soils.

Water sprinklers and air mixers (which look like large modern reverse windmills) to protect crops against frost in the winter and isolation techniques to limit the transport of salinated water between boreholes (and aquifers) have all been introduced over the past thirty years. What has become clear is that progressively more technology has been employed to maintain existing levels of irrigated land. Figures 4 and 5, which are based on data obtained from a survey of over 200 farmers, show the trend in the depth of bore holes drilled and the increasing uncertainty of obtaining water from them.

The history of technological intervention in the area has been divided between that which is initiated at the farm level (bottom up)and large scale projects sponsored at the level of local government (top down). The former has moved from the province of individual farmers to an emphasis upon group projects. This has coincided with the increased costs attached to obtaining water and to protecting against frost. Central to the large scale technological response has been the Anavalos project. This has been under construction since the 1960's and has recently been finished, although as yet not all of the works are being used. Considerable faith has been placed upon the project by the local agricultural community both as a source of irrigation water and to replenish acquifers in order to prevent salt intrusion.

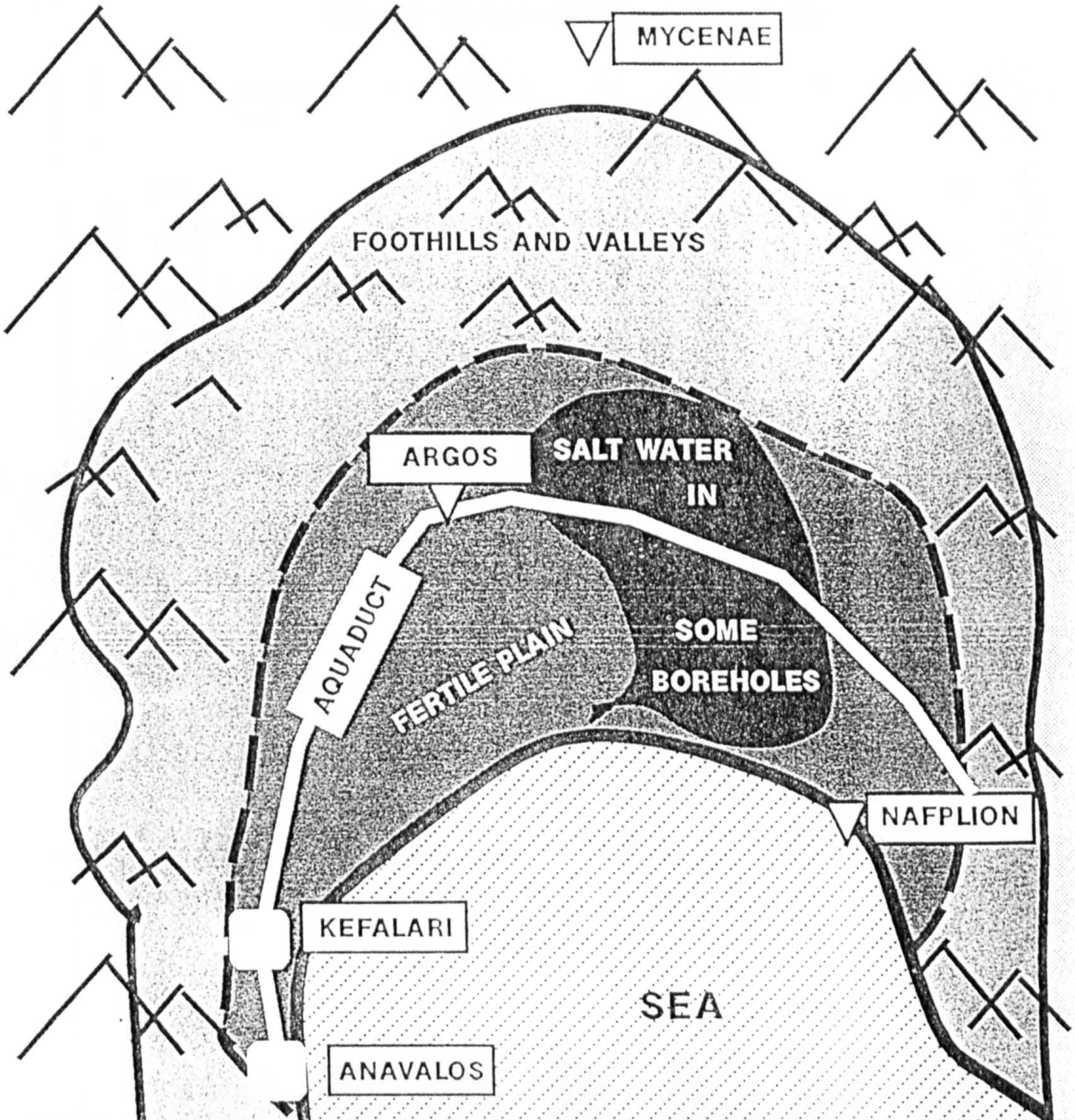


Figure 1 Thematic Map
of the Argolid Region

Figure 2 Changes in irrigation and crops

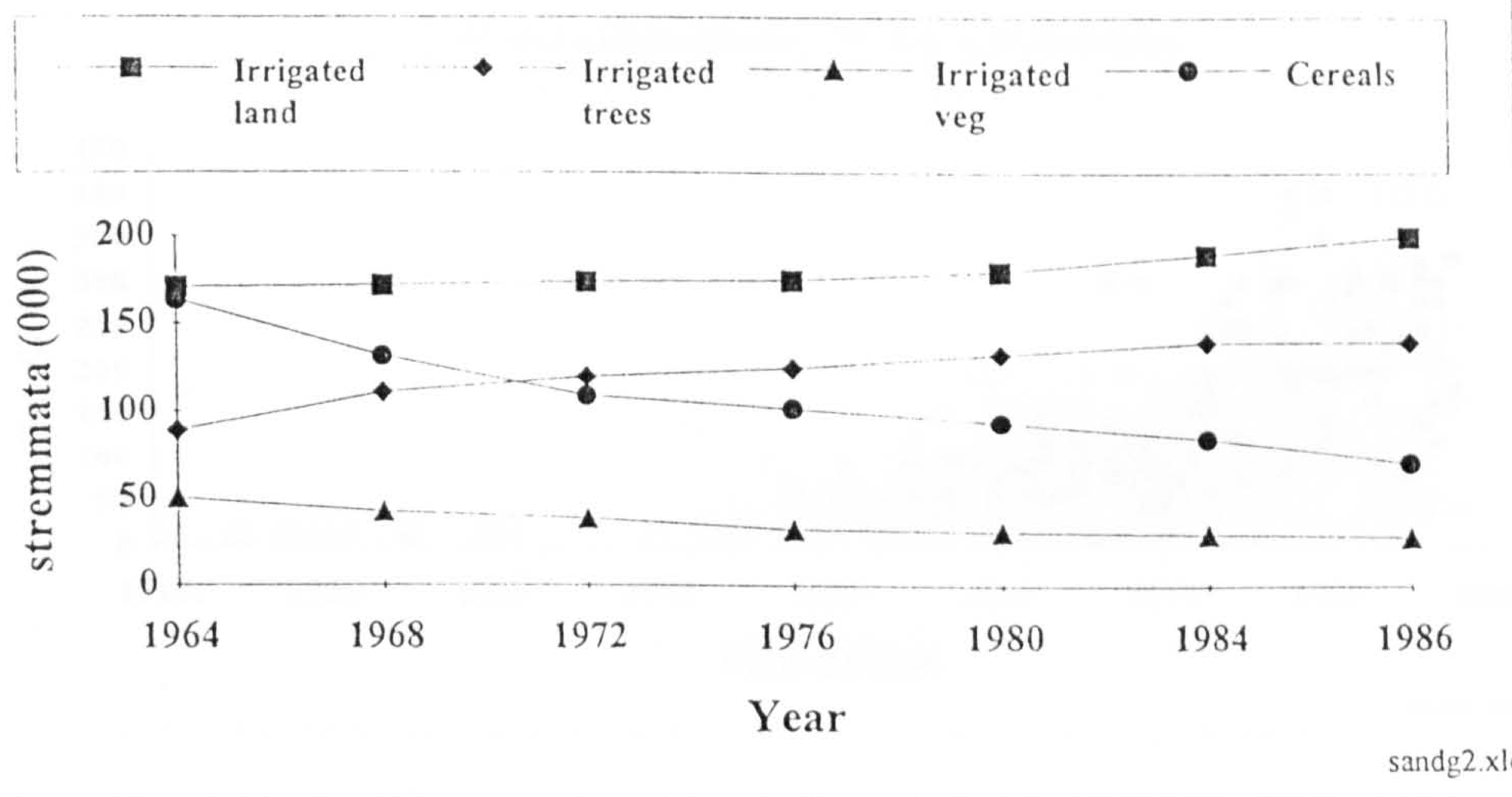
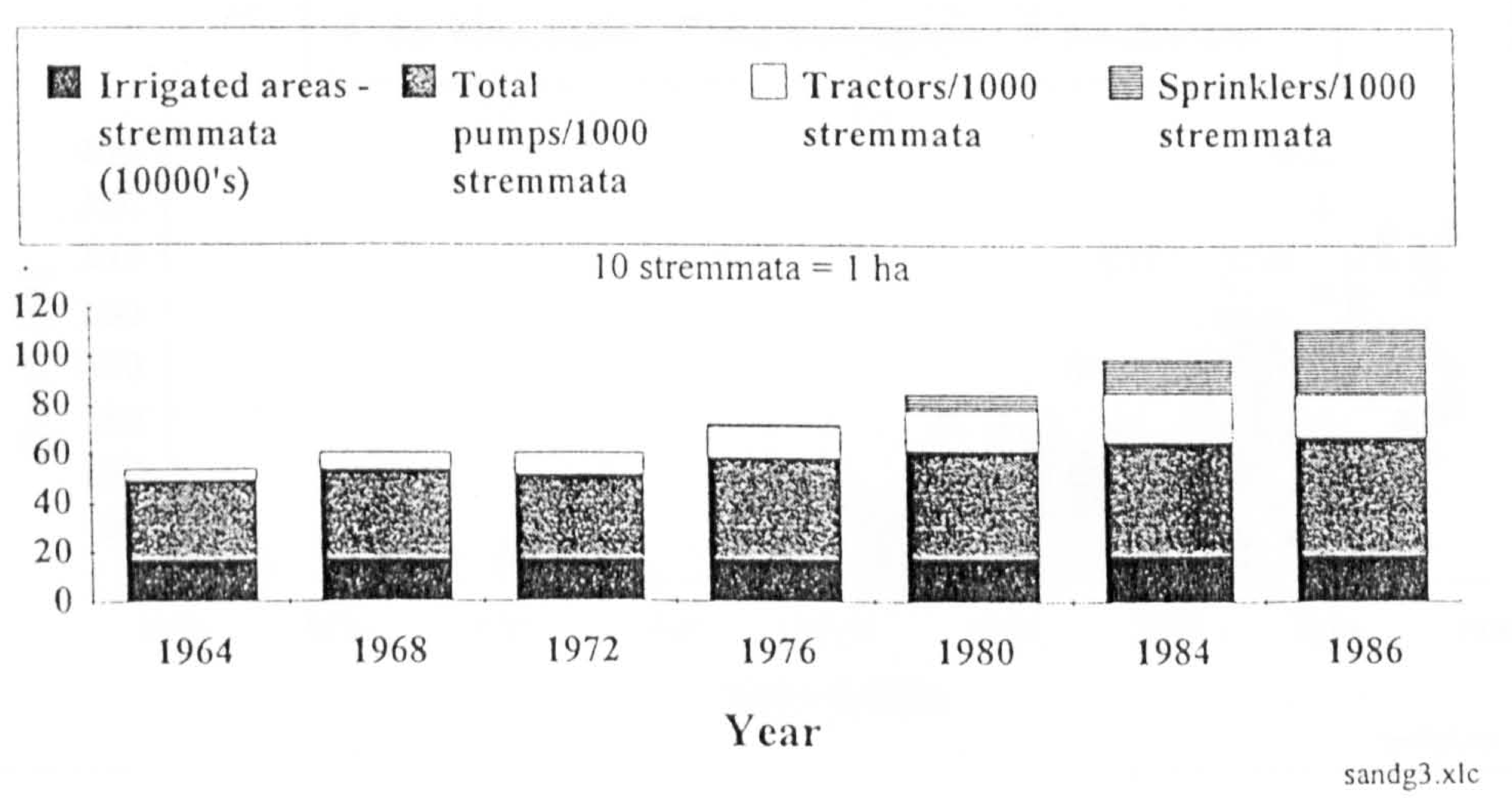


