Cranfield Institute of Technology

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FACTORS THAT INFLUENCE THE RECEPTIVITY TO FAULT DIAGNOSTIC LEARNING WHEN A SYSTEMS APPROACH IS APPLIED
A TECHNOLOGY TRANSFER STUDY

INNOVATION & TECHNOLOGY ASSESSMENT UNIT

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Thesis Volume II.

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Ph.D

Abstract.

This thesis is concerned with receptivity and response encountered at different levels within organisations when a novel approach to the learning of fault diagnosis skills is introduced. Essentially, the work involved the transfer of a learning technology from research and development on the one hand to the workplace on the other.

With only a few exceptions, previous research had taken a highly focused, machine-centred view of fault diagnosis. The same view has been adopted towards the limited range of training that is currently offered in this subject. The overall aim here was to introduce a holistic approach by viewing fault diagnosis as a social process that is conducted within a technical context. To do this, account had to be taken of the complex interactions found between a number of disciplines such as, design, production, quality assurance, buying, maintenance and management.

The learning technology that served as a vehicle for the transfer of this systems approach was a series of open learning modules. The modules were produced as part of the project.

The methodology was based upon an inductive approach that involved the interpretation of qualitative data; this was done using a triangulation of research methods: case studies, critical incidents, and survey questionnaire. The sample, of both large and small organisations, was designed to provide a mix of different types of manufacturing and service industries. In each case, the practice of fault diagnosis skills continues to be a critical influence upon business performance.

Different factors arose at different levels within each organisation, and between-organisation factor differences are also identified.

Apart from the production of open learning material, the contribution made to the subject area is of new insights into the mechanism used for technology transfer within companies, and the identification of factors that either facilitate or hinder transfer of this kind. There is also a contribution to the debate about how the theory of systems thinking can be applied in a prescriptive way as opposed to the more common descriptive delivery.

Recommendations are made for further development of the learning technology.

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A special thank you to my wife Margaret for her constant support, without this the task would have been very much harder.

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Chapter 1. The Theoretical Framework.

1.1 Background.

Fault diagnosis, the medium used for this study, does not have a long history, for example the textbooks in engineering printed before 1950 made no reference to diagnosis It was not until the early seventies and the introduction of the microprocessor that interest, and consequently research, mushroomed to the extent that, on average, one paper is produced every month on an aspect of fault diagnostic practice. Broadly speaking this interest revolves around how individuals become 'good' Diagnosticians or Troubleshooters, and how organisations can achieve effective and reliable performance from machines and equipment that are becoming increasingly complex in operation. One significant characteristic of new technology is that it is not uncommon for 90% of total downtime to be accounted for by the tasks related to diagnosis of faults. Time spent on the task of repair has decreased considerably in proportion to that of diagnosis. Currently, it is estimated that the costs of maintaining new technology are increasing at around 15% per year; an increase that is 30% greater than comparable increases in production costs. There are also other costs which are difficult to represent at this macro level of analysis, such as quality costs arising from poor fault diagnostic performance, or increases in pay-back time due to excessive lengths of downtime caused by ineffective diagnosis. There have been estimates of £15 billion a year spent on the maintenance of technology in both service and manufacturing industry, an amount required by the National Health Service over the same period. Personnel who are charged with responsibility for fault diagnosis can have a significant impact upon business performance.

1.2 Assumptions and Issues.

Two key assumptions underlying this thesis are that training support for people who must diagnose is poor in the United Kingdom, and that both research and shop-floor practice adopt a too reductionist approach to the subject in a way that is no longer appropriate for the complex interactive nature of new technology. It is argued in this thesis that more effective training and a more holistic approach is needed in order to address a number of key issues that exist at the present time. These issues, raised during the course of the field work, are presented below and serve here as scene setting for the project.

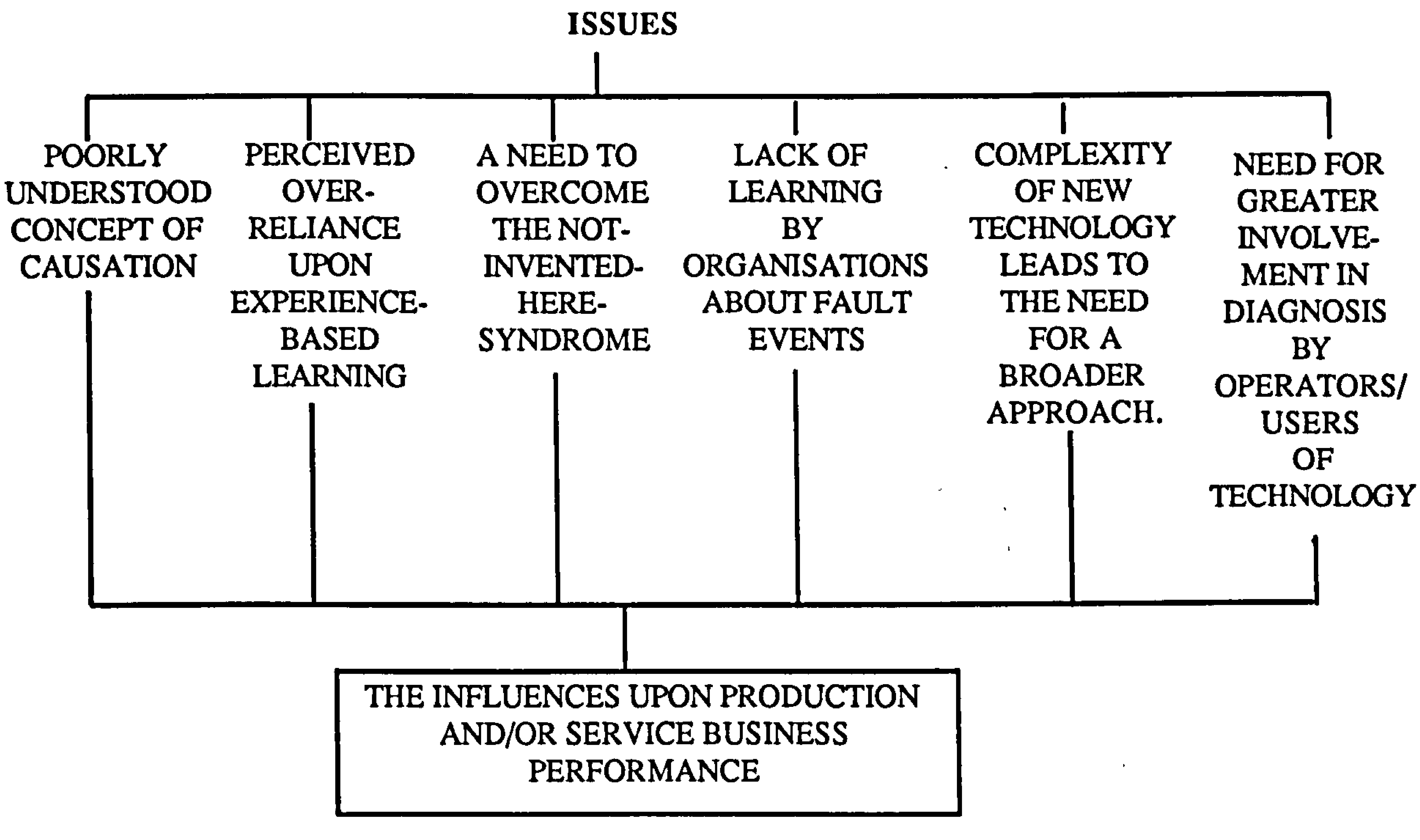


Diagram 1. Issues leading to influences.

* The concept of causation is poorly understood by the majority of people working in the field of fault diagnosis, consequently the distinction between symptom, sign, fault and cause are ill defined and confused. In practice, this leads to causes being overlooked in preference to the more narrowly focused fault fixing. An issue here is how to make the identification of causes a part of corporate thinking.

* Past practice, when the senses of smelling, touching and listening were used to fault find and diagnose, has led to the belief that skills of diagnosis are only gained through practice and experience and cannot be taught. Experience is now of limited use because the increased reliability of machines and equipment does not allow for the long reinforcement of learning through familiarisation of past events, also the use of senses are now strictly limited. Training in the use of diagnostic strategies is now necessary, but a key issue is how to overcome the idea that experience offers the only way to learn the skills of diagnosis.

* Given that the skills of fault diagnosis can be taught, an important question is to ask how generalisable these skills can be across a range of different industries. For example, can a skilled troubleshooter in the chemical industry transfer these skills to the steel industry? Evidence from research done for this project indicate that while actual processes are different the core skills of fault diagnosis are shared in common. A key issue does persist here, mainly of the 'not invented here' syndrome, that training material not narrowly targeted at in-house specific faults will be of no value.

* A cause of some inefficiency within industry is to be found in the practice of repeatedly fixing recurring faults. This practice occurs much less in situations where fault event records are maintained because such records provide, among other things, a pattern of causation; it is then possible to address causes rather than simply rectify faults. The medical profession do this very much better than engineering; the medical 'history' is an indispensable part of a doctor's work, he or she cannot perform without records of past diagnoses. There is a direct analogy to be made here with people who diagnose on machines and equipment; the nature of new technology demands that 'histories' are maintained. The issue here is that, unlike medical doctors, technical people are most reluctant to keep records, and when they do the outcome is often of records that are inaccurate and unreliable. On the evidence of this project, this last point applies even in companies where every effort is made to keep diagnostic records. Prior to this project, no training existed outside the medical profession in this important subject area.

* Faults occur exclusively within machines, processes or equipment, causes of these same faults on the other hand can occur across a wide range of functions within an organisation. The issue here is that the breadth of vision that enables this awareness to exist resides almost entirely at the level of senior management, and seldom extends down to the shop floor. In this project it was only possible to come across isolated examples of Operators or Technicians who had this breadth of awareness. In most cases the boundaries between departments were effective barriers to the necessary flow of cause-related information.

* The user or operator of new technology normally has a low profile when being considered as someone who can fault diagnose. This is an unfortunate situation because evidence from this and other research work indicates that Operators who can diagnose to even a limited extent can contribute greatly to the performance of the more specialist Troubleshooter. The issue here is why, apart from obvious safety reasons, should operator staff be excluded from this vital part of modern industrial applications.

1.3. Influences and Initiatives.

Although each issue can be said to have characteristics that influence business performance, the issues do interact to influence aspects of performance as illustrated in Diagram 1.

One influence is upon pay-back time of investment in new technology, (Figure 1, page 90), brought about by the amount of downtime. Another influence is upon the extent that costly contractor assistance is utilised, (page, 94), brought about by the level of in-house diagnostic skill use. Other examples are provided in the thesis, particularly in Chapter 9.

The identification of negative influences upon business performance leads to a perceived need for new initiatives or innovations of some kind. One option is to find ways of making fault diagnostic training more effective, both in terms of the learning content and in the approach taken to the delivery of the learning material. The initiative must also include consideration of how the learning is transferred between the research source and the points of delivery.

The adoption of open learning material, that had to be researched and written, can be seen in context when put alongside other possible options for the transfer of learning technology into a company.

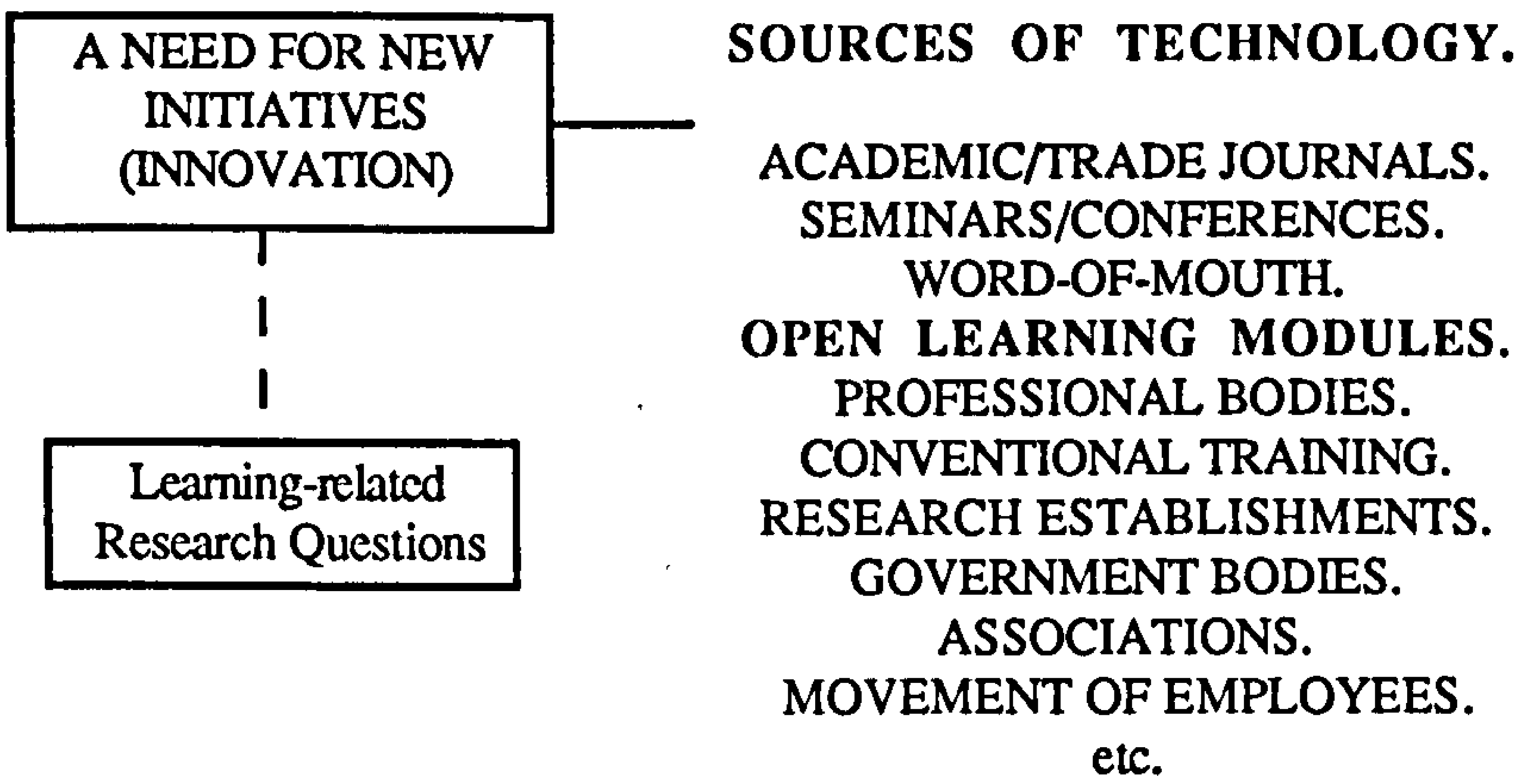


Diagram 2. Initiatives

An attempt has been made to address these issues by producing an extensive set of open learning material that in content and form has not existed previously, see Appendix C in Thesis Volume II. Like dropping a pebble into a pool to see the affects, this material has been introduced into a sample of both large and small companies in order to gather receptivity and response.

The research necessary to produce the learning material and the writing of the open learning modules addressed mainly one of the assumptions that training in fault diagnosis is poor in the United Kingdom.

1.4. Approaches.

A systems approach was adopted to address a second assumption that both research and shop-floor practice adopt a too reductionist approach to the subject of fault diagnosis. Alternative options, (Diagram, 3), to be considered are the use of condition monitoring and expert systems, both are discussed in the Thesis, (Section, 2.5), each aim to provide in their own way an approach that emphasises prevention of faults. A further assumption in the Thesis is that faults will occur despite preventive actions, no matter how sophisticated and an approach that can facilitate most effective diagnosis is still required.

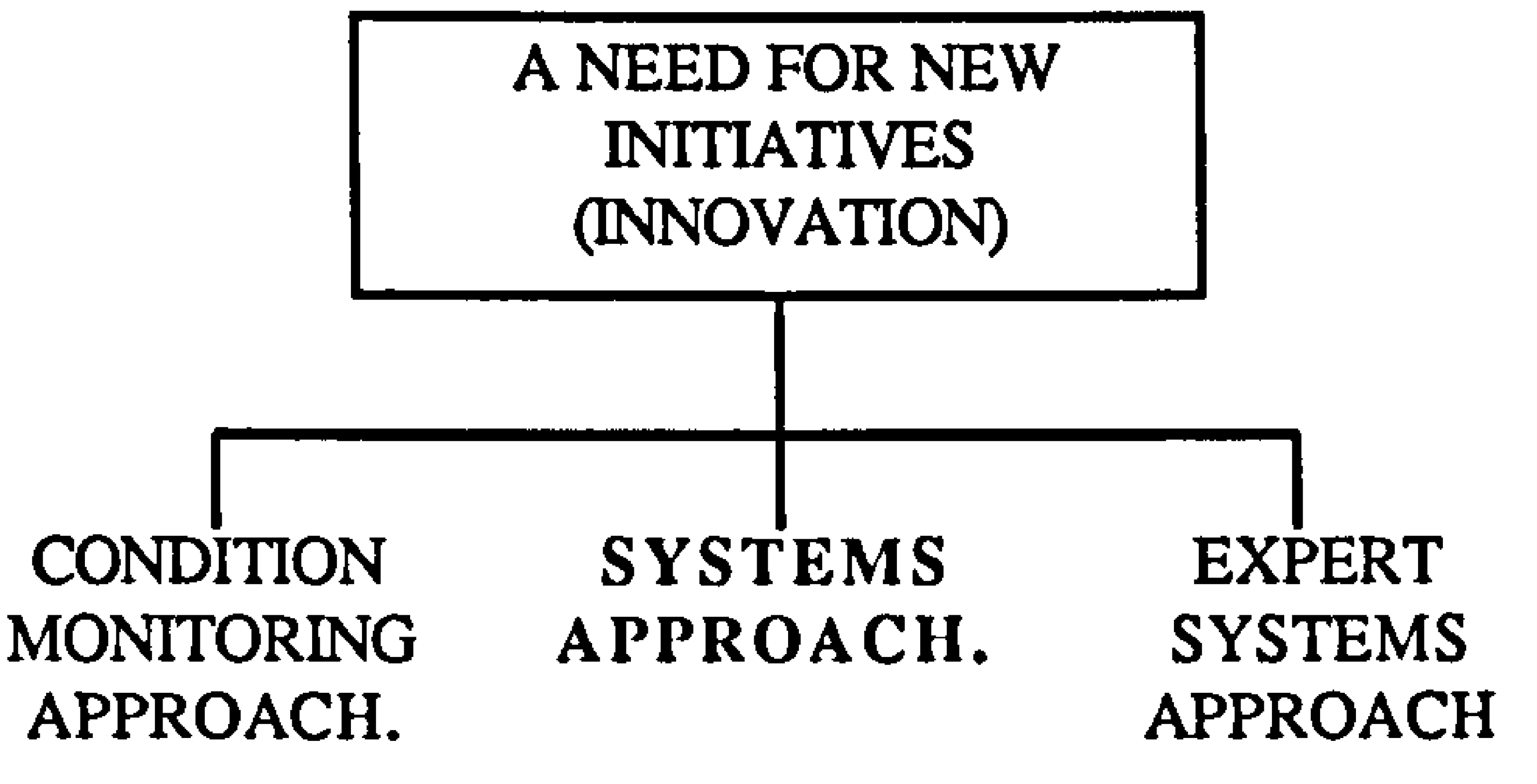


DIAGRAM 3. Approaches.

One problem in adopting a systems approach is in dealing with the distinction between how we think about events by using systems-related concepts and how people often use the term 'system' when referring to the real world. As a means of making this distinction it is useful to consider the use of words as labels on the one hand and as concepts on the other. When reporting the receptivity of people to a systems approach the systems-related words are used sometimes as labels to simply indicate that they are calling a process or a piece of equipment a system. In some cases the people who have been involved in the project, by their responses, were using the terms in a conceptual way by giving meaning to the terms; this was normally done by recognising key inter-relationships between components of the process under discussion. A difficulty encountered during the project was in moving people away from the view that there are 'systems' in reality, what can be called real-world systems, to a view that recognises that in systems thinking the terms are being used as hypothetical constructs to help give meaning to complex situations where not all events are observable. Establishing that in reality there is no such thing as 'a system' and that 'systems' exist only as a result of being conceptualised by each individual in his or her own way, can involve people in an unlearning exercise. Systems thinking is a methodology of conceptualisation, (Checkland, 1976), that, 'provides through systems ideas a way of seeing diffuse ill-structured problems in a patterned way, and tries to do so without distorting the problem in a way that the application of techniques usually does. It seeks not to be reductionist but to provide a conceptual framework with which many different aspects of problem situations can be accommodated'. It was an inability of some people to conceptualise beyond immediate or past experience in order to apply new meanings to fault events that could hinder receptivity to some of the ideas.