Figure 3 Growth in irrigated land and technology



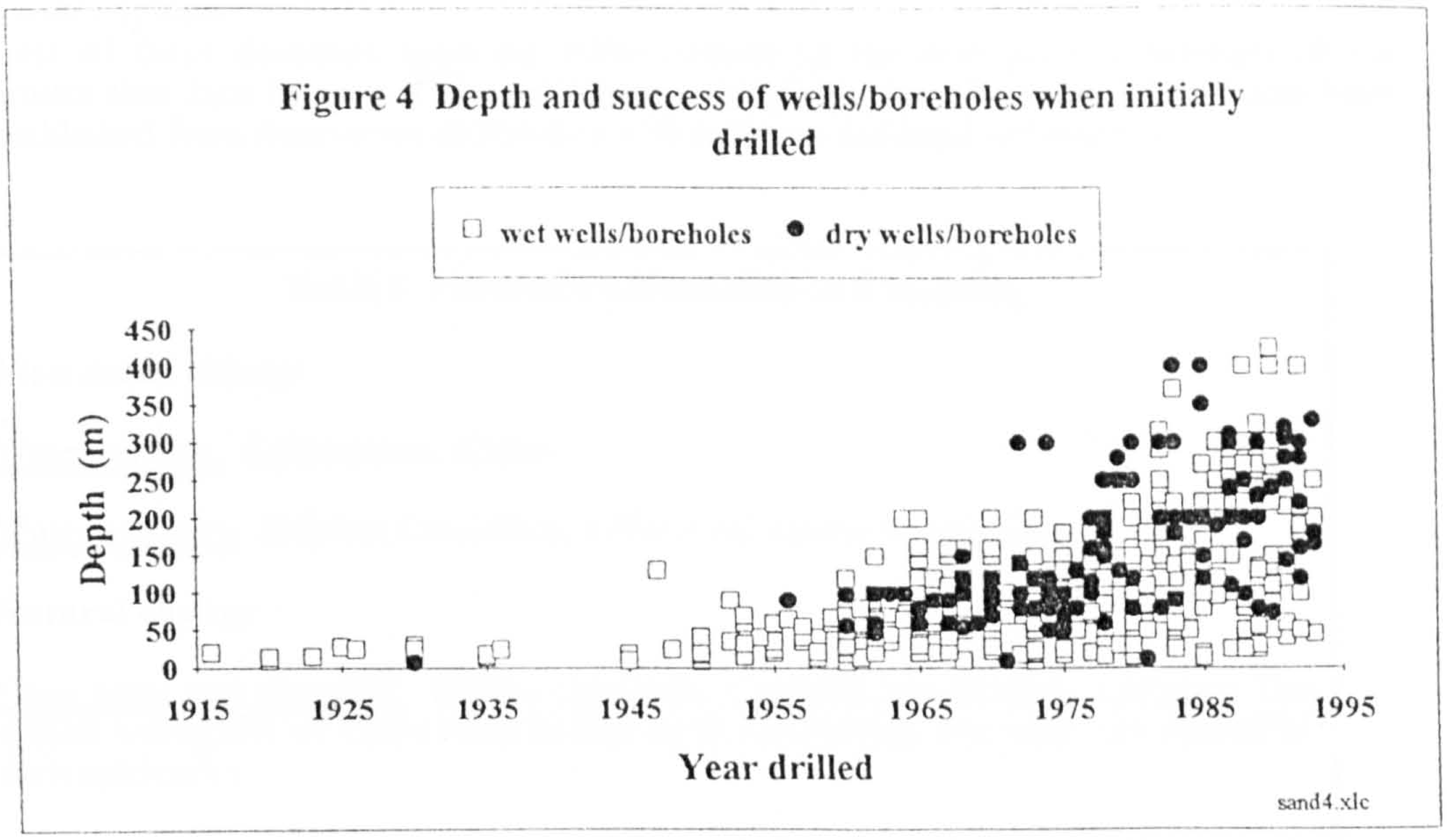


Figure 4 Depth and success of wells/boreholes when initially drilled
wet wells/boreholes
dry wells/boreholes
450
400
350
300
250
200
150
100
50
0
Depth (m)
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year drilled
sand4.xlc

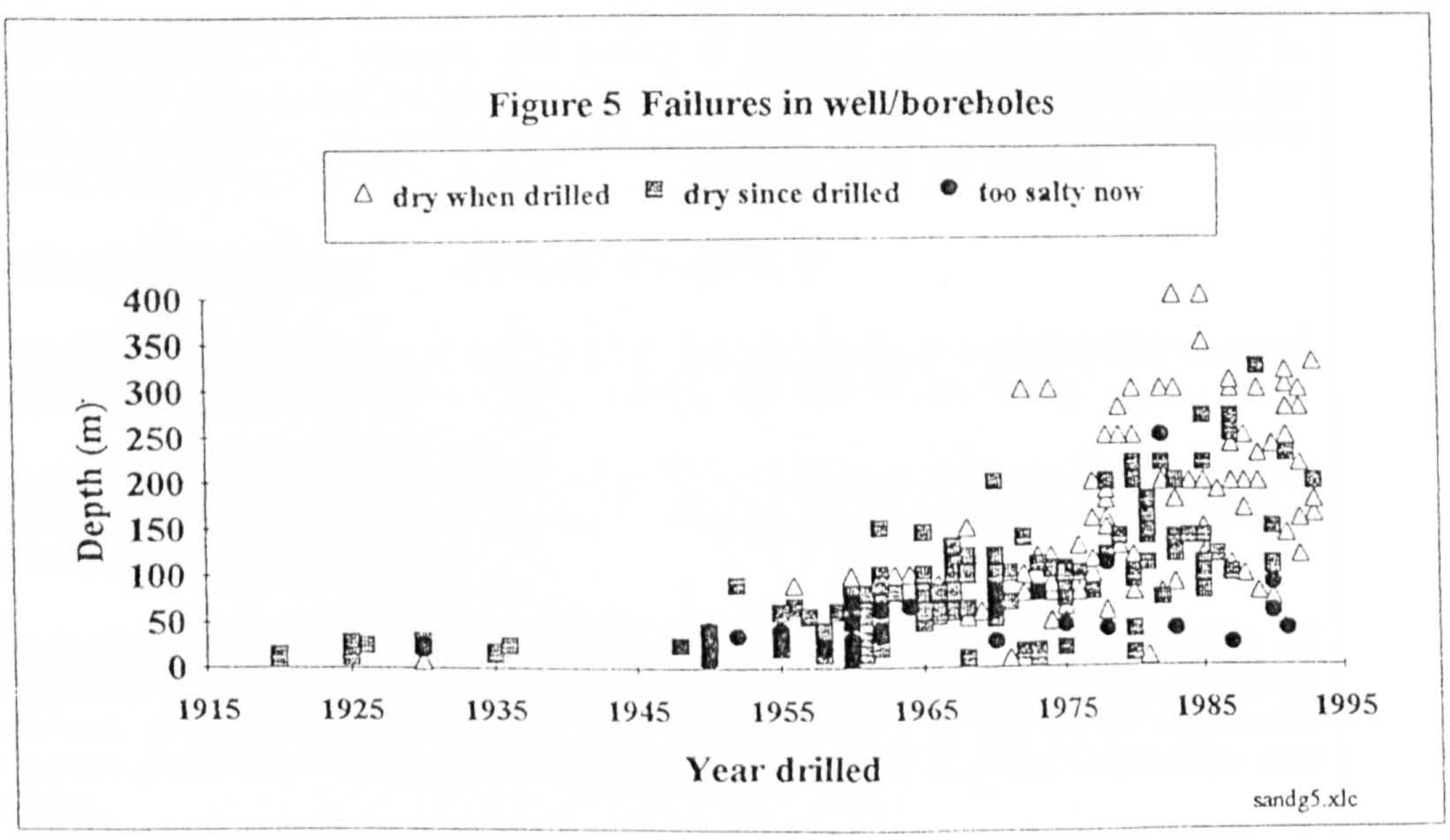


Figure 5 Failures in well/boreholes
dry when drilled
dry since drilled
too salty now
400
350
300
250
200
150
100
50
0
Depth (m)
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year drilled
sandg5.xlc

Prof. A. Poulovassilis and his team from the Agricultural University of Athens have been working on the problems of water balance deficit and salination since the early 1960's. (Poulovassilis et al). Part of this research is the production of a sophisticated hydrological model. The integration of this within a dynamic model of farmers decision making and water use is considered to be an important element of the longer term research into salinisation of the salt water system.

The effect of these demands upon the water system of the area are one example of the uncertainties that face farmers This uncertainty, and others, are shown in Table 1 and have been established from interviews undertaken within the agricultural community.

Table 1 Perceived uncertainty and farming

Man made change

Water quality: Salinisation, nitrate

Water quantity: Depleted acquifers, differential access to aqueducts

Natural change

Crop pests and diseases: Sharka (apricots), Coryphoxera (lemons /oranges) The spatial contiguity of crops with increasing mono-culture can ease the spread of such epidemics

Local climate change: Frost: Areas towards the centre of the valley (mainly orange production) have suffered from increased levels of frost over the past three decades. This jeopardises the citrus crops. The same phenomenon has been identified in Arta (Epirus) where there is extensive citrus growing.

Volatility of rainfall: The use of aggregate climate data does not provide insights into the variation in intensity and timing of rainfall, and temperature. This is particularly important if a drought in winter coincides with frost and the need for water as protection, at a time when ground water is low. Water from Anavalos cannot be used against frost because of the relatively high salt content.

Policy induced change (also see Appendix A)

Structural change: Attempts to restructure the age pyramid, increase farm size and improve economic efficiency of agriculture (Regs 797/85, 2328/91)

Market changes: Policy induced competition (Spanish oranges, Italian olives); attempts to restructure production in a market responsive manner (i.e. Uprooting of mandarins 1196/3029)

Production uncertainty: Withdrawal of input support (fertilisers); suitability of suggested crops (i.e. pistachio in response to the uprooting of apricots); disparity between production and policy cycles; uncertainty over levels of economic support; problems of support not reaching producers i.e. payment procedures and delays.

Political change

Perceived and actual role of the Public Administration as implementor and monitor of policy and source of information; problems of land access to market through 'Yugoslavia'

Research approach and activities

The focus of the study has been on agriculture as a production system. As such the investigation has concentrated more on relevant issues concerning farmers and less on the wider socio-cultural context in which the farming community finds itself (see Buttel 1989). However, it is recognised that social cultural determinants of behaviour are important and within the Archaeomedes programme there are formal linkages between the work in the Argolid and the social anthropological work being undertaken by Dr S. Green in Epirus, North West Greece.

What has been investigated, therefore, is the way in which the members of the farming community perceive the history, present and future of that production system. It is evident that problems of salination and water shortage occur to varying degrees within the Argolid, and various technological solutions have been adopted. However, it is the decisions taken by the farmers, based upon the information at their disposal and their perception of the problems and constraints, that will ultimately determine the success of natural resource management strategies. Of equal importance is the information provided by the farmers about which policy instruments and which agencies influence them when making decisions to adopt particular behaviours.

Phase 1 of the study has three components, each of which has been directed at different aspects of the farming system and the decision issues facing the farmers and agencies concerned with it. In the first component information has been sought about agencies and organisations cited in the interviews with farmers and in some cases obtained from them as monitors of the farming system. For example, the "Service of Agriculture" (a regionally based government service) has provided details about the production levels and land coverage for different crops within the Argolid. A series of interviews has also been undertaken with representatives from these agencies and organisations, including agronomists (Association of Agronomists in the Argolid 1992), geologists, co-operative managers, drillers and farm policemen.

The second component has focused on the perspective of the farmers and changes in farming practice. This has provided information on the way in which agricultural change has been perceived by farmers, the time scale and rates over which it has taken place and the agencies intentionally or otherwise responsible for aspects of such change (see Appendix B).

The third component has addressed the changes in the physical environment and some of the technical responses to it. Interviews have been carried out with respondents who are actively involved in providing technological solutions to the problems of water quality and availability, for example representatives of the Agricultural University of Athens who are currently involved with an artificial replenishment programme and other research activities in the area. Documentation has also been obtained on seminars and meetings held in the area to consider the problems of agriculture and water management. These have been translated into English and will be the subject of "content analysis" in order to provide an insight into the perspectives adopted by those who are actively involved in technological solutions.

In Phase 2 of the fieldwork a carefully designed interview format has been developed in conjunction with Greek colleagues to investigate the attributes of decision making in the farming community and the spatial and temporal components of these decisions. These do not always coincide with those anticipated within the policy formulating process and this gives rise to "incongruence" between agendas and thence to "unintended consequences" (Lemon and Naeem 1990, Lemon 1991). A similar notion is used somewhat differently in another paper in this publication by van de Leeuw.

This survey has focused upon the salient elements of the production system established from the earlier interviews which identify three key areas of policy influence:

- The extent of technological and farm management support. "Technological support" refers to the creation of access, through finance and information, to production technologies i.e. boreholes, electric pumps, air mixers, sprayers water filters. "Management support" concerns the access to technical and managerial education and training both for individual farmers and for collective organisations i.e. the marketing co-operatives.

- The extent of production support. This occurs either through price support, as in the case of guaranteed prices, or through subsidies such as those paid to uproot certain crops in response to natural catastrophes, such as viruses, or because of market imbalances. Production support has also been made available in the form of subsidised fertilisers, capital allowances for the purchase of farm equipment and subsidised electricity costs.

- The cost of water. The price of water is determined either by the cost to the farmer of drilling one or more bore holes on their land in which case the costs of electricity for pumping, maintenance and installation are all costed. Alternatively water is purchased directly either from neighbours or obtained from aquaducts that are fed by local springs. Water control and rationing are major policy issues given the variability in spring flows and aquifer levels, precipitation and the capacity of aquducts.

In addition, an analysis has been undertaken of how farmers foresee changes and how they envisage their likely responses, particularly in terms of crop choice. This is an initial attempt to demonstrate an approach to modelling crop choice, the perception of change in it and the probability associated with those changes.

The data from the three data collection components of Phase 1 on:

- agriculture as a production system
- farmers views about changes in farming practice
- changes in the physical environment and technical response to those changes

have been used to support the initial development of a socio-economic model of the farmers, agricultural production and hydrology. Table 2 gives a summary of the data obtained in Phase 1, the way in which it was acquired and the four models which constitute the output of the Argolid project. What is being attempted here is a demonstration of "integrative research" (Park 1993) suited to policy relevant issues. There are formal linkages between sociological, economic and physical research which enable policy (and other sources of change) to be linked via farmers decisions to physical effects.

Table 2: Data Acquisition in Phase 1 and output of Phase 2

Data Type	Data Source
Weather variation / Hydrology	
Rain / temperature / evapotranspiration	Meteorological service
Changing micro-climate (frost)	Interviews / public meetings
Salinity data for springs	AUA (measurement)
Salinity data for irrigation water	Interviews
Aquifer pressure	AUA (measurement)
Bore hole pressure	Interviews, AUA (measurement)
Bore hole location	Interviews
Irrigation requirements of crops	Interviews / expert agronomic opinion
Social, economic and political	
Agricultural development / land use	Service of agriculture/interviews
Expansion of irrigated area	Service of agriculture / interviews
Expansion and nature of water use	Interviews, AUA (measurement)
Crop change and production	Interviews, Service of agriculture
Crop prices	Interviews, Co-operatives
Occupational structure, demography	Interviews, Statistical Service of Greece
Levels and form of public administration	Interviews
Identification of key interest groups	Interviews
Identification of relevant EC directives	Semi-structured interviews in first phase

Output

Qualitative model of policy instrument, delivery and farmer receptivity (IERC)
Quantitative model of farmers crop decisions (IERC)
Quantitative model on the effect of those decisions on water use and water and salt flows into the hydrological system (IERC / AUA)
Quantitative model of water and salt in the hydro-geological system (AUA)