In attempting to understand the behaviour of people within the workplace, in terms of their receptivity to an innovation, some concepts from systems thinking have been applied. The concepts have been used at three different levels; operational, methodology and technology transfer.

1. To understand how shopfloor personnel and managers perceive the relationship between the behaviour of machines, equipment and users. At this operational level the concepts of interactions, boundary, environment, sub-systems, component, feedback, mess/difficulty and multiple perspectives are particularly relevant. On the evidence of this study, some people do have difficulty in using these concepts to articulate what is happening in a complex situation when diagnosis is being performed because the systems thinking application of the terms (conceptualisation) is different from the real-world or 'labelling' use. In cases where conceptualisation is possible practitioners can find the use of these terms enormously helpful in explaining complex processes when previously there had been difficulty in doing this. Examples of concept use at this level arise when discussing how past research in fault diagnosis, (Pages, 16 and 175), tended to draw boundaries, in systems-thinking terms, narrowly around diagnostic events within complex systems, and tended to view the situations as well-bounded difficulties when the situations could reflect the characteristics of unbounded messes. How the concepts of 'sub-system' and 'element' are used at this level is largely determined by the view taken of each fault event by individual Troubleshooters and the multiple perspectives that can exist here. (Pages, 81-82). A reductionist view is that elements are automatically what some Troubleshooters describe as the Least Repairable Unit (LRU). This view fits a real-world definition of 'element', if not a chemical definition, but in terms of systems thinking the term is used more flexibly and can refer to quite large items of equipment, if for the purposes of diagnosis they need not be reduced further. In a similar way, the term 'sub-system' can have a meaning in real-

world terms that fixes a section of a machine, or part of a firm permanently in that state when, as a concept, sub-systems are not fixed; when applied as part of systems thinking, the term is used in a more flexible way to help in the understanding of how complex systems adapt when faced with changing technology. Whether, for example, diagnosis is focused upon a sub-system or an element can be determined by the perception of the Troubleshooter(s), the relationship with other systems and/or sub-systems and the particular state of the technology at that time.

2. How the research methodology could be designed to reflect the attempts being made to introduce a more holistic approach to fault diagnosis also raised important differences between real-world view and systems-thinking conceptualisation of systems. First, the research work began with the writing of an open-learning approach to fault diagnosis that introduced for the first time in this area such ideas as: learning a strategy that consisted of techniques to be used at appropriate times, building in new methods of fault recording and analysis, and taking into account the various interactions between components in an organisation when looking for causal links between fault events. When the completed learning material was introduced into selected firms the methodology had to be adapted to allow for the technology transfer-type issues that were raised. At this point the original aim of taking a holistic approach by broadening the scope of fault diagnostic learning was further extended to encompass the mechanism that firms use (or do not use) in acquiring technology that could aid the diagnostic process. When 'holistic' is used in this study the concept refers to a view taken of fault diagnosis technology. The view includes all relevant interactions between, on the one hand, suppliers and researchers in the environment of a firm and, on the other, all the components of a firm that have influence, no matter how small, on diagnostic performance. From the evidence of this study, (Page, 90), the use of the term, or views that can be described as holistic are not common among Troubleshooters. In the case of research methods selection, as part of the methodology, case studies were chosen as one means of providing a more holistic approach to the understanding of behaviour in this area of work; it can be argued too that the adoption of a triangulation of methods also contributed to a more holistic approach.

To use another systems-thinking concept at this level it can be said that 'multiple perspectives' can be recognised, (Page, 56), in the response of people to training material and to training in general. If one view represented by the statement that diagnosis is learned only through experience is predominant, then any formal training whether by open learning or traditional methods can be difficult, if not impossible, to introduce. Where training can be introduced the concept of 'boundedness' can help in the understanding of peoples' receptivity to the learning material. The idea that some parts of diagnostic behaviour are context-specific and others are context-free, (Yuang-Liang and Govindarag, 1986), is not readily recognised by Troubleshooters and others who can influence diagnostic performance, (Page, 46), the 'not invented here' syndrome can be said to emerge from the practice of drawing strong boundaries, in system-thinking terms, around processes in a too-limiting way.

3. How existing technology transfer mechanisms can be understood through an examination of channels and of peoples' roles within these channels would it was felt be helped by the use of concepts from systems thinking. The concepts identified as relevant at this level are, hierarchy, feedback and multiple-causation. When for example hierarchy is used to help in the understanding of the relationships between fault events, people or departments and access to technology, the term is being used in a way somewhat different from use of the term in organisational settings, as found typically represented on organisational charts. In the systems-thinking sense the concept refers to the hierarchical relationship between the wider or suprasystem, the systems, sub-systems and elements. There is within the wider system a number of systems such as, production and maintenance which can be viewed in a real-world sense or can be conceptualised in a way that allows for a merging or semi-merging to be recognised. Other real-world functions to influence fault diagnosis are, purchasing, research and design, quality assurance and marketing. Viewing these functions in a conceptual way can provide new insights and understanding. For example, the approach of Troubleshooters who adopt a largely reductionist position is to view the machine or piece of equipment as the main system and tend to ignore the possibility that ultimate causes of recurring failure may exist within the wider system, or in some cases in the environment of the wider system. The 'whole' or wider system within its environment can

be a complete chemical plant, (Page, 105), that contains smaller wholes, (Checkland, 1992), 'this gives the idea of a layered or hierarchical structure'. Checkland goes on to say that, 'if the whole has a process of communication and processes of control, then it might, in principle, adapt and survive in a changing environment. From the experience of this study it can be said that the ability of an organisation or wider system to utilise relevant technology emerges through a series of complex interactions that occur within the layered structure. It is argued further that how well this ability is applied contributes significantly to the survival of a firm in a changing environment.

There is a possibility that concepts used in this way to aid the understanding of complex events can appear as listings in almost a checklist approach, and in Checkland's words, (Checkland, 1992), 'do not map each other'. The discussion above about systems thinking, as applied in the project, being a methodology of concept use and giving examples of the distinction between real-world labelling of systems and systems-thinking use of the concepts helps to provide a more coherent expression of ideas from systems thinking and how they are applied in the text.

The term used in the United States Navy for adopting a holistic approach is 'seeing the bubble', (Roberts and Rousseau, 1989), on a naval vessel where numerous complex operations and groups of operations interact a broad approach becomes essential. It is argued in the thesis that many service and manufacturing processes now reflect the characteristics of a naval vessel. A further aspect of wholeness is that on-going interactions between people and between processes need to be identified in order to complete the picture. Inspection of some 170 research papers on the subject of fault diagnosis has led to the conclusion that the concept of wholeness was missing from all but three of these papers. This point is discussed more fully in Chapter 2 on the literature review; sufficient to say here that this finding acted as one trigger for considering the adoption of a holistic approach. Findings from a research project, at the University of Wales, into training in fault diagnosis, (Patrick, 1985) added evidence that a too-narrow approach was being practised. A report based upon further field work that was done in a range of companies, (Craig, 1989) reinforced these earlier findings. Part of this work involved a comparison between medical diagnosis and engineering diagnosis. A useful analogy in this respect is that of respective general medical practitioners, one who takes a 'whole person' approach when diagnosing while the other will focus only upon the known symptoms. The same observation can be made of technical troubleshooters, but here, unlike in the medical profession, few troubleshooters can be said to take a 'whole system' approach, the boundaries around fault events are drawn narrowly, and as a result many causal factors are overlooked. An important aspect of this reductionist approach is that each fault event is seen as a well structured problem to be solved and each solution is seen as a battle won. Seldom is this experience seen as an on-going learning process for the groups of individuals involved on the one hand and for the organisation on the other. The result of this practice is that individual pockets of expertise exist in isolation within the company. Interaction in the form of feed-back channels is rare, and in this situation the concept of organisational learning goes unrecognised.

It was against this background that a holistic approach to this subject was transferred into a range of companies. The above observations are based upon earlier investigative field work and are essentially descriptive, there was no formal attempt to explain why this particular situation exists, there may be perfectly sound reasons for not adopting a more holistic approach; despite the claims made for the effectiveness of a systems approach it may not be appropriate in this context. Appropriateness of this approach is discussed more fully in Chapter 11. One means of discovering the reasons for particular practices, in this case the use of a reductionist approach, is to challenge the norms of these practices by presenting an alternative view.

It was anticipated that taking a broader view of this subject would come more readily to some people than to others. There are two theories to be considered here, one is that readiness to accept and respond to a broader picture is a function of a person's position within the organisation, the other is that some people are what can be called serialists and others holists in terms of their cognitive style (Pask and Scott, 1972). Holists prefer to be given the whole picture when learning or when attempting to solve a problem, while serialists prefer to proceed in a step-wise narrower manner. There is evidence from the research that serialist-type people are more attracted to technical and engineering type occupations, which could go some way to explaining the reductionist approaches commonly observed; the idea seems worthy of further research.

In this project it has only been possible to assess receptivity and response by level in the organisation.

1.5 Transfer Mechanisms.

The transfer mechanism is defined here as the existence of a pathway or channel, staffed by appropriate people, into and through a firm to enable the transfer of technology to take place.

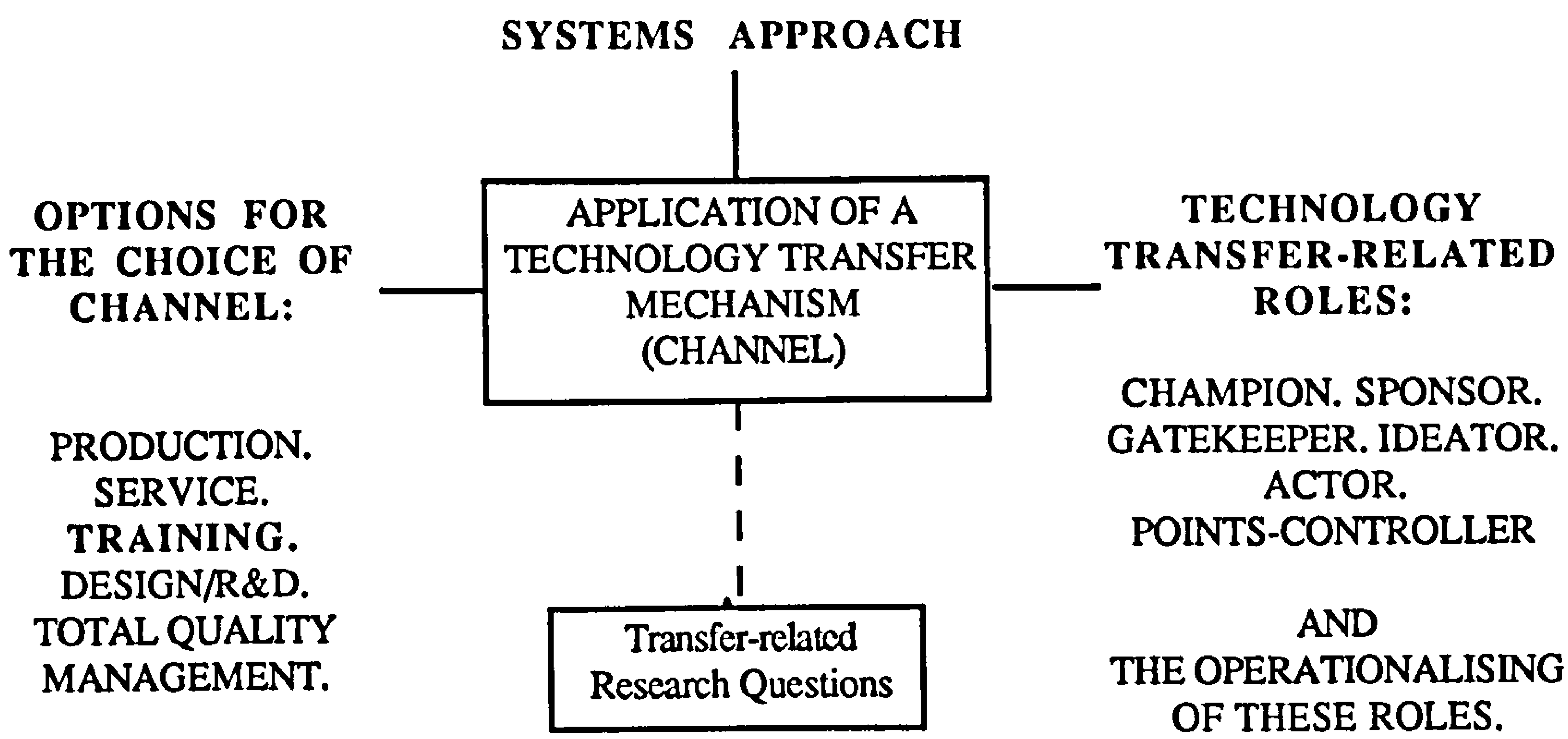


DIAGRAM 4. Transfer Mechanism.

The choice of a function to act as the main provider of a transfer channel is discussed in the next Section, and considered more fully in another part of the thesis, (Section 5.3, page 67), the application of technology transfer-related roles will be elaborated upon here.

How well people accept ideas, concepts and approaches that are novel to them and how they respond in a practical way is a significant factor in the process of any innovation. To quote, (Hatchuel, 1987) ' the success of the intervention (or the creativity of the the innovation) depends upon the kind of relationship which can be established between the parties participating in the intervention (the innovative process)'. It has been proposed that , within organisations, there are people who adopt particular roles in relation to the process of innovation. (Rosenfeld and Servo, 1990) These roles involve functions that are different from those performed as part of a person's formal job; typical roles are:

Ideator, in this role a person will generate one or more ideas but does not necessarily act upon his or her inspiration.
Technology Gatekeeper or Innovator, in this role a person is willing and able to convert ideas into reality.
Champion, in this role a person has the commitment and contacts to be in a position to promote the innovation.
Sponsor, in this role a person is in a position to find financial support for an innovation.
During the course of field work, done for this project, two further roles were identified:

Points Controller, this metaphor is used to help describe the person who, in this role, will divert ideas away from his or her area of interest to another department or branch of the company.

Actor, in this role a person will be initially reactive to ideas but is in a position of having to make them work in practice; in some cases this role can transfer to one of Gatekeeper or Champion, if the person concerned can take the ideas further.

The significance of identifying these roles is that behaviours generated by people who are in one of these positions can have an influence upon overall receptivity and response. This influence can be overlooked if each person is seen only in terms of his or her formal job title. Therefore it was necessary to recognise a company production director who promoted this learning technology with some enthusiasm as taking on the role of a champion. On the other hand, a machine operator in the same company could be seen, in terms of adopting new ideas, as an actor. This role could be sustained throughout the exercise or could change to champion, for example in talking to others about the work, or could quickly become one of points controller, or retired actor!

For the purpose of assessing receptivity and response, three dimensions were identified as being relevant to the adoption of this technology:

1. Across a range of occupation types within each company, from senior manager, through middle manager, supervisory and technician to operator.
2. Across a range of departments, taking into account wherever possible diverse groups such as design, stores, marketing and production.
3. Across a range of companies representing different processes and company sizes as defined by numbers of people employed.

It was anticipated that levels of receptivity and response would vary both across and between these dimensions. From this, it was further anticipated that factors either facilitating the adoption of this learning technology or hindering adoption would emerge. These data on receptivity and response were collected in order to find answers, if possible, to a series of research questions, (Section, 1.8) Answers to these questions, that emerged from the field work, are presented in Chapter 10.

1.6 Evaluation.

Evaluation, in this context, is at two levels; one is evaluation of the learning material contents, which is discussed in the Thesis, (Section 4.4, page 56), and the other is an evaluation of benefits, advantages and/or disadvantages to be derived from the initiatives taken, also discussed in the Thesis, (Chapter 8, page 125)

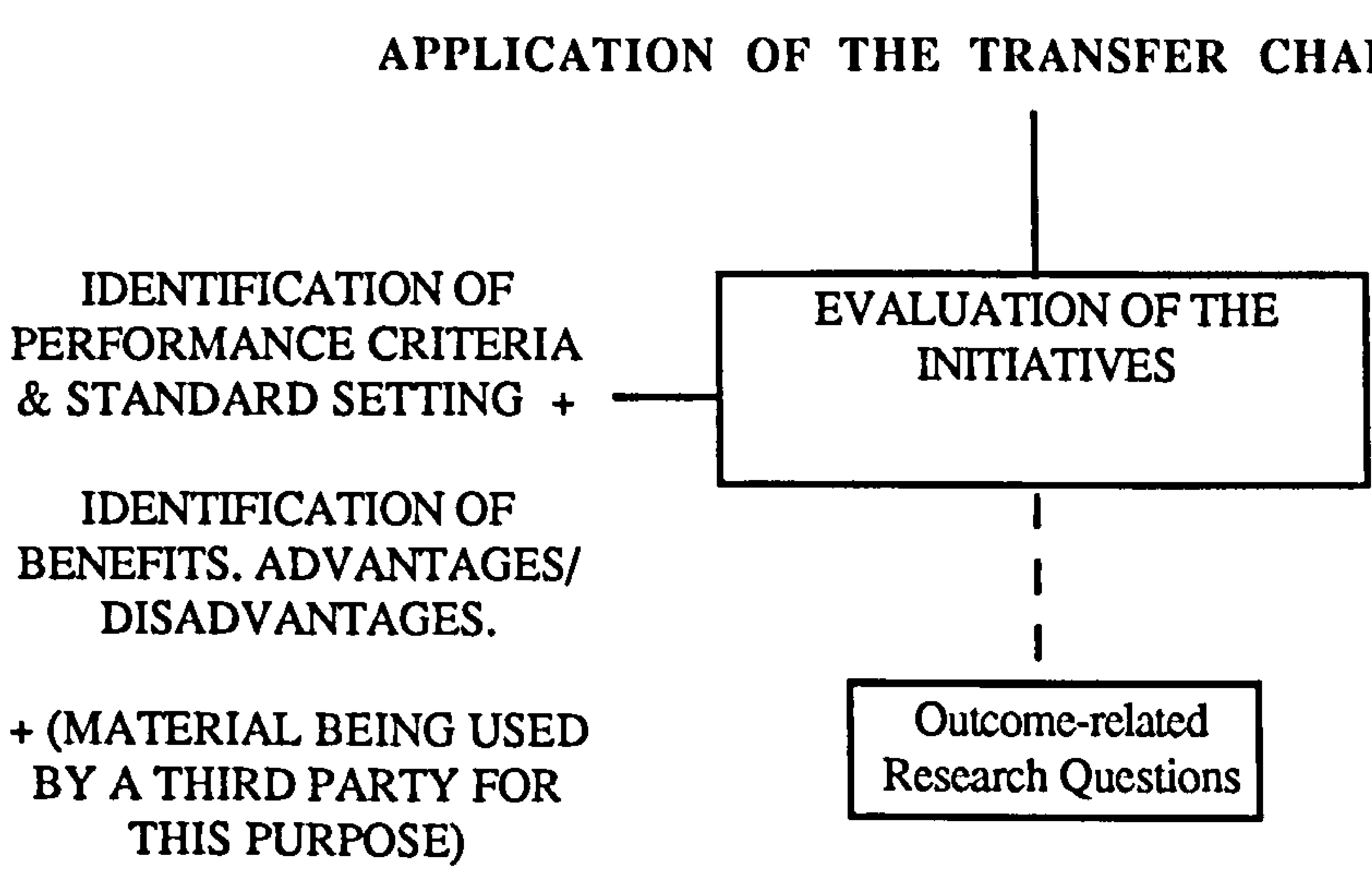


Diagram 5. Evaluation.

There can be a difference between process-orientated standards, which are predominant in the Thesis, and what can be called product-orientated standards or competencies as commonly used in current methods of work performance assessment. The emphasis here is upon understanding of processes for the purpose of diagnosing and the transfer of a technology; there is less emphasis upon the end 'can-do' type of measure. This issue is discussed more fully in the Thesis, (Chapter 10, page).

A complete model of the transfer process from issues to evaluation is shown below in Diagram 6:

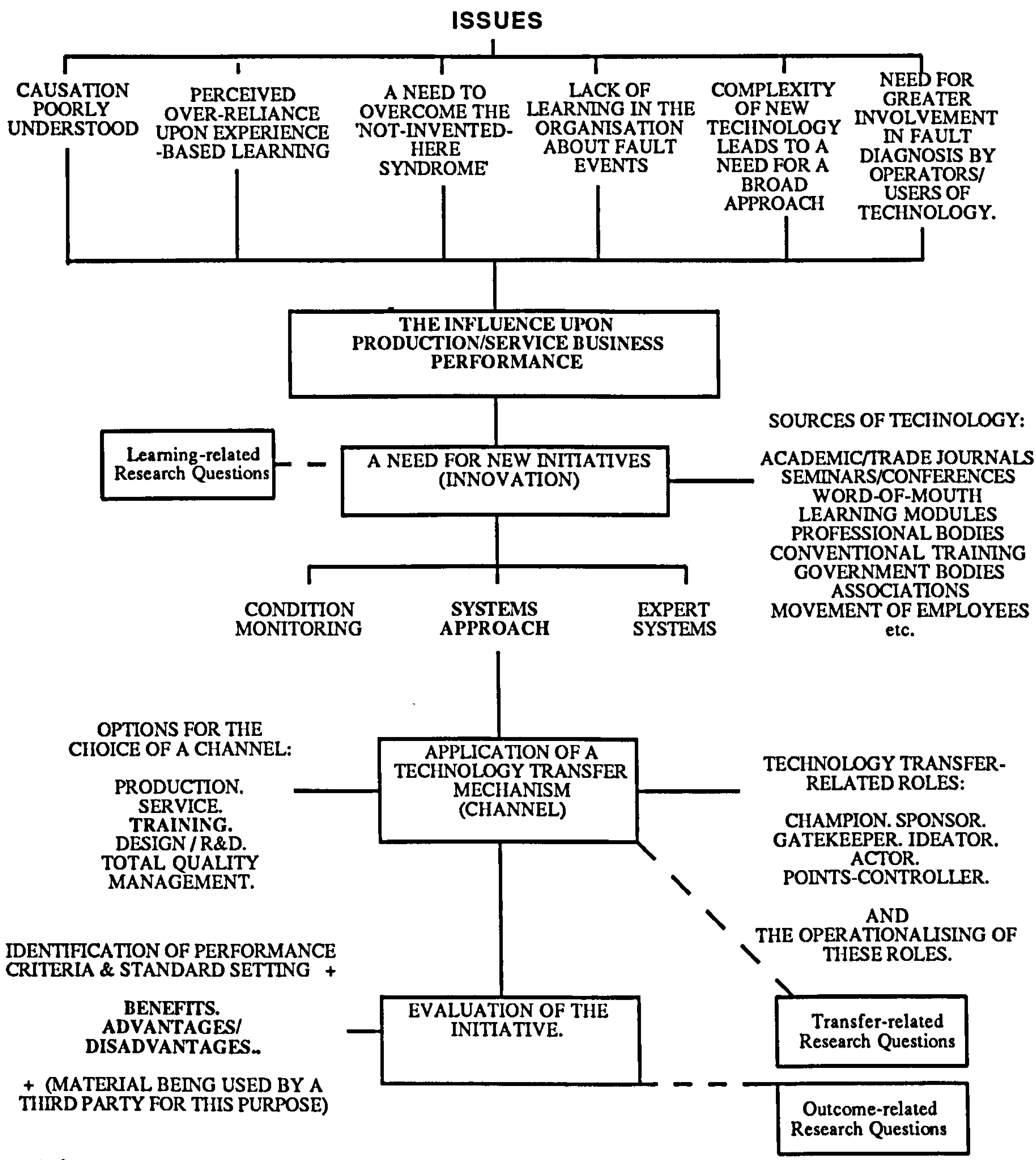


Diagram 6. The transfer model.

1.7 The Research Framework.

There are three elements which interact to form a theoretical framework for this study.

1. The use of a systems approach.
2. The 'medium' of fault diagnosis.
3. The transfer of learning technology.

The relationship between the three stages and how they form the framework is shown in Diagram 7.

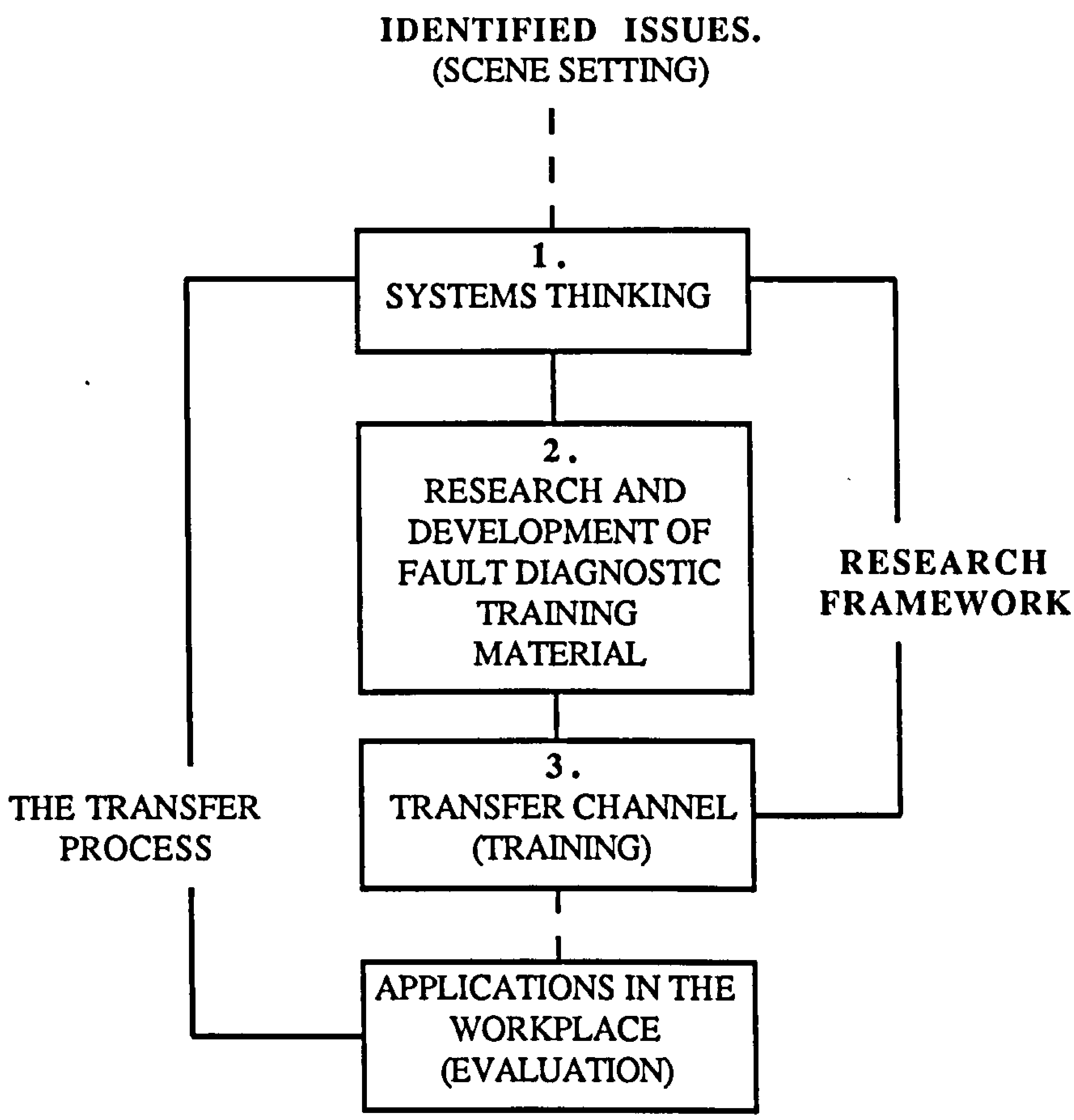


Diagram 7. The research framework.

Firstly, see Diagram 7, the approach taken to facilitate the transfer is best encapsulated by reference to systems thinking; the aim being to adopt a holistic approach where previously work in this area had been largely reductionist, as shown by the literature review in Chapter 2. At the beginning of this study a theoretical stance was taken that a more holistic approach, see the next section for an explanation of this, to training in this subject would prove to be more effective than the commonly used reductionist methods, that is in achieving improved utilisation of new technology by applying improved skills to on-going maintenance work. This theoretical stance changed from one of testing out such a hypothesis to one that aimed to investigate, using qualitative methods, the effects that come from applying a systems approach.

Secondly, the medium used was fault diagnosis as practised in a range of manufacturing and service companies. As explained in the background to this study, fault diagnosis is an area of work that is critical to business performance, especially in businesses where modern machines and/or equipment have been introduced to increase service or manufacturing output. Normally, the introduction of such technology has led to reductions in the number of people at operator level. However, people charged with the responsibility of maintaining this technology have an increasingly important role to play. Despite the development of automated testing and diagnostic aids there is still the need for human intervention when things go wrong. It is anticipated that this position will continue for at least the next ten to fifteen years. Only when fully diagnostic aids are available through the use of intelligent machines will this skill need be reduced to all but a small number of highly specialised individuals.

Thirdly, what can be called the 'subject' of the study is the transfer of a learning technology from its research base to actual implementation in both service and manufacturing companies. Inspection of technology transfer literature shows that emphasis is upon transfer between so-called developed countries and the third world. There is however a legitimate use of the concept as applied to a less macro situation such as from a University research department to a local company. How well innovation of any kind occurs is to a certain extent dependent upon the efficiency and effectiveness of a transfer mechanism. This can be said to apply equally to internal transfer of technology such as from an R&D department to the production department of a firm, as well as transfer from outside the firm. The function of training was used as a channel through which the transfer of the learning technology took place. The choice of channel is critical to the eventual transfer of ideas, artifacts or processes and has been described as mobility, (Seaton and Cordey-Hayes 1992) or the ease of obtaining technologies and the use of channels through which they are transferred. A channel other than training could have been used such as Organisation Development (OD), Total Quality Management or a Man-Machine reliability study. Intuitively, the process of training ought to be a channel suitable for innovative activity given that one aim of this function is to help people learn and to adapt to new tasks. However there are characteristics about training, as generally practised, that raise questions about this suitability. Initially it was thought reasonable to test at least one hypothesis such as ,'training will prove to be ineffective as a channel for innovation within a sample of companies', spelling out measures of effectiveness to be used, the basis for this being that one long-standing characteristic of training in the United Kingdom is of being reactive to innovation. In other words, training practitioners give consideration to the skill need of people only some time after the introduction of new equipment or methods. Examples of more proactive approaches, such as using business plan information to help anticipate knowledge and skill need, are rare. The approach taken, which has been expanded upon in the chapter on methodology, was to investigate the appropriateness of training as a transfer channel in the context of introducing a novel approach to a field of work that is of critical importance to each company in the sample.

1.8 The Research Questions.

A number of deliberations took place over issues that had been raised as a result of research that led up to formulation of the thesis. Difficulties did arise from the fact that some practical field work had already been done and that re-orientation became necessary in order to provide a theoretical framework upon which to design a new stage of field-work activity. The result was that a shift was made from forming the framework around fault diagnosis as the central focus to one that considered the wider aspects of receptivity and transfer. For example, included in the original plan was the idea of responding to Dr Michael Kirton's suggestion that the cognitive style influence of innovation and adaption ought to be researched in relation to fault diagnosis performance. Such an approach, although worthwhile and yet to be done, would be in line with many other studies of diagnostic performance, and which have been described in the thesis as machine-centred as opposed to holistic. The early realisation that the identified issues reflected a number of personal interactions that took place in an organisational context, eventually led to a number of questions being asked about how learning related to fault diagnosis transfers into a firm and across departments; this 'transfer' then became the subject of the thesis. In this respect, it was the receptivity and response of relevant individuals that became a focus. Given that the transfer of any new approach into a company can be seen as innovative it was felt necessary to explore the roles of individuals that come from the literature on innovation, and to see if new insight could be provided by exploring an area new to innovation studies. This led to some innovation-related questions being asked. Whether the relative position of individuals in a firm influenced their receptivity and response was necessary given that in most cases the entry and dissemination of the technology was from senior-management level through to operators on the shop floor.

Learning, both in terms of the individual and the organisation, arose from deliberation of the issues; mainly because the evidence pointed to learning in both cases being achieved primarily through what is called 'experience'. Although it is difficult to establish what people mean by their use of the construct 'experience' it is applied liberally to learning in industry. Another aspect of diagnostic learning to arise from the issues was the role of people who perform operator-type tasks. Although one aspect of total quality management is that operators of machines and processes should feel ownership, there was little evidence of this being achieved during the research that led up to the thesis. A critical part of such ownership is the amount of responsibility given for basic diagnosis. In developing a wider view of learning about fault diagnosis it was necessary to consider whether organisations learn from failure events.

Finally it was felt that evaluation-type questions needed to be asked about possible outcomes from the field work. In this respect it was possible benefits to each firm in the sample and what advantages and/or disadvantages could be identified as a result of adopting a systems approach to this area of work.

Following the deliberations a number of research questions were formulated that relate to three aspects of the thesis. Firstly, to the subject of the thesis, technology transfer. Secondly, to the learning of fault diagnosis, the medium of the thesis. Thirdly, to outcome of the innovation.

Transfer related:

* Are some innovation-related roles more significant than others in facilitating this learning technology ?
* Are there significant differences between people, at the same level in an organisation, in how they accept and respond to this innovation ?
* Are there significant differences in how people, at different levels within an organisation, accept and respond to this innovation ?

* Is training, as a transfer channel, more likely to facilitate or to hinder the adoption of novel approaches of this kind ?
* Are there identifiable characteristics about people who either accept or reject a systems approach ?
* Are there significant between-company differences in receptivity and response to this innovation ?

Learning related:

* What evidence exists for the proposition that fault diagnosis is learned mainly through experience?
* To what extent can people at operator level become involved in the practice of fault diagnosis ?
* Are there significant differences in how organisations learn from failure events ?

Outcome Related:

* Can the adoption of a holistic approach to the learning of fault diagnosis provide tangible benefits to a company ?
* What advantages and/or disadvantages come as a result of applying a systems approach ?

These questions form a starting point for research and in this case reflect a broader view of fault diagnosis learning than has been common in the past.

1.9 Contribution of this thesis to the area of study.

Firstly, a contribution made by this thesis is to identify factors that on the one hand can facilitate the adoption of a novel approach, and on the other hand hinder adoption. The actual adoption of this approach required a significant shift in how most practitioners, and related people, perceive the learning and practice of fault diagnosis. The common perception is of *technical problem solving in which people take part* ; the shift is in seeing the work as *essentially a social process that takes place in a technical context.*. For example, when the former perception is adopted it is quite common for some people to make a plea for human factors to be given more consideration. In the latter perception of the work, human factors are paramount and the technical aspects become simply a processing of information by learning or dissemination. The identified factors reflect how readily such a change in emphasis can be assimilated, if at all, and whether differences in receptivity and response can be explained purely by reference to individuals, to organisational factors or both.

Secondly, the mechanism available for the transfer of this novel approach to the workplace mediates to influence the eventual outcome of the exercise. This transfer mechanism has two key components, one is the channel through which the learning material and ideas are processed and the other is the combination of roles that people often adopt when faced with the introduction of new ideas. The thesis makes a contribution to our understanding of this transfer mechanism concept by exploring the use of training as a channel and the part played by people in the various transfer-related roles, which have been discussed in the previous section.

Thirdly, there is a contribution in the form of fault diagnosis open learning modules that introduce the practice of skills not previously used in the teaching of the subject but which are highly relevant. For reference to these modules see Appendix C in Document Two. In this respect the approach can be called innovative in that it involves the introduction of ideas and material for the first time, and which are discontinuous with past practices (Heller, 1985).

Lastly, there is a contribution to an on-going debate about the prescribing of systems thinking in the workplace as opposed to the statement of theory in a descriptive form, that is most commonly found in systems literature.

It has been said that these days most people salute when a systems approach is run up the flag pole (Checkland, 1978). The theory of systems thinking has also been described as seductive, (Eden, 1983) and few people will question the ideas put forward. A contribution from this thesis is to highlight differences found between systems thinking as description on the one hand and prescription on the other. These differences were emphasised most strongly between the stage of proposing the use of systems thinking (descriptive) and the stage of putting these ideas into practice (prescriptive).

1.10 Summary.

The formulation of this theoretical framework is based upon five key assumptions:

1. That the practice of fault diagnosis will continue to be an area of work that is of critical importance to business performance.
2. That skilled human intervention will be required in the diagnosis of faults for, at least, the next ten to fifteen years.
3. That training support offered to troubleshooters has been, and continues to be, poor in the United Kingdom.*
4. That where training is offered it is presented in a reductionist way that overlooks the use of some critical skills, and overlooks wider causal events that help to explain why failures occur.
5. That during the process of transferring this learning technology the people involved will demonstrate characteristics of the various transfer-related roles that have been described above in section 1.5

* Results from the survey, reported in Chapter 8, suggest that such a training need currently exists.

A number of issues have been highlighted. These issues provide a basic grounding for the framework, and provided a means of generating the research questions.
Four elements are given that together provide the theoretical framework. *Fault diagnosis*, the medium used for this study, has been described as an area of work that is critical to both service and manufacturing industry. Because this medium involves a complex relationship between people, departments, technology and environment a *systems approach* can be seen as plausible in this context and worthy of exploration. To deliver the medium using a systems approach it is necessary to take account of what is called a transfer mechanism, and central to this mechanism is the use of a *channel*; on this occasion training has been chosen to serve this purpose. Overall the exercise is one that concerns *technology transfer*.
A rationale has been given for the adoption and exploration of a holistic approach that goes beyond the idea that it is a plausible thing to do in these circumstances. In this respect there is recognition that there can be very good reasons for the adoption of the more common reductionist methods.

The distinction has been made between what are called real-world systems and the application of concepts from systems thinking. The concepts and ideas from systems thinking provide one means of understanding complex events and relationships, and for this reason can be considered to be a worthwhile approach to current fault diagnostic work. Reference has been provided to parts of the text to illustrate how the various concepts have been typically used.

Research questions, which are an important ingredient of this theoretical framework, have been presented together with the deliberations and the rationale for their choice. Finally, four contributions to the subject area have been described which completes the framework upon which this thesis is based.

Chapter Two Literature Review.

2.1 Literature search methods.

The literature search on which this review is based was conducted using the key words listed in Table 1. This was done in four ways. Firstly, computer-based search systems were used at the Main Library and Scientific Periodicals department of Cambridge University, and also at Cranfield Institute of Technology. Secondly, a manual search was conducted by using the Applied Science and Technology Index and Current Technology Index. Thirdly, a manual search was done by tracing back from lists of references and bibliographies in the most recent text books and periodicals. Fourthly, a small part of the literature was picked up 'by chance' through periodic scanning of reports, magazines and pamphlets that do not always feature in formal data bases.

Table 1. Key words

Fault Diagnosis
Fault Location
Troubleshooting
Systems Approach
Training
Reliability
Cybernetics
Failure Analysis
Failure
Maintenance
Technology Transfer*
Innovation

* Produced material that was too macro "third world-based' to be of value; key word 'innovation' proved to be more productive.

By using this four pronged approach, although time consuming, it has been possible to collect a close to definitive bibliography of 287 works over the period 1988 to 1991, inclusive. The thesis uses a reference list rather than the full bibliography. This reference list includes work done between 1952 (the earliest recorded) and 1991.
The aim in compiling the bibliography was to represent latest research and writings while the reference list contains material of particular relevance to the thesis and covers the whole period of work on this subject.

Although faults had to be fixed on chariot wheels centuries ago, and the Stephensons had problems with their locomotives, there was no reference to fault diagnosis until the early nineteen-fifties. Occasionally, a list of machine problems and a list of possible remedies can be found. (Judge, 1936). In a 400 page textbook on aircraft instrument maintenance, (Werner, 1948), no reference was made to fault finding or diagnosis, and before 1950 no research had been done on the subject. Since the introduction of the microprocessor in the early seventies, there has been an exponential growth in this research; most of this work is based in the United States but other work comes from countries world-wide.

2.2 Machine-centred studies.

The history of fault diagnosis as a concept on the one hand, or as a paradigm introduced in the face of increasing problems on the other, goes back only forty years. In this time significant advances have been made in our understanding of the subject, yet early questions such as 'how do people diagnose?', and 'what makes the difference between effective and less effective Troubleshooters?' are still being asked.
The majority of this considerable body of research uses what can best be described as a machine-centred approach; less than ten studies can be categorised by the alternative term of 'systems approach'. It is necessary to use concepts from systems thinking in order to explain fully what is meant here by 'machine-centred'; two concepts are critical in this respect, one is that of boundary and the other is of environment.