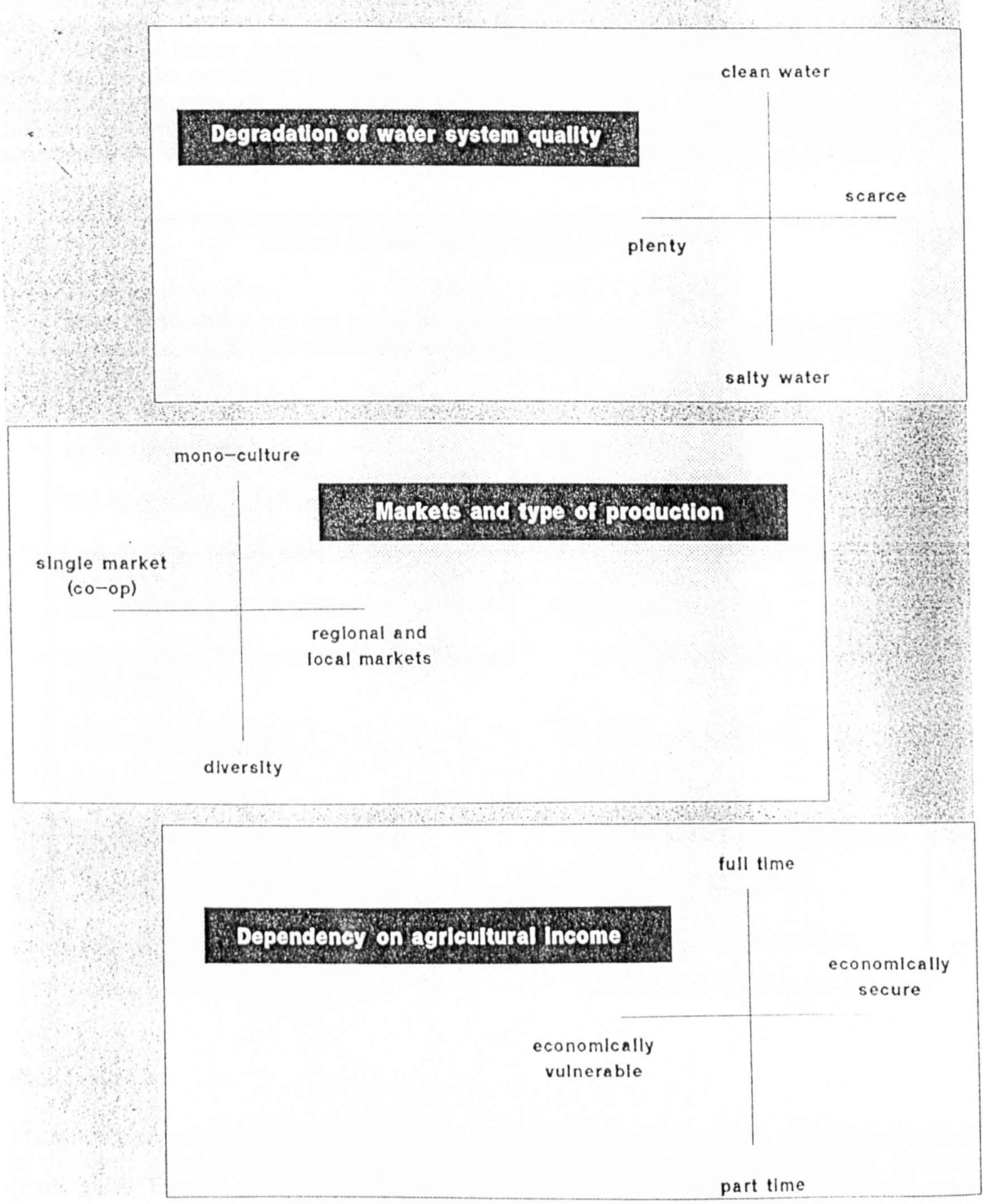
Different Perceptions

One of the most striking observations from the interviews is that considerable differences in perception exist within the farming community. Essentially these differences are between those who are considered as "real farmers" and those who are perceived to be in agriculture purely for the external supports and "easy money".

A number of the issues have already been identified around the perception of change and the uncertainty arising from these perceptions as presented in Table 1. Three main themes provide a provisional insight into the significant attributes identified in the study and are represented in Figure 6 in the form of simple attribute diagrams.

Figure 6 suggests some of the factors that are seen to differentiate "real farmers" and those who are not considered part of the "farming culture". This is expanded in Table 3 and coincides with other models generated through research into Greek agriculture. One of the most striking characteristics of Mediterranean agriculture is the level of multiple job holding and by implication the number of part time farmers. While this is evident within the Argolid it can also be misleading because some part time farmers are unable to earn a sufficient income

Figure 6 Some Perceptual Dimensions that determine farmer opportunity space



from agriculture alone and have to find employment elsewhere. This will occur in areas where the natural resources are inadequate to support the desired level of agriculture. Other part time farmers farm in such a way that they have time to undertake additional forms of income generation. Citrus fruit production lends itself to this with a short period of intensive activity (harvest) and the availability of cheap labour (Albanians, Eastern Europeans, mountain dwellers, Northern European students).

A similar distinction can be made between full time farmers who tend to mono-crop but who may invest their capital outside of agriculture (particularly in property) and those who invest in their own farms and tend to farm with more diversity. The latter group sell to the local markets as well as through the co-operatives. This requires the involvement of extended family networks to look after children, work the land and sell the produce. As such it has a reserve of labour and maintains the possibility for future changes that are more labour intensive (i.e. the production of vegetables). This is not the case with those farms that have reduced the diversity of production and have become reliant upon seasonal labour. The distinctions between these farming "cultures" are, therefore, of considerable relevance when considering the viability of future options. These broad distinctions are shown in Table 3.

Table 3 Dimensions of "Farmer Culture"

These dimensions are not mutually exclusive; no one farmer is will be at the extreme of all of these dimensions. The typology of farmers will emerge through further analysis.

Less migrant labour used	Heavy use of migrant labour
Not dependent on technology	Dependent on technology
Children have lower level of education	Children educated to a higher level
Extended family and children work on farm	Children do not farm
Farming is socially acceptable occupation	Farming not socially acceptable
Self sufficient to some extent	Not at all self sufficient
Diversity of crops	Mono-cropping
Internal/local markets important	External/export markets important
Re-invest in agriculture	Invest outside agriculture
High level of hidden investment in form of personal labour	Low levels of personal labour

Conclusions

In conclusion, some key ideas have been introduced in this paper. Firstly it is the perceptions of the farmer that dictates his decision making and not some external "objective" measure (Park 1993, Lemon and Park 1994). Secondly, these perceptions inevitably include some uncertainty about how existing change-behaviour will reveal itself in the future. What we wish to understand is the relationship between likely behaviour and current behaviour as revealed in farming practice and choice of crops. The agenda of relevant policy attributes has been set by the respondents in the Phase 1 interviews. While recognising the limitations of concentrating upon farming as a production system, the ability to work back from the individual to specific policies, policy instruments and delivery mechanisms is considered a significant contribution to the methods of policy relevant research.

The central propositions that are of particular relevance to the way in which the Argolid study has been interpreted and the methodology designed are:

- That the agendas for change set at both the policy formulating and policy delivery levels do not necessarily match those of the recipients of those policies. This gives rise to a concern about "scale", temporalities, and diversity

- Change needs to be seen as a reciprocal relationship between the local or micro level and the macro level, with one determining and responding to the other. Thus policy relevant research needs both "bottom-up" as well as "top-down". This has implications for how the agenda for change of recipients of policy can be investigated on a recurrent basis (see Lemon, Hart Seaton 1992).

- While a substantial amount of theoretical research and field observation has been directed at understanding the physical and economic attributes of agricultural production systems, little has been achieved with respect to situating these observations within a wider socio-political context.

- It is necessary to provide an understanding of the social, political and environmental interactions which are embedded in land management and decision making criteria, from the local perspective represented by the individual farmer, through the various levels of public administration to the regional and (inter)national planners and policy makers.

- The sensitivity and resilience of study areas can only be understood through a combination of ecological and socio-cultural perspectives, and not one or the other.

At the time of writing only the initial stages of qualitative and quantitative model building have been completed. The final output is intended to demonstrate how these are components of an "integrative" approach that enables physical effect to be formally linked to policy. In doing this it is also intended to demonstrate how the interface between knowledge acquired from diverse academic disciplines and decision issues in the real world can be designed. The qualitative models mentioned in this paper will be reported in the near future.

In the longer term it is hoped that the Argolid project and its colleague projects in ARCHAEOMEDES will not only further science research but also lead to ways in which the wealth of scientific knowledge can be more effectively exploited in policy formulation.