Any system is partially defined by its boundary; whether this is drawn narrowly or widely becomes a question of individual perspective and individual choice. During the course of this research an analogy between medical and engineering diagnosis was developed that serves to illustrate this concept of boundary. A medical professional who adopts a specialist approach may diagnose an illness by focusing upon a 'favourite' area where his or her expertise lies, in other words a boundary will be drawn narrowly around the problem area. In contrast, a medical professional who adopts what is referred to as a 'whole person' approach may be inclined to draw a boundary that includes not only the person who is ill but also family and possibly employment too. An analogy can be made here with an engineer who, given a fault, may focus quickly to one machine and to a part of that machine where his or her expertise is best represented. A boundary will be drawn, and remain drawn, around the machine, or part of it, in a machine-centred way. Again in contrast, an engineer who adopts a systems approach may draw a boundary to include people and events that could provide clues to the cause of the fault; areas such as design, buying and stores may be considered. This analogy can be extended to include the skills that are required by medical doctors and engineers respectively. The person taking a specialist approach is inclined to rely upon experience of past events. The person taking a wider holistic view needs to learn strategic skills, and generally is called upon to use more skills of diagnosis. The environment in this context means the areas outside a particular system boundary where various influences are to be found. For any one complex piece of equipment there can be a large number of influences outside the boundary of this equipment. These influences need to be recognised if failure events are to be fully understood for the purpose of diagnosis. Some influences can be highly critical and a cause of failure, in which case a decision has to be made to include them within the boundary and as part of the system. This interaction between boundary and environment is an important factor in the explanation of system failures, and provides one of the main reasons for introducing a systems thinking approach to this subject; the terms 'boundary' and 'environment' are being used in a conceptual way, as opposed to their use in real-world processes where the words are effectively 'labels' for real division between activities or departments (boundaries) and for 'what goes on outside' (environment).

Providing an explanation for the imbalance between research that can be seen as machine-centred and research that takes a systems approach was not an aim of this study, but it is possible to speculate upon one reason. This is the need, discussed in the next chapter, for studies to be 'scientific' by controlling variables and testing hypotheses. It can be argued that this approach forces researchers into drawing boundaries narrowly around what are often diverse and complex human situations. In systems thinking terms many fault diagnosis events can be described as 'messes,' and by taking a reductionist approach these messes are being treating as well bounded 'difficulties'. To what extent the outcome of such research has been influenced by the methodology adopted could be shown only by further study. This is not to suggest that reductionist methods should not be used, but that some balance should exist between this approach and a holistic perspective of the area.

2.3 Evidence of holistic approaches to the subject.

One of the earliest references to a holistic approach in this area, (Gosling, 1962), refers to engineers needing to predict the emergent properties of a system, that is, those properties which are possessed by the system but not by its parts. When a system fails the cause may exist within these properties as much as in any individual part.

The discipline of Operations Research (OR) provides the main source of literature covering a holistic approach. In one study, (Christer and Whitelaw, 1983), a case study method was used in two companies to analyse fault information to determine its usefulness to managers. A broad view was adopted of the operations at both sites in gathering subjective information about failure event. Emphasis was put upon causation and the many facets of causation related to fault diagnosis. There was as a result of this analysis a clear identification of preventable and non-preventable causes. It is possible for a particular process to have non-preventable causes; in this situation managers need to question the extent of any preventive maintenance policy. In contrast, a high percentage of preventable causes should prompt managers to question any breakdown maintenance policy in operation. On the evidence of current research this type of finding has not filtered through to industry; a distinction of this kind between causes is seldom put into practice. The broad investigation of fault information also revealed that a quantifiable measure of fault frequency was not a reliable explanation for downtime on machines. The collection and analysis of subjective information indicated that a preventive policy for mechanical faults, as opposed to one for the more frequent electrical faults, would have greater impact upon downtime statistics by achieving a 40% reduction.

Another project to come from Operations Research is work done in the United States. (Rault et al, 1986). This study considered the relationship between product quality and machine tool availability, and was based upon an investigation of the whole system. This was a feasibility study to demonstrate that observations of the whole process can lead to information on performance diagnostics in such a way that quality and availability are improved.

Of particular relevance to the holistic approach is research done on high risk organisations, i.e. nuclear power plants, air traffic control and oil tanker fuelling (Roberts and Rousseau, 1989). In this research the US Navy term 'having the bubble' is used. For example, data from one unit or one level cannot yield the 'bubble' necessary to comprehend air traffic control events, such as failures or near failures. The research categorises many features of high risk organisations that need to be taken into account when planning for what is the bottom line, fault prevention. Of major importance is the organisation structure and the ability to process possible failure information. There is in these situations a high level of interdependence across many units and levels. These and other behaviourial factors are discussed in relation to this type of organisation.

An example of multiple research method use in a manufacturing setting provided insight into the problems inherent in conducting such field work, but also produced valuable lessons about Troubleshooters' behaviour (Bereiter and Miller, 1989). The methods of direct participative observation, and the recording of both concurrent and retrospective thought processes when diagnosing, were applied. The difficulties in making audio-taped recordings of concurrent diagnosis were described and the inherent weaknesses in retrospective recall of diagnostic events were highlighted. In terms of methodology a conclusion drawn was that training centres where actual processes could be simulated would be a a more reliable setting for this type of field work. An alternative approach of using laboratory-based research was not considered due to the lack of realism, but it was felt that this field work lacked sufficient control. However the findings made a significant contribution to the subject. Data showed that Troubleshooters make use of a multitude of information sources. The idea of long and short diagnostic episodes was introduced. The choice that Subjects made of testing strategy determined how long an episode would be. Also, there was support for Wohl's theory, (Wohl, 1983) that Subjects choose tests that provide the shortest time to perform. Taking a broad view, the Researchers point out that systems design can influence the behaviour of Subjects and their effectiveness, since ease of testing various fault conditions is largely determined by the design of hardware and software. If possible, most probable failure points should also be the easiest to test. The observation was made that Troubleshooters perform in conditions that are highly uncertain and with information that is often incomplete. In such situations, difficulties are encountered that cannot be captured in a laboratory setting.

Various examples of cybernetic models of the maintenance function go some way towards presenting a holistic approach. (Smith, 1984). The models normally consist of blocks, as in a flow diagram, beginning with a statement of commitment to specific goals. Further blocks cover factors such as strategy, structure, interdependence,transformation and feedback of results. A key aim is to provide explanations for how knowledge is utilised during the process of diagnosis. Although the models reflect a holistic view, they appear to the practitioner as being highly theoretical, and need to be operationalised in shop-floor terms to show how the systemic view that is implied through the models could work in practice.

On the evidence of limited work done in applying systems thinking to fault diagnosis it can be said that some findings of practical usefulness have emerged. On the evidence of this study there is a significant difference between the description of systems thinking which many people will accept as plausible, and prescription of the ideas that can meet with resistance; this point is discussed more fully in chapter ten.

2.4 The contribution of psychology.

Research into all facets of fault diagnosis on engineering systems comes primarily from the discipline of psychology rather than of engineering, which may be contrary to expectations. A common thread running through psychology-based research in this area is interest in individual differences between Troubleshooters. One statement, heard often during the course of this research project, was that good Troubleshooters are born and not made. This view leads to an assumption that training can be of only limited value, and where used can only help 'gifted' Troubleshooters become more effective. Generally, the findings to come from research over the past forty years contradict this view. There are studies in the literature (Elliott and Joyce, 1971), (Duncan and Gray, 1975) and (Potter and Thomas, 1976) where novices trained in diagnostic strategy have out-performed experienced Troubleshooters. As stated in chapter one, an assumption made in this thesis is that fault diagnosis can be learned behaviour.

The contrary view needs to be taken into account however, because reactions to a training innovation of this kind can be strongly influenced if this contrary view persists within a company.

There are significant individual differences between Troubleshooters in their ability to diagnose that cannot be explained by reference to education or experience. For example, two Troubleshooters of the same age, sharing the same industrial experience, technically educated to the same level and capable of comparable results in all practical respects can demonstrate very different performances when fault diagnosing. In the United Kingdom there are very few examples of fault diagnosis training in either universities, colleges or in-company, therefore the assumption that some Troubleshooters become effective as a result of personal characteristics that are not shared by less effective Troubleshooters appears a reasonable one to make. Identifying these characteristics and explaining individual differences has been the concern of psychologists working in this area since 1952. One of the most plausible explanations for such differences is that effective Troubleshooters develop more effective strategies during the process of reasoning about faults. From this follows the idea that if such strategies can be identified and described they can be taught to other Troubleshooters. It was this assumption that has underpinned the work done in producing the open learning modules.

One of the earliest findings from psychology-based research was that a technique, given the name of half-split, could be proved to be more effective than the then commonly used input to output or random search. (Miller.et al, 1953) and (Goldbeck et al, 1957) The technique allows for a maximum gain of information from each test made in looking for a faulty item. Although today many techniques exist, it is the half-split that is most commonly known. This is surprising because the nature of new technology, which is more complex and contains networking and feedback, means that half-split as a technique is now of little value if it is not applied along with one or two other techniques.

Another early finding in the study of fault diagnosis was that the concept of mental 'set', (Fattu, 1953), could explain a good deal about diagnostic behaviour. This is a tendency for people to become locked into a line of enquiry in a self-fulfilling way. This situation is analogous with work done on problem solving and lateral thinking (Kepner and Tregoe, 1965) and (de Bono, 1971). There is a link here with observations made of particularly impulsive people who 'dive in' too quickly to a fault event, and when a fault is not found they have difficulty in breaking out of their mental set.

System complexity has been studied as it affects individual behaviour while troubleshooting. Two perspectives on complexity come from the research literature, one is that complexity is viewed objectively i.e. is a property of the actual fault diagnostic task (Simon, 1969), and the other is a subjective view that complexity is a property of the task as performed by a human (Chang. et al, 1970) and (Saeks and Liberty, 1977). For the psychologists working in this area, complexity can be further divided into perceptual and problem solving complexity. A Troubleshooter sees complexity in the lay-out of an instrument panel or of a printed circuit (perceptual); then once the problem has been perceived the problem solving complexity has to be overcome. Characteristics that make a system subjectively complex have been examined experimentally (Sanderson, 1990). In this experiment two groups of subjects were used. One group named 'efficiency' was told to minimize the number of tests used and to follow topographical information about the circuit being diagnosed. The other group named 'knowledge' used symptomatic reasoning based upon the knowledge they were given. The

results showed that the reasoning group were significantly more effective in their diagnosis. Of particular interest was that support was found for an earlier finding, discussed next, that people generally ignore disconfirming evidence while troubleshooting. That is, when a test indicates no fault the subject does not go on to say,''what is that telling me?"
In the present research, a logical step was made on the basis of evidence about people ignoring disconfirming evidence; this was to check whether Troubleshooters begin inquiry by seeking to prove a component or a process is at fault or to prove it fault free. At no time in the field work had this distinction between approaches been considered. The natural tendency is to look for a fault state (confirming evidence) yet more information about the state of a failed area is gained by taking the alternative approach.

There has been some questioning of this evidence about disconfirming information use (Toms and Patrick, 1987). This questioning is based upon what has been called consistent fault set (CFS), in which Troubleshooters identify possible faults and reduce these as quickly and as effectively as possible, thereby reducing what is called the problem space. Toms found that in fact Troubleshooters made insufficient use of zero outputs (confirming evidence). The likelihood of missing these faults increased as the complexity of the problem increased. A further development (Fisher.et al, 1983) helps to reconcile this seeming contradiction. This is that individuals are more sensitive to disconfirming information when generating hypotheses about a failure than they are during hypothesis testing. This type of research is primarily concerned with how people search a complex system after failure has occurred. During the early years of research into fault diagnosis, (Dale, 1958), this topic of search was highlighted as one that could be improved through training. Despite this early call and subsequent research on search methods, there are no known training programmes that include practice in this skill. It has been covered in the current development of the training modules, but less than adequately given the importance of the subject. The main reason for this is that previous academic research does not translate easily into the plain english required by open learning material. The material about search technique that is used in the modules comes from current field work observations.

The study of cognitive style as it affects diagnostic behaviour has produced some highly significant results. By 'style' is meant the way that people approach tasks, as opposed to levels of ability or achievement. Two measures of cognitive style have been found relevant to fault diagnosis, one is the dimension between impulsivity and reflectivity, and the other is between field dependence and field independence. The first measure between impulsive and reflective has been the most significant in helping to explain diagnostic behaviour. During the research studies (Rouse and Rouse, 1982) and (Henneman and Rouse, 1984) subjects were classified as either impulsive or reflective on the basis of the matching familiar figures test and the embedded figures test. Those subjects classified as impulsive made significantly more errors while diagnosing than did the reflective subjects. The impulsive subjects did not improve significantly as a result of prolonged practice. This last finding supports outcomes from other research on cognitive style that it is an enduring factor in human behaviour and is not easily changed. There was evidence for this style influence in earlier research, (Moore et al, 1955), when trainees were asked to plan their strategy for diagnosis by listing possible causes of a fault on a generator. Next they selected critical tests most suited to the hypothesised causes. The diagnosis then followed this pre-planning exercise. Trainees who diagnosed on the generator using the plan solved significantly more faults than a control group of trainees who were asked to diagnose as they wished.

The strong evidence that cognitive style of impulsivity/reflectivity can not be influenced by training intervention has implications for the learning of diagnosis. During the course of the present research a number of managers, without knowing anything of the style measure, said to the effect, "I wish I could get John to stop diving in to a problem, whatever we do or say seems to make no difference". On the evidence of the research, managers in this position simply have to live with this problem. The results from replicated studies on this particular cognitive style prove to be consistent.

The other relevant measure of cognitive style, that of field dependence/field independence has had less influence upon this subject. People who are termed field dependent can be easily distracted or influenced by other unrelated detail when looking for a specific item in say a complex circuit or in a collection of items. In the studies, subjects who were classified as field dependent were initially slower to diagnose but eventually achieved results comparable with those of field independent subjects.

Ability measures, as opposed to cognitive style, have been researched with respect to fault diagnosis. Two abilities in particular, flexibility of closure and spatial scanning, have been shown to have a modest influence upon fault diagnosis. (Rose et al, 1974). Flexibility of closure refers to the ability of people to find hidden figures within a complex diagram or picture. Spacial scanning ability refers to the speed that someone can search a given area, for example in proof reading. Both abilities are closely related to the general subject of searching referred to earlier. There has been an attempt to improve these abilities through training (not all abilities can be improved through training) and only spatial scanning showed an improvement (Levine et al 1979, 1980). However, there was no improvement or change in diagnostic performance.

Training in fault diagnosis has also been an interest for psychology-based research. Here the emphasis is put upon different methods for achieving effective learning rather than upon the content of what is being taught. Typical of this approach is work done with chemical plant employees (Shepherd.et al, 1977) in which three different kinds of instruction were given to groups of trainee process plant operators. One group was given only a description of the panel displays and how to interpret them. A second group was given instruction in theory about the system and how it operated. The third group was given instructions in rules of thumb and heuristics for use in diagnosis. The third group performed better than the other two, and this applied to both familiar and unfamiliar examples of failure events. A further finding of interest was that no difference was to be found between the first group, called the 'no story group' and the second group instructed in theory. Other research studies, Van Matre and Steinemann, (1966), Steinemann et al, (1967) and Miller, (1975) have produced similar results in which it has been found that instruction in theory and fundamental principles has failed to improve diagnostic ability, and in some cases made it worse. A comparison has been made with mathematical problem solving, (Morris and Rouse, 1985) in which it has been empirically shown that fundamental understanding is useful for answering theoretical questions but not for problem solving. This finding contradicts a common view in the teaching of engineering that given a full understanding of the technology and systems an engineer will be able to diagnose effectively. This may go some way to explaining why fault diagnosis is not taught and why so little research in this subject comes from the discipline of engineering. Training in fault diagnosis, where it has been applied, has come mainly as a result of psychology-based research and consists of process specific simulation of failure events. In one study (Duncan, 1975),three measures of fault diagnosis performance were used to evaluate a diagnostic training course which was based upon simulation techniques. These were, First Shot Success (FSS), Wrong Diagnosis (WD) and Diagnosis Time (T). After five training sessions each of two and a half hours duration significant improvements were shown in all three responses. The post-training results were superior to those of people with experience, though here the time measure was not statistically significant. The use of magnetic tiles to simulate the instruments to be read, (Marshall et al, 1980) was simple and inexpensive. Despite the success of this approach it has to be discussed in the past tense because it is no longer in use. No further comment can be made in this respect because this is not the place to discuss the demise of formal, apprentice-based, training in the United Kingdom. A further aspect of diagnostic training through simulation is given in a study (Brooke, 1983) on computer aiding. The method was to present trainees with a series of logic AND gates on the screen and through use of a programme simulate different fault conditions. The programme gave the trainees feedback on test results. A second aid was used and this was called pre-training in which trainees were given strategies for solving this type of fault; in this case half-split and bracketing. Trainees were randomly assigned to four groups depending upon the combination of aids being used and their results were compared. Both aides helped improve error rates in diagnosis but the pre-training strategy proved to be the most effective. In general the combination of both pre-training and computer aiding was to be preferred. Context-free simulation can be a valuable means of training where Troubleshooters are likely to be faced with unfamiliar problems (Hunt and Rouse, 1981). In this study an interactive computer programme was used called Framework for Aiding the Understanding of Logical Troubleshooting (FAULT). One purpose of this study was to assess how far context-free training can transfer to context-specific situations; a study relevant to the transfer issue in this thesis. The trainees had their decisions costed, and initially all trainees were suboptimal in that during diagnosis they had low information gains at high cost. There was improvement in performance as a result of this training but this was much greater among fourth-semester trainees than with first. A considered conclusion was that context-free programmes are of more help to people further on in their training. The improvements indicated that trainees learned strategy and developed a structure to the problems, in contrast to earlier behaviour of focusing on what Rouse calls 'single candidate failure'. The modules developed as part of this thesis can be described as context-free training and some of the issues around transfer to the context-specific situation will be discussed in Chapter 6.

This concludes the review of psychology-based research literature that is relevant to the thesis. The literature is considerable and a more detailed review and critique has been produced separately.
Increasingly, Troubleshooterss are faced with unfamiliar fault events and in this situation experience can be of little value; there is a need for strategies and the learning of strategies rather than facts (Rouse, 1978, 1979)

2.5 The contribution of engineering.

It can be argued that research and any related teaching of engineering students about engineering systems concentrates upon how things work, rather than how they do not work; there is also an emphasis upon the avoidance of faults rather than upon diagnosis. While failure avoidance is undoubtedly the preferred approach, the realities of industrial life are that both production and service functions are regularly punctuated by periods of expensive downtime that can only be made less expensive by a combination of prevention and diagnosis. There is again an analogy with the medical profession; the doctor who seeks to promote health as a means of avoiding the administering of medicine is in a position similar to that adopted by most researchers working in engineering. Two methods are currently pursued in order to remove the need for diagnosis. One is the application of condition monitoring, and the other is the development of fault diagnostic expert systems based upon the use of methods taken from work on artificial intelligence. Although engineering research is involved in the development of these systems there is a strong reliance upon psychology and in particular cognitive psychology. (Boden, 1979).

A range of condition monitoring systems are used in the United Kingdom. For example British Airways operate a system where readings are taken of vibration, starting behaviour, and surge response as a means of gaining advance warning of problems. Another example comes from B.P Tankers Ltd where vibration monitoring was pioneered as a means of having condition or 'health' of a vessel accepted by Lloyds Register of Shipping. The fundamental aim of condition monitoring is to predict the most likely time of failure and then take corrective action as close to this time as possible. The successful application of this technique has clear implication for the practice of fault diagnosis; the outcome ought to be a major reduction in the number of unexpected faults that have to be diagnosed in emergency situations. Despite the promised benefits of this approach the application of condition monitoring has not been widely adopted. The cost of the technology, about 1% of the capital value of the plant and up to 5% in hazardous environments, (Mahadevan, 1981), and the need for a specialist engineer to run the system appears to be a restraining influence upon its adoption. Balanced against this cost issue is the evidence of significant reductions in costs due to a reduction of faults. In one study, (Morris, 1989), an insurance company using condition monitoring, uncovered 345 critical problems and 353 problems that were potentially dangerous over a one year period. The use of condition monitoring has been discussed as it applies to the nuclear industry, and how there is a need for more widespread use, particularly in process industries. (Thompson, 1981). Finally with respect to condition monitoring and as one of engineering's contributions to fault diagnosis, a report from British Coal reflects upon the potential value of this method. (Jennings,1990). It is said that if the technique had been available fifteen years earlier the industry would now have a comprehensive historical record stored on computer of every fault that had ever occurred on every piece of machinery. With such a data base it is unlikely that any breakdown would not be foreseen easily. In other words a complete co-ordinated failure prediction system would be available to engineers and to managers.