Appendix A: Agricultural History of the Argolid

	1945 1950 1955 1960 1965 1970 1975 1980 1985 1990
Hydrology, technology and research projects	Kefalari spring Commencement of Anavalos project First replenishment project Current replenishment project A.U.A. Archaeomedes, Life 92/GR/003
Local technology	Establishment of more bore holes 'Horse-drawn and oil pumps Centrifugal pumps Introduction of electric pumps First air mixer Use of isolation techniques (against salt intrusion) Pormone pumps Stone crushing machines (Skafadaki) Extensive drilling of bore-holes Submarine pumps More extensive use of air mixers Wider use of artificial rain
Local organisational/ economic support	Loans readily available from Agricultural Bank 'Early cooperatives (for obtaining loans and internal support) Formation of early T.O.E.B.'s (1954) Establishment of Co-ops in current form (for marketing and transportation) Formation of "Young Farmers"
Politics and policy	Support for equipment, fertilisers and electricity Merlin oranges subsidised as new crop 'From 1924 licences for tobacco growing in hills Accession to EEC Election of New Democracy (1989) Pasok (1 Pasok (19 (797/85) and reg. 2328/91 improving efficiency of farm structures Uprooting programmes for apricots (1988-93), vines (1988) and mandarines (1990) Withdrawal of tobacco licences (1992) Restructuring programme for citrus production Increased subsidy for non-EEC exports (11 Dr/kg. within EC, 32-43 Dr/kg. outside) Support for dumping or withdrawing excess production Withdrawal of subsidy on tangerines
Production and marke	Few oranges sold by unit for internal market First orange trees planted intensively, for export market Apricots planted and expanded around 1960 'Cereals, cotton, tobacco and vegetables grown in valley 'Some cattle (Koutsopodi), sheep and goats (mainly in the hills) Construction of factories for food preserving 60% oranges to EEC in 1991, <10% in 1992 Expansion of juicing factories (EEC support)
Natural threats	Coryphoxera in lemons Lowering of ground water levels Increased problems with frost (1963 notably) Salination problem (Asini) Sharka in apricots Problem of water availability Alevrodes virus elsewhere in Greece Bad frost (1992) destroys mandarin crop in Asini Increased salination in Valley

Appendix A: Legislation relevant to Argolid Agriculture

On improving the efficiency of farm structures. **797/85 (Reg.2328/91)**

Assistance for new farmers. **797/85 (Reg.2328/91)**

Programme for the assistance of the mountainous and disadvantaged areas: (income compensation) **797 and Reg 2328**

Agro-tourism **797 and Reg 2328**

Programme of farm electrification.

Programme for the uprooting of apricots.

Programme for the abandonment of vines. **(1442/88)**

Programme for the uprooting of Mandarins. **1196/3029 (1990)**

Programme for the marketing and cultivation of hard shell crops. **789/89, 790/89, 2145/91**

Programme for the establishment and working of groups of fresh vegetables and fruit producers. **1035/72**

Appendix B: Agencies of agricultural change (cited in interviews)

Political policy/administration
European Union
Ministry of Agriculture: Athens
Prefecture:
Regional Services of Agriculture:
Local offices of agricultural development:
Y.E.B. Service of land improvement:
G.O.E.B General organisation of land improvement:
T.O.E.B Local organisation of land improvement:
K.E.G.E (local) centre for education and farm research:
Field Guards (Farm Policemen):
O.G.A: (agricultural insurance agency)
Agricultural Bank of Greece:
Ministry of Public Works: (responsible for the construction of Anavalos)
Political Parties: PASOK and ND

Education and Research:
I.G.M.E: The Institute of Geological and Meteorological Research; A.U.A: Athens Agricultural University; University of Patras

Interest Groups:
Organisation of Young Farmers; Professional Associations (Agronomists)

Economic Organisations:
Co-operatives; Dealers:

On the ground:
Drillers; Geologists; Technical suppliers and maintenance: drills, pumps; Private agronomists: Water companies

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EVALUATION METHODS FOR THE DESIGN OF ADAPTIVE WATER SUPPLY SYSTEMS IN URBAN ENVIRONMENTS

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ABSTRACT

The issue of sustainable modes of development are not restricted to those concerning environmental protection or pollution control / minimisation. In generic terms, sustainable systems are those which can be adapted to changing circumstances. Given the essential nature of utilities there is a clear need to plan and manage their technologies in a sustainable manner. This paper offers an initial theoretical structure for designing and managing adaptive technological infrastructures for utilities in generic terms and suggests how such a framework may apply to water supply systems. In particular, the development of new water recycling technologies and the emergence of 'complex system' modelling techniques provide opportunities for the design of water supply systems which are adaptive to changes in the urban social and physical environment in which they are embedded. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Complex modelling; infrastructure; recycling; sustainability; water supply.

INTRODUCTION

The decision issues faced by the water industry and public policy planners concern the selection of appropriate technology options and network configurations that can meet system design criteria such as cost and user acceptance. Opportunities for water reuse within the sustainable city are numerous. Indeed, the very nature of the city space, including as it does domestic, commercial, industrial, open space (gardens, parks etc.), and occasionally agricultural water utilisation patterns, constitutes a complex web of water reuse potentials. However, tackling issues of sustainable water use by immediate large scale infrastructure replacement is considered by the industry to be a costly, risky and possibly ineffective response. Contrastingly, steady progress has been made in the design of small scale water recycling / reuse technologies, some of which are already on the market. Hence, whilst the introduction of water recycling systems is desirable from the viewpoint of policy makers and feasible from the viewpoint of engineers, project implementation remains problematic with regard to issues of suitable technology configuration, appropriate scale, and user acceptance.

This paper draws upon recent research into technology assessment which has used concepts from complex systems theory as a way of introducing the attributes of sustainability into the evaluation of utility systems

(Jeffrey 1992). It also draws upon research into the development of complex systems models of urban systems by Allen (in press) which follows from Prigogine's theoretical work (Prigogine and Stengers, 1984). It describes the early theoretical thinking about a research project which will contribute to the research programme in the UK into Sustainable Cities (EPSRC 1996).

TECHNOLOGY AND SUSTAINABLE DEVELOPMENT

As is the case with many research fields, the current global concern with Sustainable Development exerts an influence on the study of technologies and technological systems. All shades of the Sustainable Development literature are in broad agreement that unchecked technological development in general is at least partly responsible for some of the undesirable and survival threatening phenomena observed today. Problems of pollution, over-production, resource (and capital) concentration, restricted product lifecycles, and lack of social control, have all been laid, rightly or wrongly, at the door of the generic beast called technology. However, whilst there is general consensus regarding the role of technology in creating the problem, there are diverse attitudes towards its future contribution. Emergent from this uncertainty, two broad opinions concerning Sustainable Development and technological futures are identifiable. The first of these advocates a reining in of technology and a return to more simple modes of technology use. The literature stream emanating from the work of E.F. Schumacher (1974) represents a prime example of this tradition. The second of these opinions is that the solutions to problems of sustainability will be found in the use of even more advanced science and technologies. The debate between the various positions is extensively developed by Gillot and Kumar (1995).

We would draw attention to two particular features of contributions on technological futures within the Sustainable Development literature which restrict the breadth of debate. The first of these restrictions concerns the perceived nature of the problem (as discussed at the end of the previous paragraph). In summary, queries concerning the identification of a desirable and positive role for technology within sustainable societies has been dominated by questions about how much technology rather than what type of technology. The second restriction on debate has been the emphasis within the literature on environmental issues, resulting in a prescriptive movement which espouses a 'greening' of the economy; i.e. designing environmentally friendly technologies and production systems. Although issues such as pollution and habitat destruction are today's challenges to a sustainable future, the challenges of tomorrow may be quite different. Sustainable development, whatever its precise definition, is suggestive of continuance. Those seeking its promotion should therefore be as concerned with setting in place structures and procedures which promote sustainability in a generic way, as they are with addressing the more immediate threats to our survival.