The application of expert systems is intuitively at least a panacea for all fault problems in the future. There are however major difficulties in capturing the deep reasoning used during the process of diagnosis. It has been pointed out, (Fink and Lusth, 1987), that expert system development relies upon shallow knowledge, and the result is that systems with impressive capabilities within a limited range of expertise degrade quickly when faced with a problem just outside this range. Research work is on-going in an attempt to capture the full range of fault diagnostic reasoning for the purpose of expert system design. One, (Narayanan, 1987) uses heuristics as well as semantic knowledge about the behaviour of a system under fault conditions. Another approach, (McCoy and Lavery, 1988) is to build performance models of fault diagnosis to aid system design. Claims have been made for a system that allows machines to learn from themselves, (Mirzai, 1989), but one limitation is that it applies only to linear systems. A survey of expert systems for fault detection, (Pau, 1986), lists four areas where systems can contribute to improvements:

* More effective fault detection and isolation.
* Discrimination between alarms.
* Reduction of reliance upon skills needed to diagnose.
* Integrated diagnosis.

Most promising development has been achieved with the use of knowledge-based systems; here the computer programme allows access to accumulated knowledge about faults that previously was shared only by experts. It appears that the full use of an expert system for fault diagnosis, that is a knowledge base that together with an inference engine can arrive at solutions in the way that an expert Troubleshooter would, is some years away, that is if it is ever to be achieved.

A further piece of research to come not only from engineering but which is totally industry-based concerns fault diagnostic practices within British Gas. (Newcombe, et al, 1989). This study was set against a background of an increasing number of appliances that require complex control. The writer began by making comparisons with earlier technologies in this field and went on to describe the demands made upon current Troubleshooters. The need was recognised for constant updating of diagnostic skills within the workforce. The study focused upon local and national surveys of faults, and from these it was found that failure rates for appliances that had been regularly serviced was higher than for those that had not. The general conclusion was that service to the customer could be improved without a reduction in safety levels if unnecessary stripping and cleaning could be avoided. This is a further example of research into fault diagnosis methods taking a broader view of the subject. The more reductionist view leads to a situation where successive engineers perform a cycle of creation and fixing of faults without, at any time, standing back in order to see the whole picture.

2.6 Transfer of past and present research to industry.

Evidence from this literature review suggests that there have been some significant benefits to industry as a result of research into fault diagnosis. It has not been possible to quantify these benefits in an overall way, all that can be done is to highlight specific gains as they have been reported in individual research reports. In terms of technology transfer the key issue is to what extent such benefits can be transferred between companies, and in particular how effective the transfer mechanism is for achieving such transfer. If no effective mechanism exists the relevant findings from this research will fall upon stony ground; this applies to transfer within companies as well as between companies. It has been possible, through this literature review, to identify some transfer mechanisms at work, and these will be discussed in this section. A specific aim of this study was to take account of factors that influenced such transfer during the actual process of introducing the learning technology.

One study that serves to illustrate transfer effects was conducted in order to deliver a new form of simulation-based training in fault diagnosis. (Duncan, 1975). This training achieved impressive results by improving the diagnostic performance of chemical process plant trainee operators. The transfer of ideas about simulation and about learning in this situation was achieved through the relationship of the Researcher with what can be described as a 'Champion' within the company. It is interesting to note that this effective learning technology was in use only as long as the initial company contacts remained in place. Over the past seventeen years it would have been possible to up-date this training through the application of computer graphics while still retaining the learning methodology. The message here appears to be that for a transfer mechanism to be successful it must have within it the means of sustaining innovative ideas as well as transferring the innovation in the first place.

Valuable ideas have emerged from past research, such as various uses of techniques, the effect of a persons' cognitive style upon diagnostic performance, and the application of models to represent complex diagnostic situations. These more generalisable benefits have no recognisable transfer mechanism for their dissemination. How practitioners become aware (or fail to become aware) of these ideas is not clearly understood. One quite plausible explanation is that occasionally people working as Troubleshooters come across reference to these ideas and methods, and transfer is achieved by word of mouth. Most fault diagnostic research in the past has had impact only in the centre where it has been conducted; where such centres have been colleges or laboratories the impact on industry is in general negligible. The results of this research become known only to readers of academic journals.

With respect to the current research, again the initial impact has been only with field-work companies. At present the wider dissemination relies upon two main transfer channels. One is the Cleveland Open Learning Unit where the modules are being published, and as part of this channel there is the possibility of Open College involvement. The other channel operates from the Department of Employment through to what are called Training Enterprise Councils. Details of all the research and the outputs have been disseminated from the Department to the Councils. As another example of transfer channel, there exists a similar relationship between the Department of Trade and Industry and Regional Technology Centres. (Seaton and Cordey-Hayes, 1991). The Researcher for this project gave a paper at a conference organised by the Royal Military College, and this was a further means used to transfer the research findings.

One of the most critical issues with respect to transfer mechanism is the one of overcoming what has been called the 'not invented here syndrome', which effectively represents the discussion in Chapter 4 about the reluctance of people to readily accept context-free principles and ideas. On the evidence of the current research it can be said that some people display a readiness to accept general principles and accept that they can be transferred from one context to another. On the other hand, some people are reluctant to do this. From observation and discussions, reported in Chapter 6, the respective types of people in this respect can be found at any level in an organisation, and the effect does not appear to be confined to people with any particular type of education or background.

The general findings based upon a study of the literature, from observation and from subsequent attempts to disseminate findings is that the mechanisms available for the transfer of learning technology from research source to the workplace is rather hit-and-miss.

2.7 Summary.

The literature search methods have been described, and this work led to the production of a bibliography covering the four years from 1988 to 1991. This bibliography which contains 287 studies was conducted for the purpose of gaining, as far as possible, an overview of current interests in the subject. The reference list used in this thesis on the other hand contains research that is of direct relevance only to the present study, and covers the period from 1952 to 1992. For the purpose of the literature review a distinction is made between what has been called in this study a machine-centred approach and a systems approach, and this is explained by making reference to an analogy between medical diagnosis and engineering diagnosis. The limited research in this area that can be said to adopt a systems approach is generally confined to the disciplines of Operations Research and Cybernetics; here relevant studies are described. The contribution of psychology is reviewed and these studies are predominantly of the machine-centred kind. The key findings from this research are described. The contribution from engineering emphasises fault avoidance or fault prevention as opposed to diagnosis; two main methods for achieving this, condition monitoring and expert systems development, are discussed in the light of studies relevant to fault diagnosis. Finally literature that is relevant to the transfer of fault diagnosis research from source to workplace is discussed with particular reference to the concept of transfer channel. The general conclusion was that, now and in the past, this is rather hit-and-miss.

Chapter 3 Methodology.

3.1 The setting: a social process in a technical context.

The on-going development of new technology in the form of automated or semi-automated machines and equipment, can have a significant influence upon the structure, and climate, of organisations. There is now ample evidence to support a prediction made fifteen years ago, (Simon 1977) that line operational personnel would decrease in numbers, and that technical/professional staff numbers would, in contrast, increase. A characteristic of this trend, as Simon also predicted, is that groupings of people at work become more complex with the result that greater lateral interaction is required across traditional department boundaries. The increasing adoption of matrix structures and the development of project teams serve as a practical example of a move away from formal hierarchical ways of working. Organisational climate is affected too. The need for individual autonomy, possibly the most critical dimension in the measure of organisational climate, is in greater demand as control of work practices occurs *across* the organisation.

It is argued in this thesis that changes in the way people interact and exercise autonomy at work has shifted emphasis from concerns about technical data and know-how to concerns about how individuals behave in response to on-going changes in technology. Hence, the statement made in chapter one that fault diagnosis perceived as a technical subject in which people take part, is treated in this project as a social process in a technical context. A further characteristic of current developments serves to reinforce this position; this is the greater accessibility of technical knowledge, data and know-how. This type of support is now, to use a metaphor, like water on tap. It is argued that the receptivity and response of people and how this is transferred across department boundaries now has considerably more potential for influencing business performance. In this argument, technical know-how is perceived as necessary but no longer sufficient for the task of adapting to new technology. This change from the position where organisations emphasised technical expertise built up over many years to the position, now, where they become learning organisations is, as this thesis aims to demonstrate, well reflected in the changing approaches to fault diagnosis.

The way that people learn and act in response to these changing circumstances can be viewed from different perspectives. Three common perspectives come from the literature on organisational theory (Pfeffer 1982). First, is that individuals behave in a purposive rational way and their actions are clearly goal-directed. Second that peoples' actions are largely constrained by external forces, and are context-determined. Third, that actions are much more random and dependent upon an emergent unfolding process. Although these perspectives cannot be treated as being discrete because there is some overlap between them, it is possible to recognise any one of these perspectives as being predominant in the opinions and actions of people at work. The particular perspective adopted normally influences the choice of research method. When a perspective has been stated, a method is chosen that is appropriate to this view of organisational behaviour, rather than allow preference for a particular method to drive the perspective adopted; in such situations results can be artifacts of the methodology used. It is the third emergent perspective that has been adopted during this study. The actions of individuals are seen as segmented, discontinuous and changing over time. In this situation it is claimed that the behaviour of individuals, in the case of this study behaviour in terms of receptivity and response, cannot be predicted *apriori* from what is being done or from what is happening in a department, a company or in the environment of a company. To quote, (Pfeffer, 1982) 'rationality cannot guide action in this view because rationality, goals and preferences are viewed as emerging from the actions rather than guiding action'. It can be argued that the first perspective of purposive rationality, sometimes known as bounded rationality, is more appropriate to circumstances where strict hierarchical lines of control exist and where processes are relatively unchanging. The second perspective, of context- determined action, can be said to be more appropriate in situations where little control can be exercised, or where people believe this to be the case. In organisations where fault diagnosis and troubleshooting are key activities the business is invariably characterised by a number of on-going changes, many occurring at the same time. In such circumstances a reasonable precept is to say that actions are best guided by rapid on-going learning that comes from a full awareness of the emerging behaviour of both technology and people. This emergent view is best served by research methods that allow discovery to take place, and which produce patterns of actions that can be interpreted in context.

3.2 Rationale for adopting a qualitative approach.

The subject of this section invites participation into the on-going epistemological debate about the relative values of science-based and naturalistic-based research approaches to the study of people in organisations. Instead, the aim of this section is to present the characteristics of the study that have led to the adoption of the second approach, that of qualitative naturalistic enquiry.

The subject of the study, transfer of learning technology, involves numerous independent variables that can influence the level of acceptance (the dependent variable) that is, whether to absorb, adapt or reject the technology. One source of independent variables is to be found in the various actions and interactions of roles that people adopt when faced with the introduction of any novel ideas or methods. These roles, given names such as Technology Gatekeeper, Champion or Points Controller, are more fully discussed in chapters five and six. An important factor, relevant to the emergent perspective, is that there can be a change of role as experience of the technology develops. The mechanism of technology transfer within an organisation involves quite complex personal inter-relationships, often against a scene of fluctuating company fortunes generating an overall atmosphere of uncertainty. This situation has applied in particular to the recessionary early nineties when this field work was done. Other independent variables arise from the fact that these roles, related to technology transfer mechanism, are played out in circumstances that can change dramatically over a short period of time; changes to structure, to staffing levels and to methods of working. In such circumstances it is difficult to assign subjects randomly within and across the companies being studied. One approach was to use a quasi-experimental design. For example, by selecting Subjects from a frame of people in gatekeeper roles. and then performing a quantitative between-gatekeeper analysis of receptivity and response based upon structured survey data collection. This example of a reductionist approach to the subject would fall short of addressing some of the wider issues identified in this project and described in chapter one. The application of reductionist quantitative analysis to situations that involve aspects of human behaviour has already come under vigorous attack (Legge, 1984) over problems associated with internal and external validity of the studies. Also, there has been a call for more hypothesis-free research because hypothesis formulation often reflects the bias of the researcher. In this situation the hypothesis provides examples of biased pre-understanding that leads to results that limit rather than expand understanding.

The medium of fault diagnosis used in this study, unlike technology transfer, does however invite the application of quantitative research methods, some of which can be justified as appropriate in certain contexts; also by background and training the Researcher was biased towards this approach. Two reasons are put forward for the shift from a quantitative to a qualitative methodology. First, the change in perception of fault diagnosis to one of seeing it as a social process. Second, the problem of independent variable control in industrial settings is fraught with many difficulties, a less rigid methodology was required to accommodate the rapidly changing circumstances to be found in most workplaces. However, the majority of fault diagnostic research in the past has been performed using the hypothetico-deductive method. A number of mathematical models have been designed to help organisations optimise their maintenance function, of which fault diagnosis is included as a key activity. In these cases the measures used are being applied at product or outcome rather than at a process stage. The analysis of reliability measures can highlight points of weakness and recommendations can be made for corrective action, but what is not explained is the process features that make one diagnostic exercise more effective than another. The measures needed in order to assess the practices that take place during the course of troubleshooting work are difficult to represent in quantifiable terms. This fact has been highlighted by various unsuccessful attempts to set standards of competency for jobs that require fault diagnosis. This standard setting is done as part of the National Vocational Qualifications (NVQ) initiative. The diagnostic material, produced as part of this project, is being used as a guide to the setting of these standards. Other examples of this reductionist approach come from experimental psychology-based studies that are discussed in the next chapter.

Having considered some of the difficulties inherent in adopting a hypothetico-deductive approach in this context it is necessary to reframe the view of the subject and consider the characteristics that make an inductive phenomenological approach more appropriate. Three elements of this study in particular provide these characteristics. Firstly, the aim of adopting a systems approach brings in the need to view the transfer of this technology in a holistic way. This is in contrast to what can be called a machine-centred approach in which learning of fault diagnosis and transfer of this learning is seen as a well bounded mechanistic exercise mainly requiring technical expertise. Assessment of receptivity and response to a holistic approach requires a methodology that can reflect the complex lateral interactions between people. Secondly, the study of technology transfer involves the participation of people in roles that are not normally associated with their regular jobs, and as pointed out earlier these roles can change in response to emerging experience. In these circumstances a methodology is required that allows for on-going discovery to take place, and where *a priori* hypotheses cannot be established with any confidence. Thirdly, the medium of fault diagnosis learning can be hindered or facilitated by numerous independent variables, that come to light only when people have been exposed to the learning experience. Of particular importance in this respect, and discussed more fully in chapter four, is the characteristic that learning is for improvement in skills and not to provide new skills. A methodology is required that can reflect the richness of human behaviour when people are faced with a novel approach to what is, for them, a familiar subject.

3.3 Moving from the positivist paradigm.

In the previous section there were reflections upon the deliberations that took place in designing a research methodology. The technical nature of fault diagnosis suggests that methods should be chosen that would satisfy what is described as the positivist paradigm. In forming a conceptual framework for this study it was necessary to state expectations about the type of data that could be generated as a result of using a quantitative approach on the one hand and a qualitative approach on the other. Typical quantitative data, that could be expected, came from performance measures of troubleshooters before and after training and structured questionnaire results. Analysis methods in these cases would include regression analysis, factor analysis (of behaviourial responses) and possibly analysis of variance. Such analyses, it was felt, would serve three functions. Firstly, to identify a causal link between the innovation of the learning technology and changes in work performance. Secondly, to predict behaviour in other comparable situations. Thirdly, to indicate the generalisability of the training material across diverse organisations. This, in total, would be in line with the positivist paradigm. In practice these results would be discrete and significant findings, where found, would apply only to the controlled and narrowly defined context in which the measurement took place. This statement is based on the evidence of a considerable amount of quantitative research done in this area. Such research results, even those that are significant, would fall well short of addressing the issues raised in the background to this thesis.

This is an appropriate stage to raise what is a fundamental point about the introduction of this learning technology. Most training performed in either service, manufacture or commerce, is done in order that people can learn new skills and knowledge, much less is done for what can be called 'learning for improvement.' All troubleshooters, supervisors, managers and operators involved in this project would consider themselves skilled, if not highly skilled, in fault diagnosis; that is, up to a level required of the particular job. In such circumstances any comparison of before-measure (no skill) with an after-measure (new skill) is not appropriate. Although new skills are introduced, for example listening and questioning for fault information and the development of a strategy through greater use of techniques, such skills are not normally included in the perception that most practitioners have of fault diagnosis. Essentially, this innovation consists of applying a novel approach to a familiar area of work. In these circumstances even a large number of controlled hypothetico-deductive studies would not be likely to capture the varied responses or come near to a whole picture of peoples' behaviour when faced with an approach that effectively challenges the current and dominant way of doing things. The words of Aristotle in the Composite Law: "The whole is more than the sum of its parts. The part is more than a fraction of the whole" are to be held in mind when attempting to introduce what is called a holistic approach to this subject.

3.4 The sample frame.

As explained at the beginning of this chapter, the population for this study consists of people within organisations who are either directly or indirectly involved in fault diagnosis. Directly involved people include such roles as technicians and operators who have the task of troubleshooting, and supervisors or managers who act more in the transfer of information. Indirectly involved people are those who, by the nature of their roles, can influence fault diagnostic work and its outcomes, for example buyers, stores personnel and designers. From this population of directly and indirectly involved people it was necessary to chose a sample frame. The format of this frame was crucial to the overall research design. Although it was possible to amend the frame as the findings emerged it was felt that, if possible, this had to be avoided; any changes would have to be made also in companies seen earlier to maintain consistency across organisations whenever possible. Given the broad span of the project it was tempting to make the frame as wide as possible but some compromise had to be made to prevent too much dilution of information from such a wide coverage. A particularly narrow frame consisting only of technicians who troubleshoot and who have between five and ten years service was contemplated. Such a frame was clearly unsuitable for the purposes of the project, so further essential roles were added. In addition to Troubleshooters* the following roles were included: senior manager, middle manager(s), supervisor(s) and operators. This formed the basic minimum frame for sampling purposes. In practice there were contributions from people in other roles beyond this frame which have been included in these data. As explained earlier, other roles have been identified that can be related to technology transfer, the subject of this study, such as gatekeeper, champion or sponsor. These roles are operationalised through the behaviour of people when faced with novel situations or ideas. Normal work behaviour tends to operate in reverse, that is people are inclined to behave according to what is expected from their job role. What can be called technology transfer-related roles were allowed to emerge in the course of the project and were not anticipated in the design of the sample frame.

* The term 'Troubleshooter' used in this thesis refers to all people who are directly involved in locating faults and diagnosing to discover the cause; it does not necessarily include the fixing of faults.

3.5 The research methods used.

Working within the sample frame, described in the previous section, a form of theoretical sampling was used, (Glaser, 1968) this is the process of data collection done for the purpose of generating theory. By this method data is collected, coded and analyzed before deciding what data to collect next in order to develop theory as findings emerge. The starting point was the theoretical framework described in chapter one which provided concepts, issues and an indication of who was involved. Overall, this served to provide a structure for the field work; as will be seen this structure had to be modified as events unfolded. As Glaser says, 'this gives a beginning foothold on the research". Reasons have been given earlier for the decision that methods of true-experiment random sampling were not feasible.

To overcome, or attempt to overcome, weaknesses inherent in qualitative research, the technique of triangulation was adopted (Denzin, 1978). This technique is based upon a principle used by navigators and map readers that at least two, and preferably three reference points or bearings are needed in order to fix a position at sea or on the ground. In terms of research triangulation, the bearings are a metaphor for methods; two or more research methods should provide more accurate results that one method alone. In this project a multi-method comparison has been used between, case study, critical incident technique and survey questionnaire. As far as is known, this is the first time that triangulation has been done using a combination of these particular methods. Twelve case reports were produced, sixty-four critical incidents identified and fifty-eight questionnaires were analyzed.

An important criticism made of research triangulation is that it is difficult, if not impossible, to replicate. This problem can be overcome, to a certain extent, by giving as much information as possible about the methods and procedures used. For reference to this information see the Appendices A and B in this Volume (1).