It is the contention of this paper that, due the restricted nature of the debate on desirable technologies for Sustainable Development, a significant aspect of the problem has been largely ignored. In general terms, sustainability is promoted by adaptive change; a concept rarely, if ever, addressed in the literature on technological options for Sustainable Development. If technologies are to make a genuine contribution to the achievement of sustainable communities and a sustainable world, then the pertinent focus of attention should be on the design, operation, and management of adaptive technologies and technological systems. Such systems may be broadly termed 'resilient'. The planning of long term technological infrastructures concerns the development of planning methods and implementation strategies designed to ensure consistency in technological system performance over changing operating conditions. Within this framework, consistency of performance may relate to a number of aspects of the system such as product/service quantity, quality, reliability, cost and availability. Additionally, various characteristics of the system will influence its ability to achieve consistency, including; the system's spatial configuration, the technological attributes of individual items of plant, and the interactions between specific technological attributes such as scale, cost functions, design life and the diversity of technologies being used.

To summarise the foregoing text; the potential contribution of technologies and technological systems in promoting sustainability is not restricted to the development of environmentally friendly goods and production processes. In particular, the design of resilient, adaptive technologies and technological systems will enhance the sustainability of our communities and economies under conditions of change. The remainder of this paper expands on these arguments and begins by presenting a discussion of how the design of sustainable (resilient) technological infrastructures is informed by the contribution of complex systems modelling. We then go on to discuss the nature of resilience both in generic terms and in terms of technological infrastructures, emphasising the role of system attributes as compared with system states. Finally, the contribution of novel water recycling technologies to promoting resilient infrastructure design is detailed and discussed in terms of the development of a relevant evaluation methodology.

CO-EVOLUTION OF CONSUMPTION PATTERNS AND TECHNOLOGICAL INFRASTRUCTURES

Cities and city regions can be seen as complex systems which evolve over time (Allen *et al.*, 1986; Pumain *et al.*, 1989). Research into the dynamics which underlie such evolution has characterised the city or regional economy as the compound result of different activities that to some extent fit together and need each-other; a process of co-evolution which is typical of many complex systems. The spatial organisation which is observed in these models emerges as a result of the interplay between positive and negative feedbacks. Examples of positive feedbacks include the urban multiplier effect, economies of scale and the influence of externalities. The dominant negative effect is spatial competition for both production and residential space (Allen, in press).

The ability of urban areas to adapt in a sustainable way depends, in part, upon the co-evolution of the utilities which deliver fundamentally important services and products such as water, waste disposal, energy, telecommunications and transport. The development of models of cities as complex self organising systems shows that the spatial dynamics of a sustainable city would be likely to give rise to substantial changes over time in the patterns and nature of water demand (consumption 'footprints'). Indeed, changes in technologies, social priorities, spatial and temporal demand and rainfall patterns may, in time, necessitate major modifications to the configuration and operation of the system. Therefore, the concept of systems which can provide sustainable resource provision is closely associated with issues of technology flexibility, change, and socio-economic policy, and to associated issues of Demand Side Management (DSM) (Guy & Marvin, 1995).

Within the context of designing and managing a sustainable urban area, planners require an understanding of the interactions between the macroscopic dynamics of the urban system and its component sub-systems. One major feature of this interaction is the way in which utilities' infrastructure and technology can be designed to allow for flexibility and adaptivity of urban built form as urban systems evolve under conditions of uncertainty. In particular, the nature of demand for water in terms of user attributes and spatial configurations will change over time dependent on what individuals, households, and organisations see as relevant to themselves. Equally, science and technology will create new water processing opportunities. These two worlds interact through the interplay between supply and demand attributes.

How can planners ensure that water supply infrastructures are capable of adaptive change, thereby enhancing the potential for co-evolution with consumption patterns? The discussion presented in the introductory section of this text suggested that such systems can be described with the term 'resilient'. The following paragraphs explore the nature of resilience both in generic terms and in terms of technological systems, drawing on a range of literature to illustrate the component features of resilient systems.

THE NATURE OF RESILIENCE AND ITS INTERPRETATION IN TERMS OF TECHNOLOGICAL SYSTEMS

Resilience indicates durability or continuity. Its achievement is promoted by enhancing both the potential for change (flexibility), and the ability to change (adaptivity) in the system's plans, configurations and functions (*'reorganising a system's resources'* Shakun, 1981). In more detail, flexibility indicates a potential for change or the existence of alternative positions/strategies/configurations (Gupta & Goyal, 1989). In evolutionary terms, such a potential for change is defined by the totality of an organism's behaviour and its physical characteristics. The concept of flexibility has received wide attention in both the social and natural sciences

(Carlsonn, 1989; Sawhill & Silverman, 1983; Aggarwal & Soenen, 1989). For example, the field of management science has provided a useful interpretation of flexibility, viewing it as '*the number of future alternatives from which a choice may be made*' (Pye, 1978). Flexibility is promoted by two additional phenomena; diversity and learning.

Diversity is a central concept in evolutionary theory. A useful interpretation of diversity is provided by Pielou who comments that '*diversity bears to qualitative observations the relationship that variance bears to quantitative measures*' (Pielou, 1975). As a concept, diversity is readily transferred from biological to other systems. In its elementary sense, diversity alludes to the number and relative proportions of different typological groups in a community. Flexibility is also promoted by learning; the process of gaining knowledge or skill. Learning about your environment enables you to adapt your behaviour to exploit opportunities and avoid dangers.

Adaptation has been described as a process as the '*modification of structure or behaviour*' (Holland, 1975). Organisms adapt to their environments because in order to survive and reproduce, they must meet their environment's conditions for existence (Pianka, 1978). If flexibility is the potential for change, then adaptivity is the ability to execute or exploit such change. Hence, a system may be flexible (have options for alternative action), but not adaptive (be able to utilise these options). Although most discussions of adaptation are couched in the terminology of the biological and ecological sciences, the field of General Systems Theory has been prominent in interpreting the key concepts for use (by analogy) in planning and modelling activities. For example, Shakun characterises an adaptive system as one that '*reacts or responds to change to attain goals*'. (Shakun, 1981). Such change may be internal or external and the response type may be passive (changing itself) or active (changing the environment).

Translating the concepts discussed above to the subject area of technological systems, we can readily identify analogous processes and structures. A resilient technological system will possess both options for alternative modes of operation (flexibility), and the ability to exploit these alternatives (adaptivity). The central components of resiliency in technological terms might include; modular technology design, diversity of technology configurations, diversity of technology types, scale independent technology designs, and adaptive infrastructures.

For example, technology design can enhance the resilience of the system by ensuring that options for future action are not restricted by current attributes. In addition there will be a series of more qualitative features of the technology which may be dictated by considerations of resilience from a different perspective (i.e. environmental, economic etc.). The type of design considerations which will enhance resilience may include the use of a modular design approach which would enable the potential for re-utilisation of components in other system types either during the proposed life-cycle of the plant or post decommissioning. Generally, this ensures that the life-cycles of specific items of plant and their constituent elements are not necessarily identical, thereby engendering an element of modularity. Scale considerations are also an important factor in determining the resilience of a technological system and are closely linked to the network aspects discussed below. It is erroneous to assume that by scale issues is meant a preference for small scale applications. The relevant issue is rather concerned with appropriate scale dependent upon technology type and other factors. Life-cycle considerations can also influence the resilience of a system as the interactions between different component, sub system and system life-cycles create opportunities for change and adaptation.