Each of the three methods contribute to the research by encouraging people to view issues, critical to the subject, from different perspectives. The case study material comes from structured observation in each workplace, together with semi-structured discussions about the learning and practice of fault diagnosis. Three main uses have been identified for case study research, (Yin, 1984) exploratory, descriptive and explanatory. During the earlier stages of this research, (Craig 1989) case studies were used in an exploratory way with the aim of formulating key questions and possible hypotheses. In this study, the aim has been to provide description of events, the reactions to an innovation and to offer some explanation for these reactions by making comparisons between the findings from cases and from other methods used. One important advantage of the case study method is that it provides a holistic view of an area under study. There are two aspects to this, the holistic view gained of one case alone, and the same type of view gained when a number of cases are compared. Initially, each case must be seen as discrete and unique before any comparisons are made. To quote, (Patton 1990) 'each case must be represented and understood as an idiosyncratic manifestation of the phenomenon of interest. The description of the case should be holistic and comprehensive, given the focus of evaluation, and will include myriad dimensions, factors, variables and categories woven together into an idiographic framework.' It can be argued that a number of factors relevant to technology transfer on the one hand and to fault diagnostic learning on the other can only be identified and defined by an approach of this kind. For example, any assessment of how people learn and then transfer the learning of fault diagnosis needs to be done in the light of how those people generally learn within that organisation. To what extent the climate of the organisation either promotes or hinders learning needs to be taken into account, and is gained more readily from a holistic view of the workplace. However, explanations are difficult to provide on the basis of case-study data alone, there needs to be further evidence from other perspectives.

The second method used, the critical incident technique (CIT), (Flanagan, 1954) encourages people to move from a more general perspective reflected in case reports to a more specific perspective. the actual procedures used in CIT are given in the Appendices, document two. The principle underlying critical incident use is that peoples' actions and their learning contain what can be called 'padding' or non-critical events in every-day work. Critical incidents on the other hand are those events that contribute or detract from the general area of activity in a significant way. Data are generated with the level of detail and richness that puts the researcher close to the realities of the processes being studied. The method is inductive where no hypotheses are needed, (Gummersson, 1988) as the incidents, as they appear in the answers, are allowed to form patterns that the researcher can develop into concepts and theories. This approach was developed when analyzing the behaviour of United States aircrew during the second world war. Since then, over seven hundred research projects have been critical incident-based, (Fivars 1980). Three studies have been done specifically to consider the reliability and validity of findings collected in this way, (Andersson and Nilsson, 1972. Ronan and Latham, 1974. White and Locke, 1981) all three studies have reached positive conclusions about uses of the technique. Incidents have been collected in this project as they relate to the learning and practice of fault diagnosis and to the circumstances that either promote or hinder acceptance of the innovation introduced. The use of critical incidents is particularly appropriate to the study of fault diagnosis, focusing as it can on specific failure events. There is however a need to perform a number of critical incident interviews across an area in order to build up a broad picture, 'to see the bubble'. During this research, and in earlier related research, there emerged a phenomenon that could almost take on the mantle of a law, this was that six or seven critical incident interviews done in a homogeneous group will exhaust the number of incidents available. This fits with the concept of research saturation common in qualitative studies, (Fleck, 1935). In the case of interviews with Troubleshooters the sixth person is unlikely to contribute any further information that goes beyond marginal utility, and certainly the eighth or ninth person is highly unlikely to provide any new incidents to what has been gathered already. It is at such a stage that the area under study is said to be saturated. Analysis of these critical incident data is done by categorisation of the incidents into subject areas, this is explained more fully in chapter nine.

The survey questionnaire, the third method used in the triangulation, was designed initially to assess respondent's perception of fault diagnosis in terms of skills to be learned. After piloting with a group of Troubleshooters the scope was extended to gather information on how learning is achieved in general, and also to identify possible criteria of fault diagnosis effectiveness. The final format, see Appendix A in this Volume (1), was established after the second pilot run. Earlier there had been attempts to design a questionnaire that was primarily of the open type to encourage respondents to give qualitative answers to the questions. In most cases this brought a poor response in terms of information. When the pilot was followed up reasons were revealed, for example, a question asking for criteria of fault diagnosis effectiveness produced little response because practitioners do not normally consider this question. As can be seen from the final version, criteria are listed that have been gathered for the first time as a result of this research, then respondents are asked to add further examples if possible. In this case the given criteria are partially acting as a prompt. Other questions have been presented in a similar way. The outcome is a semi-structured questionnaire. There is still a weakness, common with all questionnaires, that questions reflect what is seen as important to the designer of the questionnaire rather than to the respondent. The follow-up open type questions help overcome this weakness, and the critical incident responses, which are totally open and consist only of issues that concern the respondent, provide a further safeguard.

The issues relevant to technology transfer are identified through the case material and critical incident use but it was an omission that specific questions were not addressed in the questionnaire. The development of concepts and ideas with respect to transfer in this situation were developed only after the survey had taken place. Upon reflection, this is a problem to be avoided when applying an emergent approach to research by using triangulation of three methods in combination; the sequencing of the methods has to be carefully planned in advance.

3.6 Entry Methods.

For researchers, entry methods can be either overt or covert, (Jorgensen, 1989). For this study all entry was of the overt type. Initial contact was made by telephone to the most senior person at director level who could be contacted. On the evidence of this study it can be said that the mention of fault diagnosis brings a positive response from people at senior level in more than 90% of initial contacts. There was little difficulty in gaining access to field work. The first contact was followed up with a description of the research being done, a description of the learning material and a request to spend time with a range of people from senior management to operators. In all cases, one person acted as main contact for logistic purposes and another acted as a sounding board for ideas, occasionally this was the same person. On entry, one main hurdle had to be overcome, that of the image created by the words 'research' and 'Cambridge' in the description of what the Researcher was doing and where he came from, even though it was made clear that it was City and not University. The academic non-practical image took time to break down particularly in the manufacturing environments and could still be considered as one of the uncontrolled, (and uncontrollable?) variables to influence outcome.

3.7 Summary.

It has been argued that technology, in the form of automated and semi-automated machines or equipment, brings a significant influence to bear upon the structure and climate of organisations. Some implications of this are that working groups of people become more complex, greater autonomy is demanded of individuals, and there is an increased need for lateral interaction between people in organisations. It is also argued that these implications are particularly relevant to groups that have to learn and practice the skills of fault diagnosis. Such developments put a greater emphasis upon the behaviourial aspects of work rather, as in the past, upon technical know-how based on many years of experience. Three research perspectives were discussed, and one chosen that can be described as most appropriate to the current situation being described. This is the emergent perspective, which in turn leads to a choice of methodology. A qualitative inductive approach has been chosen to allow these changing experiences to emerge as people involve in the study display their receptivity and response to the learning technology being introduced. Reasons are put forward for shifting from what could be described as the more plausible positivist paradigm to one that is phenomenological. A description of the sample frame, together with a rationale for its design, has been provided. The idea of research triangulation has been discussed in terms of the particular research perspective being adopted, and how three methods, used in combination, can help overcome some of the weaknesses inherent in qualitative research. Finally, the mechanics of the research entry process were described as being relevant to an understanding of the project.

The overall aim of this section has been to share the thoughts and deliberations that were an on-going part of the project in attempting to provide a sound rationale for the methodology in use.

Chapter 4 Developing the training technology.

4.1 Options for the choice of training technology.

Given the characteristics, discussed earlier, of a novel approach to the learning and practice of fault diagnosis, it is felt that four options are available for the presentation of learning material.

1. Open Learning (text, audio, video, multi-media).
2. Distance Learning.
3. Peer Group Learning, on-the-job.
4. Training of Trainers, to disseminate the material.

The first option in the list, Open Learning, is claimed to offer more flexibility to the learner than any known method used in training at the present time. By flexibility is meant freedom of an individual to choose the pace of learning, to choose what to learn and when, and to dictate when 'expert' tutor help is needed. To achieve these ambitious objectives a considerable amount of skill has to be used in designing the source material, and any weakness in this approach can often be traced back to weaknesses in this design process. Given that valid and reliable material could be produced the option was one that deserved serious consideration.

An alternative but related approach to Open Learning is Distance Learning. At times the two terms have been used synonymously. There is however a clear distinction. (Race, 1989). Open Leaning by design and philosophy is a discrete approach to learning. In contrast, Distance Learning refers only to place and can consist of any type of learning that is conducted away from the place of work or away from a place of education. For example, an Open University student who chooses not to attend tutorial sessions and residential schools is taking part in Distance Learning and the material used, while quite flexible, cannot be described as 'open' due to the strict time limits imposed (open in the Open University sense means open access without the need for entry qualifications) As can be seen from this discussion, the idea of Distance Learning needed to be considered because it offered the opportunity for off-the-job learning but by a range of means one of which could be

Open Learning.

The idea of Peer Group Learning though difficult to put into practice and difficult to evaluate was worthy of consideration. In one company, which was included in the field work, a technician was referred to as a fault diagnostic guru. In reality he did not fulfil this role because he helped out struggling colleagues without providing any enlightenment along the way; here there was a clear opportunity for Peer Group Learning if the structure, necessary to make this happen, could have been established. In these situations most of the needed knowledge and know-how is locked away in only one or two heads; actual learning material is of less importance than awareness about how people learn, and about what they need to know in relation to the fault diagnosis strategies which are typically practised by 'gurus'.

The fourth option of training people who are in the role of Trainers has one main advantage that dissemination of learning material can be more rapid than by using other methods. This applies in particular to the use of trainers who are based in training centres. It is still necessary to consider how learning material is to be used in this situation. One approach is to produce fault diagnostic learning material in the form of hand-outs, overhead projector transparencies and/or photographic slides to enable formal class-based learning to take place. Another approach is to encourage Trainers to change their role and become Tutors in order to deliver Open Learning material. In considering this fourth option a decision would have to be made between these two approaches because they do not co-exist too well together.

Having described what is considered to be a set of options, the rationale for making a choice will be described in the next section.

4.2 Rationale for the choice of technology.

In an attempt to make a choice of 'best option' the first pilot survey questionnaire included a section in which questions were asked about preferred methods of learning fault diagnosis, and responses were followed up in selected cases with a discussion around this issue. On the evidence of this early enquiry, the concepts of

Open and Distance Learning are still a mystery to most people. In such circumstances it is difficult to make a serious choice between methods of learning; understandably choice is based upon terms that sound familiar such as on-the-job or training manual-based. With respect to Open and Distance Learning there is a tendency to equate the terms with Open University or Open College where some Distance learning takes place but where neither deal precisely with Open Learning. Unfortunately there is a strong emphasis upon 'experience' in response to questions of this kind. Although there is a some evidence from research (Rouse, 1979) that the ability to learn from experience improves with experience, the real risk of experience serving only to reinforce ineffective learning does not appear to be generally understood. Experience is recognised to be a factor in the learning and practice of fault diagnosis but it has been found (Potter and Thomas, 1976) that differences in performance as a result of experience are less apparent as more troubleshooting guidance is provided. It is an argument used in this thesis that reliance upon experience hinders both individual and organisational learning, and contributes to the hindering of innovation. The observation made four hundred years ago (Ascham, c1560) that more is learned from one year of teaching than in twenty years of experience can be said to still hold true. A final point to be made with respect to experience is that the pace of change in technology significantly reduces the opportunity for the gradual assimilation of knowledge and know-how. However, as indicated earlier these factors are not being reflected in the general view people have of experience as a means of learning.

Two key factors, that emerged early in the field work, pointed to Open Learning as being the strongest option. One was that 'slack' in terms of human resources had suddenly become scarce as a result of companies making reductions in the size of the workforce. Slack, (Galbraith, 1974), is normally discussed with reference to information flow and materials, the concept however on evidence from this work, can equally be applied to people. Without some leeway in human resources it is difficult to plan for conventional methods of learning. The result is that the much criticised sitting-next-to-Nellie system which was common in the past is now an option forced upon companies. The other factor is that, as a group, troubleshooters are busy people who have fluctuating demands upon their time, and these demands cannot be easily delayed while an activity such as training takes place. The flexibility inherent in Open Learning made it appear to be an obvious option. Open

Learning can be delivered at a distance, on-the-job or in a classroom setting. An important point is that learning by this method is self-paced and self-directed. Also, it is felt, intuitively, that the flexible approach of Open Learning ought to be more conducive to the learning of novel methods than the more conventional approaches, though there is no evidence for believing this; the idea seems to offer a research opportunity.
One consequence of adopting a holistic approach to this subject is that less emphasis is put upon narrow context-specific learning; there has to be instead a learning of generalisable principles. In this respect a distinction is made between context-free and context-specific fault diagnosis learning (Yuang-Liang and Govindarag 1986) where the concept of Initial Fault Set (IFS) is used. This is the idea that Troubleshooters form sets in their mind of symptom-cause pairs, and that these pairs are referred to before deciding upon possible hypotheses. The sets are based upon context-specific knowledge. On the other hand, the strategy used to diagnose is context-free. In the planning of any training in this subject there is a need to combine both types of knowledge; as far as is known this has not been done previously. It was felt that the flexibility of Open Learning would more readily allow for this combining of context-specific knowledge and the learning of strategy through practical exercises.

The aim to use Open Learning format in the design of the material added a significant variable to the project. In addition to the introduction of a novel approach to fault diagnosis there would be the application of a still unfamiliar learning medium. For this reason it was important that the material could be assimilated into the accepted ways of learning in each company. The extent to which this has been achieved is mixed, both within companies and between companies. This aspect of training is discussed more fully in the chapters dealing with receptivity and response.

For the reasons outlined above it was decided to adopt an Open Learning approach, but only one of the three remaining options has been dismissed entirely. The option of Distance Learning was eventually dismissed as being inappropriate. The main reason for this decision was that learning, by whatever means, needed to be quickly reinforced with practical on-the-job activity. It has been pointed out in the previous section that theory alone has proved to be of little value in achieving the skills of fault diagnosis or problem solving, and even techniques of diagnosis if not applied directly in context effectively become theory.

Peer Group Learning was not dismissed entirely, and attempts were made to utilise this approach. In trying to encourage individuals to adopt the role of someone who could promote learning, as opposed to the concept of training, a number of difficulties were encountered which are discussed in Chapter 10, dealing with factors that inhibit the transfer of learning.

The option to utilise Trainers was not actively adopted, but has happened through the initiatives of three companies in the sample. The main reason for not actively taking this approach during the project was that conventional training has become reactive to learning need and tends to deliver ready-made solutions to whatever problems a company encounters. Proactive working or the introduction of creative solutions tends not to feature strongly in most Trainer's activity. Such innovation comes mainly from Production, R&D or more often from isolated individuals. A further consideration is that formal training functions have decreased as a proportion of other industrial activity. The companies used in this study serve to confirm this trend. Increasingly the responsibility for training is being decentralised to be accepted by people who have other quite separate functions. The novel approach to fault diagnosis had to be accommodated by people who do not necessarily recognise themselves as Trainers with a training role but who have the task of learning others (yes it is ungrammatical) by whatever means.

4.3 Description of the open learning modules produced.

For an illustration of how the Open Learning modules 'fit together' to represent a holistic view of the subject area see Diagram 1 on the next page.

The most obvious item for inclusion in a fault diagnostic learning programme is the use of techniques, and how techniques can be combined to form a strategy. To do this it was necessary to bring all known techniques together, plus one omitted in the past, into one document and provide guidance in the appropriate choice of these techniques. This has not been done previously, and adds something to the very limited training currently in existence. This learning of techniques and the choice of techniques is incorporated into module 2. If this represented the sum total of Open Learning produced in this area it would stand as a good example of machine-centred training. Although by definition the learning of strategies is context-free, the actual presentation of the material emphasises, through the use of exercises, that learners relate what they are learning to actual fault events. To begin developing the more holistic approach it is necessary to combine learning from other modules. This important module became number two when it was decided to introduce the learning of listening and questioning into this area of work. Listening, as a skill, despite being the most used of our senses and critical to the act of learning is not normally taught in centres of education and/or training. There are some notable exceptions, such as in the training of air traffic controllers, and in some customer care programmes where active listening is taken seriously. The same comment applies to questioning; this is a most important yet undervalued skill that receives little attention in either education or training. Both skills can be significantly improved through tuition and practice, and this is the main purpose in producing module 1, to improve the skills in relation to the task of collecting fault information. In the past it was possible to come across fault diagnostic tasks where minimal questioning was required. A good example of this was the mechanical switching equipment (strowger) used in telephone exchanges. The senses of smell, touch, sight and listening were used to detect faults and to diagnose causes. This is no longer the case and either automatic diagnostic programmes are used or a strategy is required. In production areas such as pharmaceutical packaging or in service areas such as point of sale terminal use it is increasingly important to question the users of this equipment about symptoms and signs of failure. It is just as important to listen actively to the responses given. It was for these reasons that both skills were presented in the same document, and it is the first time that they have been included within fault diagnostic training.

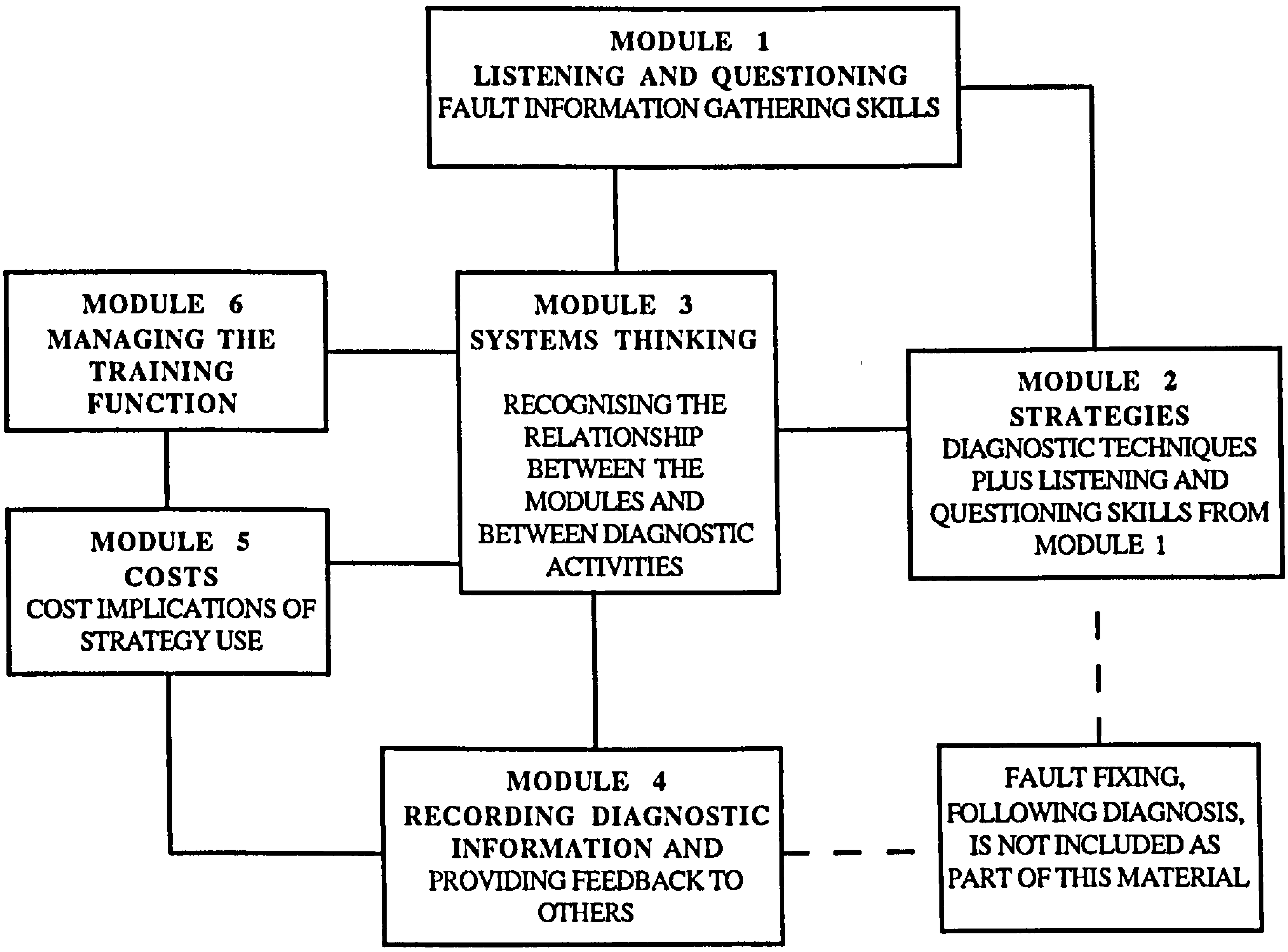


Diagram 8. Inter-relationship of the modules.

One aim in designing the modules was to give module 3, dealing with systems thinking, a central position to emphasise the inter-relationships not only between the modules but between the various activities involved in fault diagnosis. In practice it proved difficult to transfer this holistic view to the workplace; it was more common for each module to be viewed as a stand-alone unit of learning. The model, illustrated by Diagram 8, finally used in planning the presentation of the material needs some modification in any subsequent re-writing, to incorporate module 3 material into appropriate parts of the other five modules even if it is at the possible expense of some repetition.

The topic that follows naturally from strategy use is that of fault record keeping. As part of the initial research for this project, a discussion was held with a Professor at St Marys teaching hospital in London with the purpose of relating industrial-based diagnosis to medical diagnosis. One area discussed was the use of records as an aid to diagnosis; what medical Doctors call 'histories'. The writing and maintenance of medical histories are seen as vital parts of a Doctor's training. The Professor could see no reason for engineers to treat this part of their work differently. In contrast to Doctors most engineering Troubleshooters give this aspect of their work low priority, and may ignore it altogether. On the evidence of this project the exceptions are to be found in Japanese-owned companies. Generally there is little recognition that well maintained fault records can become one of the most powerful diagnostic aids available. The main purpose of module 4 on fault recording is to encourage a change in attitude towards this aspect of fault diagnostic work. The keeping and analysis of full records also provides a broad picture of failure events; it helps 'see the bubble' referred to earlier. In content, there are descriptions in the module of various recording methods which includes one devised by the Researcher. These methods are presented as being appropriate to certain contexts, and guidance is given in the choice of method.

Between module 4 on fault recording and module 2 dealing with strategy there is a module covering systems thinking. This module proved to be difficult to write in a non-academic way, that is 'systems for the lay person who has to troubleshoot'. There have been mixed responses to the module but in general terms it has not been readily accepted. Upon reflection, and after discussions aimed at evaluation of the modules, the conclusion is that key parts of the module ought to have been integrated into the other five modules at relevant points where systems thinking needs to be applied. The purpose in producing the module was to help people to see failure of equipment and their organisation in systems terms. That is to define either a machine or their department as a system which includes sub-systems interacting together. The aim was to encourage people to analyze a whole picture rather than only one-off fault events. There was no attempt to go beyond this level of systems thinking; for example into emergent properties, weltanschauung or types of feedback. Based upon this experience of writing such a guide for troubleshooters there is the feeling that with more deliberation a guide to systems thinking suitable for the workplace ought to be possible.

The fifth module on costing has the aim of isolating costs that can be incurred by an organisation if fault diagnosis practice is not as effective as it should be. One of the most important messages in this respect is that one diagnostic strategy can be more costly than another. Another message is that the cost of quality (quality cost) is largely dependent upon the effectiveness of fault diagnostic practices. The module has been addressed to Troubleshooters and Operators of equipment as well as supervisors and managers. Overall the response has been that this module is only of concern to managers.

The overall response to module 6 was also that the material is of interest only to managers; this was not the intention because a number of points made about learning should be of general interest.

For each small firm in the sample a shortened customised fault diagnostic manual was produced that addressed their particular needs. This was done in an attempt to overcome the time constraints imposed upon training by the lack of human resource slack in each of these firms.

A series of exercises have been developed based upon the fault diagnosis of digital circuits; a manual version of these exercises is included in the appendices, see Appendix D in Volume II. The exercises have also been converted to software for delivery on a computer screen; effectively there is little difference between the two versions apart from the screen presentation being prettier in colour. These exercises have also been used as a means of selecting people for jobs where troubleshooting is critical. There has been no validation of the exercises for this purpose however. As with a majority of job selection tests true validation is extremely difficult if not impossible due to the problems of controlling variables and getting reliable criteria of job performance. The exercises were designed to help demonstrate the use of strategy when diagnosing; digital circuits proved to be a convenient way of doing this and it can be shown that the fundamental principles also transfer to other situations.

4.4 Evaluation of the open learning modules.

Any evaluation plan needs to state clearly what is being assessed for worth; whether it is the output, the process inherent in the programme, or both. It is common for planners of training programme evaluation to emphasise two states, one before training has taken place and one afterwards. The resulting difference in measures is said to provide an evaluation of the training in terms of outcome. This outcome-based approach is different from one that is process-based. This second approach seeks to explain how far subjects have understood the programme content, and to what extent ideas, methods and principles can be transferred to other situations. This distinction between the two approaches has been highlighted during the evaluation of a fault finding* training programme. (Duncan,1975). The importance of output measures from this programme was fully appreciated and were given as: time to fault find, faults correctly identified, and mistakes made in fault identification. The key objective of the programme was to improve fault finding competence and Duncan points out that the extent to which these outputs were measures of competence was uncertain. To quote, 'in fault finding, as in all problem solving, the processes that intervene between problem presentation and problem solution , the process variables, are more informative than the outcome. Without information about intervening processes, prediction of a man's future problem-solving performance can be made with little confidence. Unless we know how he went about solving problems, we doubt whether he really understands, no matter how successful he may have been'. This quote arises from reflection upon a programme that was highly machine-centred. The identification of learning process criteria is further compounded when, as in this study, a broader view of fault diagnosis is being considered; the number of process variables is greatly increased. The observations made by Duncan about output measures being weak indicators of fault diagnostic understanding can be said to apply even more, due to the introduction of more extraneous variables that can account for output results. The more that a holistic view is promoted the greater becomes awareness of other factors that can dictate the eventual outcome of a fault diagnostic exercise. In other words any variability between before and after measures cannot easily be explained by reference to a training programme intervention.

* 'Fault finding' is the term used throughout this study, i.e. no distinction is made between

finding on the one hand and diagnosis on the other; it has to be read as including diagnosis.

In Chapter 1 the point is made that the tasks of fault diagnosis amount to a social process in a technical context. In terms of evaluation, a basic assumption can be said to follow on from this statement, 'that social phenomena, unlike natural phenomena, have intrinsic meaning, and that as a result, engaging in variable analysis is inappropriate'. (Legge, 1984). When evaluation is based primarily upon output measures there tends to be an avoidance of the many process variables that compete for attention in explaining the outcome.

These other variables have been described simply as reality, 'and that positivist designers who seek to shield the causal process of a study from buffeting by practical realities during implementation render unreal any inferences drawn from their evaluation'.

In order to reflect in this evaluation the qualitative methods used in this study, it was necessary to adopt what evaluation researchers call an interpretive design. One design of this kind that emerged from the literature search was the CIPP model for programme evaluation. (Stufflebeam, 1971). CIPP is an acronym for context evaluation, input evaluation, process evaluation and product evaluation. A central belief in the formulation of this model was that, *the most important purpose of programme evaluation is not to prove but to improve*. The overall aim of the model is to use evaluation as a tool by which programmes can be made to work better for the people they intend to serve. The emphasis is upon exploratory, and discovery-orientated investigation. This discovery approach helps resolve the problem of trying to work to a 'best' plan. 'There is no single best plan for an evaluation, not even for an inquiry into particular programmes, at a particular time with a particular budget'. (Cronbach, 1982). The CIPP model was applied during this study to uncover, where possible, any weaknesses in content and in delivery for the purpose of making improvements. The Context (C) Evaluation was concerned with identifying need. As the development of the material progressed, and later during implementation, iteration had to take place to check whether the need perceived at the beginning was in fact being met by this initiative. Initial research for this study, (Craig, 1989), had highlighted, through a series of case studies, gaps in the practice of fault diagnosis and an almost complete lack of training in the subject. The studies covered a wide range of industries: chemical processing, pharmaceuticals, plastic processing and office equipment servicing. It was on the basis of this evidence that needs were identified and agreed with the companies taking part. At this stage the key context-based needs could be listed as a need for:

* Greater Troubleshooter and line Operator or user interaction in the sharing of fault information (this need prompted the listening and questioning module).
* Improved use of fault diagnostic information recording (history taking) (this prompted the fault recording module).
* A means to transfer the strategy of effective troubleshooters to less effective Troubleshooters. It was this need that prompted the collection of modules, and in particular module 2 on strategy use.

By observation and through various discussions it was possible to recognise in a number of failure events, described in this thesis, that faults were being diagnosed repeatedly due to a narrow focus upon symptomatic information, rather than upon broader causal information. It was this observation and discussion that led to the idea of introducing a further need of systems thinking into the programme. These needs provide the information for the context (C) evaluation part of the model.

The input (I) consists of an on-going evaluation of how far the Open Learning approach fits into the existing training structure and climate of the companies involved. This form of evaluation is concerned with assessing the worth of the programme against competing programmes. In terms of fault diagnosis there was only one example of a competing programme within the sample of companies, and this programme was being established concurrently with this study. Eventually selected parts from this study were incorporated into the programme.

Despite this lack of opposition, it was still necessary to assess the general acceptance of this approach in the light of prevailing training methods used in a company.

The process (P) evaluation was seen as the most important part of programme development. The activity prompted many points that required attention which are discussed in the chapters dealing with receptivity and response. As a result of

feedback, changes were made to the modules.
In addition to feedback from fieldwork, two independent means of process evaluation were used at this stage. One was inspection of the material by Educational Technology at the Open University to provide assessment on the modules as an appropriate example of Open Learning text; no comment was made about actual content. The response was positive, predicting that the material ought to be universally well received (not a correct prediction as it turned out) and the one recommendation was to change the print font size. The other independent response came from Cleveland Open Learning Unit, again the result was positive in terms of Open Learning approach and technical content; subsequently the modules have been published by the Unit.

The product (P) has proved to be the most difficult to assess. In terms of outcomes, these are presented in Chapter 8 as either tangible or non-tangible benefits to be derived from such training, and actual benefits as described in Chapter 7. Outcomes are discussed further in Chapter 10 and fall into two areas, one being of outcomes that can be identified as a result of attempting to introduce a novel approach into a familiar subject, the other is the identification of factors that either promote or hinder a systems approach to fault diagnosis.

4.5 Training delivery, the issues.

During the design of this material a number of issues have been raised concerning the delivery of training and in particular the use of training as a channel for the transfer of this learning technology. At present there exists a range of mediums through which training is delivered:

* Simulation techniques.
* Audio-visual programmes.
* Interactive video.
* Text-based.
* Multi-media presentation.
* One-to-One tuition.
* Classroom-based.
* Sitting next to Nellie.
* Mentoring.
* Assimilation through experience.

Each of these methods and their application raises issues about how people learn from attempts to do what is described as 'training'. Before asking about the effectiveness of this training initiative it is first necessary to establish that people who evaluate have a common perception of what training is; on the evidence of this project there are various perceptions to be accommodated. For some people training only happens when the activity is course-based and off-the-job. In one base used for field work the instructions and guidance given by a manager was not recognised as training. Where Peer Group Training is used a common reaction is that training has not taken place. Other people will recognise some on-the-job learning as resulting from training. For most people learning too can be difficult to define, and to recognise when it has happened; few people use the psychologists simple definition of learning, that of ' a change in behaviour', if the new behaviour is effective then the learning can be said to be effective, and the reverse of this applies too. For these reasons the perception of fault diagnostic learning was included in the survey questionnaire.

Another issue concerns the fidelity of training that can be conducted away from the place where the skills and knowledge are to be used. These modules come into this category along with computer simulations, multi-media and training packages of various kinds. Advances in the development of computer graphics have provided an opportunity for the use of high-fidelity simulation of real-life failure events. Despite the level of computer sophistication there are still doubts expressed about how well learning transfers from such systems to the workplace. While this transfer issue is more precise than the technology transfer issue considered as a main part of this thesis it will be considered in Chapter 6 which deals with transfer-related responses.

Early in this project it became apparent that troubleshooters generally display a reluctance to read technical literature, and keep the reading and the writing of words in this respect to an essential minimum; this habit has clear implications for the introduction of text-based material. This issue is also central to the discussion earlier about a general reluctance to maintain fault records. There are indications that more transactions in organisational life are becoming oral at the expense of the written word; the introduction of this text-based material runs counter to this trend.

A continuing belief that most effective learning is achieved through experience has been referred to already in this chapter; with respect to the delivery of training this belief has important implications. If the belief is found to be part of common thinking in a company, in fact as part of the organisational climate, there can be a strong resistance to any kind of formal learning. The idea that training can achieve a good deal by accelerating the learning process and possibly uncover ineffective practices which have been built into collective experience will not be readily accepted.

The issues listed above had to be considered at the design stage of this project, and they persisted to varying degrees throughout. The actions that could be taken to address them are described in the next section.

4.6 Addressing the delivery issues.

In addition to gathering perceptions about fault diagnostic training through the use of a questionnaire, there were follow-up discussions about what training in particular means in this context. There was in each case an attempt to identify what could be described as the learning climate, in other words what can be said to particularly promote or hinder learning of any kind and not only that of fault diagnostic skills.

In addressing the issue of training fidelity there had to be an emphasis upon module evaluation which has been described in the previous section. One aspect of this issue that was not fully addressed is the extent to which troubleshooters will recognise the fidelity of context-free learning material. Only in isolated cases were people found who would readily accept ideas and principles of general application that were not narrowly confined to their immediate context-specific fault diagnostic needs. A more determined effort was needed to demonstrate that both types of learning were required.

The issue concerning an observed resistance to text-based learning was addressed mainly through the design of the modules. There was generous use of white space around the text, and use of only small blocks of text interspersed with exercises that involved practical activity, often with other people. This approach led to thicker modules, which at first proved daunting but which did not appear to persist as a problem.

To overcome or attempt to overcome an emphasis upon experience-only learning, it was necessary to begin each module by tapping into the positive aspects of the reader's experience, and to highlight where negative aspects could exist. This was done by introducing a diagnostic section that allowed the reader to compare his or her current understanding and practice of the topics with those presented in the module; the implication being that here was a topping-up of skills and knowledge, and that in some cases no topping-up will be needed....but you never know! In this way it was hoped that some change to effective behaviour (learning) would be achieved.

4.7 Summary.

The options available for the design of the learning technology had to be considered, and the rationale for arriving at a final decision is discussed. The modules were produced by skill groupings and in an order that reflected the typical process of diagnosis; a diagram has been provided to show how the module material inter-relates. Evaluation of the material was done by using an interpretive approach, and the rationale is provided for this after consideration of other evaluation methods. The steps in the chosen CIPP evaluation model are described as they relate to different stages in material development and implementation. It was necessary to address certain training delivery issues as they are seen to influence implementation of the material; issues and action taken to deal with them have been described.

Chapter 5 The choice of transfer channel.

5.1 The concept of technology transfer channel.

In its simplest form a channel which is used for the transfer of data and information consists of a link between the sender and the receiver; the start and finish points for the transmission of messages are quite specifically defined. The nature of the channel itself is also clear to the users. An example of these characteristics can be found in telecommunications, (Graham, 1983), 'a link between two terminals over which the users at each end can communicate to one another'. This link may be a simple hard-wire connection between two telephones or a more sophisticated link using fibre optics and transmitting many messages simultaneously through what is called multiplexing. Whatever level of technology is applied the principle of channel use remains the same. In contrast, the concept of channel as used in relation to the transfer of technology and the promotion of innovation is qualitatively different. Possibly the most important characteristic of technology transfer to influence the choice of channel is that of diffusion, which has been described as a special type of communication, (Rogers, 1983), 'diffusion is concerned with new ideas, and it is this newness of idea that gives diffusion its special character'. A further point made by Rogers is that this newness means that some degree of uncertainty is involved. In the simplest form of channel described earlier a key aim is normally to transfer information in order to reduce uncertainty; in other words the transfer of uncertainty is not readily recognised as a function of this type of channel. A technology transfer channel on the other hand has to accommodate both new ideas and uncertainty as an intrinsic part of the transfer process. At a more detailed level it is possible to specify behaviours of people that become an integral part of a channel, these are listed in Chapter 6 Table 5.

A second characteristic of a technology transfer channel is that the respective roles of sender and receiver are less clear than in the basic model of a communication channel. Early in this present study it became apparent that a number of people from diverse roles and in heterogeneous conditions would become involved in the transfer process. In this situation it is possible for potential adopters of the technology, normally at the receptive end of the channel, to be in the role of senders. This condition existed when such people became involved in adapting the learning material during the innovation process. This type of approach has been described as a de-centralised diffusion system. There are circumstances in the transfer of technology where a more centralised diffusion system is in use; this has been described as the centre-periphery model. (Schon, 1971). Such circumstances are normally characterised by highly specialised technologies being transferred from a central source directly to potential adopters who operate in homogeneous groups.

A further characteristic of technology transfer that became apparent as the study progressed was that a 'black box' type function had to be fulfilled, between the sender and potential adopters, as part of the actual transfer process. There was a chance that characteristics of the channel could add clarity to the messages being processed, and a chance that distortion could also occur in this way. Although such clarity and distortion can be part of the basic channel model there does appear to be a greater potential for these influences in a technology transfer channel, due mainly to the existence of newness and uncertainty discussed earlier. The concept of technology transfer channel can be described as a means to transfer novel ideas to a diverse and sometimes large population against a background of almost inevitable uncertainty.

In practice, there is a stage-by-stage progression from a proposed innovation, normally in response to a perceived problem, and final outcome. The stages, illustrated in Diagram 9, are those experienced during this project, and different patterns of stage development will emerge depending upon the particular innovation and the context.

The eventual outcomes at the end of the twelve attempts at transfer during the project were: rejection, adaption, acceptance, and a suggestion that the principles could be used in other areas (promotes new ideas); there were also attempts at diversion, but none that were successful. The outcome of absorption was difficult to judge so near to the event; this outcome ought to becomes more apparent after some time has elapsed. There was no evidence of the innovation being a means of promoting new products; it is included here for completeness as the one other possible outcome to be identified in the literature on technology transfer. The outcome of diversion is the one new outcome to be added as a result of this work.

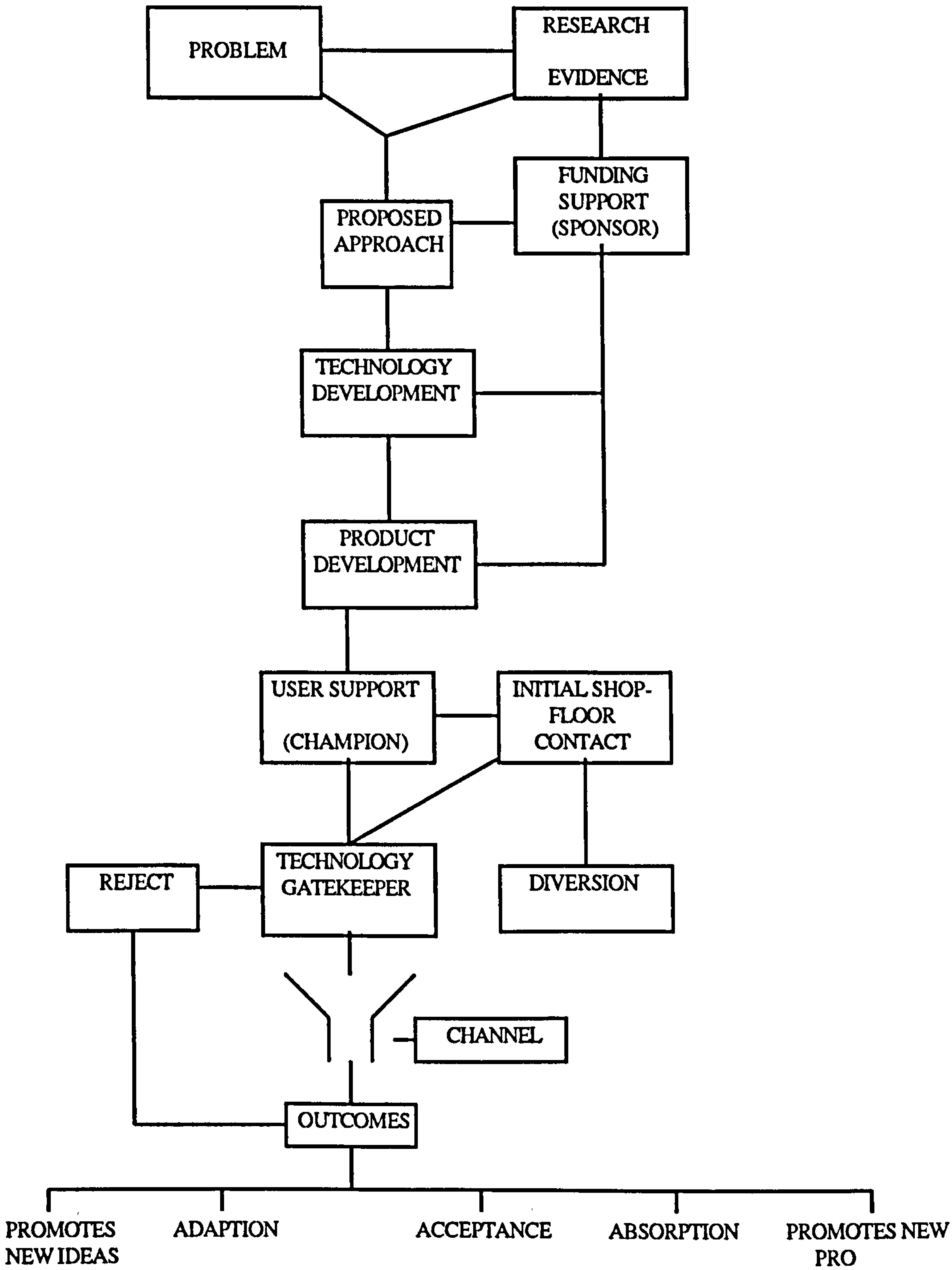


Diagram 9. Stages in a technology transfer.