The design of network characteristics will also have a significant effect on the resilience of a technological system. Both spatial and structural aspects are important here, resilience being resultant from the potential for additive or distributive flexibility. Similarly, investment strategies can exert a major influence on resilience as project timing, size, and level of commitment determine a measure of exposure, both financially and organisationally (resources etc.). Diversity of project attributes is a key feature of an investment strategy focused on resilience, allowing risk to be spread and learning processes to be engaged in without over-commitment.

At this point we would draw attention to several specific studies (both completed and ongoing) which demonstrate the potential contribution of thinking about resilient technological systems in the terms discussed above. The effect of a diversified technology base (multiple technology types exhibiting similar functions but varying scales and operating characteristics), on total system cost stability has been demonstrated by Jeffrey (1992), who also made some broad conclusions regarding the generic benefits to be gained from such a technological configuration. Further contributions, carried out as part of the European Community's Environment and Climate research programme, (van der Leeuw, 1996), have focused on the relationships between technological infrastructures and land use change. This work has drawn attention to the need for designing water supply infrastructures that are capable of supporting social and economic changes rather than 'locking' communities into rigid spatial and temporal patterns (Lemon *et al.*, 1995).

In concluding this discussion of the characteristics of resilient technological infrastructures, we would identify two additional issues which require attention. Firstly, it should be noted that the concepts that have been reflected on in this and the foregoing sections are concerned with the **attributes** of the system under study rather than **states** of the system. This is a non-trivial distinction which is worth some further discussion. The difference between these two phenomena has particular relevance within the context of planning methodologies, where a focus on system states has been allied with a mechanistic approach to problem solving whereas a focus on system attributes has been associated with an evolutionary approach. The significance of this distinction in terms of technologies and technological systems has however not been widely addressed in the literature. The intended distinction here is that states are measures of specific system performance parameters whereas attributes are general qualities of system or sub-system behaviour. The distinction thereby emphasises the difference between quantitative and qualitative assessments of system performance. As an example, we may take the case of electricity supply systems where a state focused analysis would concentrate on issues of cost (capital and operating), efficiency (conversion and transmission), and return on investment. Conversely, an attribute focused analysis may look at system diversity, flexibility and adaptivity.

The second issue which requires some attention when thinking about resilient technological infrastructures concerns the nature of the relationships between various attributes. In particular, the hierarchical structure of the relationships between various attributes dictates their influence on overall system performance. For example, any utility in the form of flexibility that can be gained from the attribute of diversity is dictated by a dependence relationship between different hierarchical levels where diversity at a lower level promotes utility at a higher level. To illustrate this point consider the case of manufacturing technologies. Diversity of production technologies (each one held by a different firm) does not promote flexibility at the level of the firm but at the level of the sector. Likewise, the benefit of a diversified set of electricity generating technologies (each owned by a separate operator) is not of benefit to the operators of individual technologies but to the customers of the industry as a whole. Generically, diversity of individual behaviour does not further the interests of the individual but of the group.

OPPORTUNITIES PROVIDED BY NOVEL RECYCLING TECHNOLOGIES

As noted in the introduction to this paper, a central feature of much recent research into water recycling / reuse technologies has been the focus on small scale applications. Perhaps the leading source for such applications is Japan where there is a well developed research programme into in-building wastewater treatment and water recycling processes (Kimura, 1991; Chiemchaisri *et al.*, 1993). However, rising demand profiles and increasing incidences of water shortages in many parts of the world have prompted wider interest in the sorts of technologies which provide opportunities for designing resilient (adaptive) water supply/recycling systems.

For example, the use of household scale sandfilters has been suggested (Glücklich, 1995), and physical filter/membrane systems for recycling domestic bath/shower water have also been proposed (Murrer & Bateman, 1996). Perhaps of even greater relevance are those process treatment technologies based on the use of membranes (see for example Till *et al.*, 1995). Of particular significance, advances in recycling systems based on biological aerated filter (BAF), molecular oxygen-dosed membrane bioreactor (MOD-MBR) and ultrafiltration (UF) based membrane bioreactor techniques have been reported (Pankhania *et al.*, 1994) and are currently under test in both the UK and elsewhere. Similarly, there are opportunities for exploiting the performance attributes of technologies which have reduced chemical requirements (Parsons *et al.*, in press). These 'small footprint' technologies (Stephenson *et al.*, 1993) extend the opportunity space for the design of water supply infrastructures by providing greater flexibility with regard to technology scale, siting and functionality. This flexibility is also reflected in the logistical and economic properties of the system. Hence, the capacity of these types of technologies to recycle grey and black water at the neighbourhood, street or even household level exposes new opportunities for the design of water supply/sewerage networks.

The implications of these types of technologies for such networks are primarily to do with the development of evaluation methods Given a set of recycling technologies such as that described above, we can begin to see how an appropriate analysis methodology for designing a water supply/recycling infrastructure for an urban area might be constructed. The following issues will form the basis for such a methodology.

Flexibility: temporality and uncertainty: Issues about specific processing technology units can be explored through calculating the cost and performance envelopes of a set of technologies under conditions of uncertain input costs, demand levels and quality over sustained periods of time.

Adaptability: system configurations and cost/performance trade-offs: These issues can be addressed by considering water recycling technologies within the wider infrastuctural system of catchment, processing, delivery and disposal as part of an evolving logistical system and investigating how different technologies perform.

Scale, hierarchy and complexity: It is necessary to formally identify how the water system can be introduced as an interactive sub-system into wider urban system models. The way in which such water supply (and disposal) systems will consist of different technologies at different spatial scales (building, street, community, district, city) and hierarchies, all of which have some economic, physical and social dynamic, is part of a wider research agenda into sustainable cities as complex, dynamic and evolving systems.

Sustainable communities will require water supply systems which are capable of adapting to temporal and spatial variations in the demand profile. By viewing the co-evolutionary relationship between demand and supply in these terms, the criteria for desirable infrastructure characteristics are subtly altered. In particular, the system will be required to exhibit flexibility and adaptivity in the face of changing demand patterns. These characteristics can be enhanced by the use of novel water processing/recycling plant which provide opportunities for adaptive infrastructure configurations.

CONCLUSIONS

It would be easy to be critical of the water supply industry for failing to provide our communities with technologies and infrastructures that are not better capable of supporting changing economic and social patterns. However (and as has been the case with the other utility industries), imposed institutional, legal and financial frameworks have favoured a specific sub-set of available technologies and configurations. These statutory functions (Brandon, 1984, p. 103) effectively constrained the development of appropriate physical systems and suppressed the realisation of potentially useful intellectual contributions from the Water Science community. With the removal of these strictures and increased awareness concerning the dangers of adopting an indifferent attitude to infrastructure design, new opportunities arise for the planning of systems which truly contribute to the sustainability of our communities. By exploiting the attributes of novel wastewater recycling technologies within an infrastructure design philosophy that reflects an understanding of issues such as co-evolution and adaptivity, such opportunities can be exploited to the full.

Existing research has already demonstrated the principles of this approach but two main challenges now present themselves. The first is to work with actual engineering and economic data about real technologies and networks in order to show how such an approach can be operationalised. This requires collaboration between scientists, engineers and technology modellers. The second is to show how the notion of sustainability in water systems, which themselves are at the base of a hierarchy of urban systems, can be integrated with the notion of Sustainable Cities. This requires collaboration between urban and technology modellers. Finally, both of these challenges require a proper understanding and representation of the needs of people. Ultimately, societies are the sole reason for the construction of cities and the design / management of technologies. The matching of the diversity of water demand profiles (in terms of quality and quantity across time and space) with opportunities provided by novel recycling technologies is a central challenge for the development of sustainable water utilisation strategies.

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