5.2 Options for the choice of channel.

In the literature on technology transfer and diffusion research a number of functions have been listed as being potentially useful channels.(Allen, 1977). These have been added to during the course of this study and a complete list is given in Table 2.

Table 2. Potential technology transfer channels.

(From the literature)

Mass media.
Literature (magazines, journals, reports).
Mobility of labour.
External sources (Consulting and Government Agencies)
Vendor's communications.
Company networking.
Customer's communications.
Company research.
Technical staff communications.

(Added later)

Training.
Computer networking.
Mobile servicing.
Production control.
Total Quality Management.

Six of the functions listed in Table 2 have been analyzed in an attempt to measure their effectiveness as technology transfer channels. (Allen, 1966). In this study a comparison was made between the respective use that engineers and scientists made of these channels while working in an R&D department. The functions examined were: literature, technical staff communications, vendor communications, company research, customer communications, and external sources. One of the most significant findings was that the channels used most often, vendors and customers produced the lowest proportion of acceptable ideas. Two channels which were used the least, technical staff and company research, produced a far higher proportion of acceptable ideas. There was a significant difference between engineers and scientists in their use of channels, with engineers relying far more upon sources of technical expertise from technical staff, company research and external sources. In both cases, engineers and scientists, there was little use of literature and this was described by Allen as 'mediocre at best, in terms of acceptance performance'. Now, twenty-five years later, a similar observation can be made about engineers in the present study; scientists have not been considered here.

Mass media has been described as one of the most effective means of transferring information; its actual role as a channel for technology transfer is less clear. There appears to be considerable potential through the pages of broadsheet newspapers in the form of technology supplements, and articles by in-house technology staff or freelance writers. The media of BBC television in the form of programmes such as Tomorrows' World and Horizon appear to serve as technology transfer channels.

In the literature, the function of training is not commonly thought of as a technology transfer channel. Also, on on the evidence of this field work such a role is not recognised within companies. A recent study, (Salahaldeen, 1991), produced disappointing results when he analyzed the use of education and training, with particular reference to training, as a vehicle for the transfer of technology across the borders of Kuwait. To quote Salahaldeen, 'although the most important part of technology transfer is the transmission of know-how through education and training, the transfer of technology through such means was given little attention by either suppliers or recipients (8%)'. This statement has to be considered against a background where 87% of projects had to seek skilled labour outside the country; the provision of training as a means of transferring technology know-how is extremely limited. When, in the literature, training has been considered as a channel in this way it is done as a macro study similar to the example from Kuwait. (UNCTAD, 1981 and 1984). Although training has been neglected as a technology transfer channel it is possible to recognise a link between this function and that of Vendor communication. The transfer of technology, in terms of hardware, from Vendor to Client is seldom accompanied by adequate know-how support in the form of training. In practice there is a tendency for the Vendor to seek further contracts for servicing equipment and an inverse relationship exists between the amount of know-how supplied and the extent of service contracts. In this situation it is normally the Client who has to take positive steps to ensure that training support will be part of the overall contract. An example of this Vendor/Client relationship was recorded as part of this field work during the introduction of newspaper printing technology. One possible weakness in relying upon training as a technology transfer channel is that the training function needs to operate effectively at both ends of the channel, that is Vendor-training and Client-training or the ability of both to absorb training. Given the reluctance of Vendors to provide training and a dearth of effective training systems in the United Kingdom, the probability of operating an effective training channel between Vendor and Client appears to be slight.

External sources are limited in the literature to Consultants and Government Agencies. In the United Kingdom there has been growth in the use of Consultants and this trend provides companies with a series of channel options for transferring-in technology from Universities and from individuals who in some cases may well have worked previously for a company's main competitors.

The mobility of labour provides a major channel for the transfer of technology. At times the channel operates informally and companies can transfer-in technology know-how by chance. At other times the channel operates through a 'poaching' system conducted particularly by companies in high technology areas of work.
Two case studies in this current project provided examples of mobile technical services acting as transfer channels. In each case the companies use service engineers as a means of promoting latest available technology, and the engineers transfer know-how to customers to a limited extent. Paradoxically, it was discovered that a major problem exists in providing an adequate transfer channel between engineers themselves because they operate in a 'lone-ranger' type way.

Customer communication provides a channel that is of particular interest due to there being a greater amount of interaction between the source of technology and the would-be adopter. When a technology transfer has taken place there can be a reverse flow of technology usually in the form of modifications to design or information about diversification and wider applications of the technology. This only happens when the provider is sensitive to the customer's needs, and keeps close to the customer through effective use of this particular channel.

Company networking takes a number of forms, sometimes through trade bodies, professional institutes or more informal social gatherings. The potential for providing transfer channels in this way is high and it is one role of Government Agencies such as the Department of Trade and Industry (DTI) and the Training Enterprise Councils (TECs) to make these channels operate in a more unified and formal way.

Computer networking has considerable potential both for transfer of know-how, and for creativity, (Tebbut, 1992), but this function has seen little exploitation as a technology transfer channel either within or between companies. The active promotion of computer networking on some MBA programmes may lead to a wider adoption of this channel by Managers.

Two other potential channels identified are production control and total quality management; both are closely related. Production Control was considered from the beginning of the study but total quality management was referred to only as the work progressed. There was frequent reference to the learning material as being relevant to the concept of Total Quality Management (TQM), this was more in respect to how the systems approach was introduced but content of the material was also recognised as having messages for the promotion of quality. The role of Total Quality Management as a technology transfer channel has been little explored, it is however a function that seems worthy of consideration in this respect. Production Control, as a function, offers an effective channel both within a company and between branches of a company, and was used as a channel during this project in the absence of adequate training provision.
There is no claim here that Table 2 provides a definitive list of potential technology transfer channels. There is a sufficient range of options however to satisfy most demands for a means of transferring know-how and knowledge which are vital as support to the more physical transfer of technology hardware between source and client.

5.3 Rationale for the choice of channel selection.

At the beginning of this study, training as a function was chosen as the vehicle for transferring the learning technology into companies. At first this may appear to be a logical choice, however there is not necessarily a logical link between training on the one hand and learning on the other. Learning takes place that can be recognised as quite removed from the training function, and it can be said that learning takes place in companies *despite* some training functions. One danger in making an early choice of channel is that cognitive dissonance can take over, see Chapter 6 (6.1), and justification rather than rationale is offered in support of the choice. The aim in this section is to provide a rationale.

Making reference to Table 2, there were four options that could reasonably be considered, these were: production control, vendor communications, technical staff and training. Of these it was believed that production control ought to offer the most effective channel; in non-manufacturing areas this would be service control. A disadvantage in using this channel is the difficulty in achieving a uniform acceptance across companies that this is a suitable area for people to learn to do things differently, as opposed to learning to do things better. Inevitably, the first is seen as a high risk strategy and the second as low risk. In practice, much of the field work did eventually involve both production and service control functions in a direct way, but this was not the intention at the beginning of the study. It was felt that apart from the risk aspect the demands of production or service would leave little slack for direct transfer of the learning material to take place.

It was felt that the vendor communication option would limit the scope of the field work, even though there are strengths here due to the vendor often being closest to the latest technology. The conditions necessary for this channel would have been a number of suppliers willing to incorporate the learning material into the work being done to transfer the technology to the customer. In practice there were only two possibilities involving a Swiss-based company and one Japanese-based company representing manufacturing and service respectively. In addition to the difficulties of finding more vendors there was the problem, discussed earlier, of persuading vendors to include customer-learning as part of their contract. Despite the fact that this function ought to have considerable potential as a technology transfer channel the difficulties apparent at the present time are considerable.

The option of using technical staff as a transfer channel most often involves the cooperation of one or two individuals who are prepared to champion the ideas and diffuse them during the course of their normal work. An apparent problem with this approach is that a degree of informality exists, and there is less likelihood of having any control over the transfer process, which in turn makes any attempts at evaluation quite difficult. There are however advantages to this approach; as Allen, referred to earlier, found, this channel can produce a high level of acceptance especially among engineers. As a means of diffusion within a company this is possibly the most effective channel available. From observations made during this study two main conditions are required for this channel to operate effectively, one is that the technical 'champions' are able to communicate the ideas as well as support them, and the other is that they have the means of crossing traditional department boundaries. Again, as with the production and service functions, such people were utilised during field work but not in such a structured way that it could be described as a transfer channel in effective use.

One rather pragmatic reason for the eventual choice of training as the channel was that originally this study was spawned out of a realisation that in the United Kingdom training in fault diagnosis was almost non-existent, and 'training' was seized upon rather than, what would have been better in hindsight, a focus on 'learning'. One other reason for this choice was that training is largely untested against the criteria of a technology transfer channel, and that there would be some interest in identifying characteristics of the training function that can be said to either promote or hinder the transfer of a technology.

5.4 Summary.

The concept of technology transfer channel, as used during this study, has been described by emphasising important differences between the operation of this type of channel and the more common communication channels in every-day use. The characteristics of a technology transfer channel that are seen as most critical are newness and uncertainty of information handling (diffusion); a 'black box' function in the actual processing of information, and a lack of clarity about the respective roles of 'senders' and 'receivers'. These characteristics lead to the adoption of what has been called a de-centralised diffusion system as opposed to one that is centralised or of the centre-periphery model type; reasons are given for adopting the former in this study.

Various functions to be found within companies are listed as potential technology transfer channels; nine have been taken from the literature, and five have been added from this study. Each one is briefly described in terms of opportunities they offer for technology transfer.

Finally a rationale is provided for the choice of training as a channel. This is done by considering the strengths and weaknesses of three other functions that could be recognised as reasonable options, and making a comparison with the eventual choice.

Chapter 6 Transfer-related responses.

6.1 Receptivity Response and Attitude Theory.

When an object, in this case a set of fault diagnosis open learning modules, is introduced into a company it can be said that the overall receptivity and response from people will be largely determined by the prevailing attitude towards the subject in question. In addition, there are prevailing attitudes about how skills and knowledge ought to be transferred into the company; it is this second set of attitudes relating to transfer that is considered in this chapter.

Whenever receptivity and response are referred to in this thesis there is an underlying assumption that they are being influenced by prevailing attitudes. In broad terms, people are receptive to a proposed innovation in either a favourable way, an unfavourable way or are undecided. To a certain extent, the response that follows will be dictated by their initial receptivity, even though it may change as a result of subsequent exposure to the innovation. During this study a number of key subject areas have been identified where attitudes can be said to influence overall receptivity and response to the object; these are listed in Table 3, and will be referred to during this discussion on transfer.

Table 3. Key subject areas.

* How learning of fault diagnosis ought to be achieved.
* Relevance of text-based learning material.
* Readiness to share fault knowledge with others.
* Reliance upon experience in gaining fault diagnosis know-how.
* Relevance of open learning.
* How any knowledge ought to be transferred into the company.
* The use made of outside sources of skills and knowledge.
* Contact with other departments and sharing of knowledge.
* Amount of multi-skilling that is possible and acceptable.
* Whether non-technical staff ought to learn diagnostic skills.

* Readiness to accept systems thinking concepts.

A number of theories exist to help in the assessment and interpretation of attitudes; some link attitude belief and behaviour specifically, (Fishbein and Ajzen, 1975), others can be said to be of a more general nature. (Warren and Jahoda, 1976). From what is a considerable amount of research it is possible to make some general statements about attitude that are seen as relevant to a basic understanding of receptivity and response among individuals.

Most theories refer to a person's beliefs as representing a significant factor in attitude formation. Relating this to the subject of transfer in this study, it can be said that if a person believes the only way to learn effectively is through off-the-job course-based programmes then it is possible that attitude towards the use of open learning on-the-job will be influenced adversely by this belief.

Nearly all theories accept the assumption that attitudes are learned. Again relating this to transfer, it is unlikely that a persons' attitude towards a systems approach to fault diagnosis learning will be based exclusively upon any knowledge gained about this approach, but will contain residues of past learning that can be related to this subject.

Some theories attempt to link attitude directly to behaviour, on the other hand most view attitude as a contributory factor in behaviour. In terms of transfer it can be expected that a person's attitude to this approach will not necessarily be a predictor of behaviour; an unfavourable attitude may be followed in practice by favourable behaviour and vice versa, because factors other than attitude could be having an influence. Two specific attitude theories have been identified as particularly relevant to the present study, one is cognitive dissonance and the other is expectancy-value.

It is claimed in cognitive dissonance theory, (Festinger, 1957), that people attempt to reduce any difference (dissonance) that exists between what is known about themselves and what is known about the surroundings. In doing this two elements are compared, one element is what the person knows about his or her behaviour, and the other element is what is known about the surroundings. If one element cannot be said to follow from the other element then dissonance is said to exist. If on the other hand one element can be said to follow from the other then consonance exists. In terms of this study a statement from the individual behaviour element, and made often during this study, reads: '*fault diagnosis can only be learned through experience*' ; this element is then compared with an element taken from the surroundings, in this case a research project, that reads: '*trainee technicians taught fault diagnosis techniques prove to be more effective than experienced technicians* ' In the above example it can be seen that one element does not follow from the other, so dissonance exists. The theory can help in our understanding of a persons' response in such situations. For example, the person making the first statement will attempt to reduce dissonance. The main tactic adopted for doing this is to introduce further elements that will add value to the first element (learning only by experience) and will decrease the value of the second statement (formal learning is more effective). There is a recognisable link here with expectancy-value theory in which it is said that the more an object is instrumental in obtaining positively valued goals or consequences and in blocking or preventing negatively valued goals, the more favourable is the person's attitude towards the object. In other words, like in cognitive dissonance theory there is an attempt to enhance personal goals and inhibit those factors that threaten or contradict these goals. Sometimes, according to cognitive dissonance theory, dissonance can be reduced by modifying one of the elements. If, in the example above, the first statement was changed to read: '*formal learning of fault diagnosis techniques can be more effective than the use of experience alone*' it could be said that the second element now follows from the first and that consonance existed. There is an important message here for the understanding of receptivity and response to an innovation, and this is that initial reactions are likely to persist if an attempt is made to reduce any dissonance by the introduction of further elements. There appears to be more chance that learning will take place if people are prepared to review elements in the light of knowledge contained in the innovation.

As pointed out earlier, it is possible to recognise a link between the theories of cognitive dissonance and expectancy-value. This second theory, expectancy-value, states that attitude formation can be understood only in terms of the function *that* attitude serves for the individual. This assumption has been adopted in this thesis, that the way people respond to an innovation reflects how they view the approach taken in terms of whether it helps or hinders the attainment of valued goals. This assumption in turn leads to an idea that where a homogeneous group of people work together and share more or less the same goals a consistent and prevailing attitude ought to exist towards an innovation. In terms of receptivity and response it is the effect that an object has that plays a strong role. It has been said that the measure of effect is the most essential part of attitude. (Thurston, 1931). The measure of effect can be quite problematic. The initial approach in the study of expectancy-value, (Fishbein and Ajzen, 1975), was to identify what have been called modal salient beliefs from a group of people by using a pilot open-response survey. A second survey, based upon the resulting set of modal salient beliefs, is then conducted with a larger sample of people. This approach assumes that there can be a homogeneity of beliefs towards a given subject. An alternative approach has been proposed, (Towriss, 1982) in which individual beliefs that are idiosyncratic to each person are utilised instead of modal salient beliefs. In this approach there is no assumption about homogeneity of beliefs, and also an assessment can be made of how beliefs vary across a given population.

In the present study it is receptivity and response in individual-behaviour terms that has been recorded, and beliefs when they have been expressed together with underlying attitudes where they can be identified and supported by evidence.

6.2 Background to the transfer-related responses.

Two stages have been recognised in this transfer process, the acceptance stage and the innovation stage.

At the first acceptance stage only directors, senior managers and middle managers were involved, although in the case of large organisations middle managers were not included. It is at this stage that people who can fulfil the role of Idea Champion are either gained or lost. A finding of interest from this study was that with respect to large organisations all unfavourable receptivity and response (no champions) came as a result of having telephone and correspondence contact alone; all favourable receptivity and response (champions) came as a result of face-to-face contact following initial contact by telephone and correspondence. Similar results were found with small companies; in one case only was an unfavourable response given after face-to-face contact had been made. There is no way of knowing whether the follow-up personal contact simply reinforced already formed attitude towards the proposed ideas or whether the personal contact was crucial to acceptance of the ideas. Only two cases offered a clue, one, when a middle manager in a small company said towards the close of personal contact, " I feel happier now than I did on reading the information you sent", and two, when a senior manager in a large company said "must say I had some reservations when our director asked me to look at this but feel more assured now". The readiness of managers to follow-up proposed ideas in the face of uncertainty needs to be recognised as a factor in the initial receptivity of a company to new ideas. This finding is relevant also to the explanation of a transfer channel in Chapter 5 where the ability to handle uncertainty is described as a crucial part of channel functioning. Stage one closes at a point where relevant material has been read, discussions have been held, and a decision has been made to either become involved with the promotion of the ideas (innovation) or to deny entry to a transfer channel.

By the beginning of the second stage support has been declared for the ideas by directors and/or senior managers in large organisations and by directors and/or senior/middle managers in small organisations. In hindsight, two factors have been identified as crucial at the beginning of this stage. One is how well this early support is communicated to the next-in-line, and the other is the choice of person who is to be next-in-line.

With respect to communicating support, this was normally done in any one of four ways: by stressing potential benefits to the company; by stressing potential benefits to a department; by stressing enhanced skills for individuals, or by stressing support for the research. By giving their agreement, senior managers were supporting the research project but this aspect of the work was played down as far as possible; the primary aim of the field work was to provide some tangible benefit to the companies involved.

The choice of person is a vital decision, and in making this decision it appears that the characteristics given for someone to fulfil the role of technology gatekeeper can be a useful guide. (Allen, 1977). These characteristics have been summarised in Table 4 with two additional characteristics (H and I) identified during this study.

There is evidence from this study that where people with these characteristics exist in an innovation-driving role the chances of achieving favourable receptivity and response are greater; this table will be referred to again during this thesis.

Table 4. Characteristics of a technology gatekeeper.

A. More inclined than others to read job-related and other technical literature.
B. Has job-related contact with people outside the boundary of the company.
C. Colleagues turn more readily to this person for information.
D. Is technically competent.
E. Often holds a first-line supervisor type role.
F. Has many lines of contact in the company; tends not to be a loner.
G. Senior managers, when they have the concept of 'gatekeeper', can readily recognise a member of staff who fulfils this role.
H. Is an effective listener.
I. Is happy to consider doing things differently.

In addition to personal characteristics given by Allen, it has been possible in this study to identify specific behaviours that facilitate the introduction of technology when performed by people in what has been called the gatekeeper role. These behaviours together with their respective relationship to personal characteristics are given in Table 5.

Table 5. Typical behaviours of the gatekeeper role.

* Acts as a 'sounding board' to the idea originator and to the people who participate in the innovation who are given the name of 'Actors' in this study. (related to characteristics A, B and D, see Table 4)
* Informs everyone who needs to know about the ideas and about what is being done. (related to characteristics B and F)
* Identifies the most suitable actors to become involved in the innovation. (related

to characteristics E and F)

* Timetables the sequence of tasks necessary for the introduction of the innovation without causing upset to others. (related to characteristics E and F)
* Quickly shares information about the innovation with others. (related to characteristics C and F)
* Displays active listening at all times. (related to B,C,F and H)
* Will readily try out new ideas. (related to A,B and I)

When any of these behaviours were not displayed effectively there was some disruption to the performance of the transfer mechanism.
Two additional innovation-related roles were introduced during this second stage as a result of feedback from the innovation process. The first one of 'Actor' is used to describe the person who actually performs the necessary tasks for the innovation to take place. The response of Actors could be purely reactive, doing as instructed, or could become proactive to a point where the role changed to one of Idea-Champion. The second role identified has been given the name of 'Points Controller' to describe the behaviour of three managers in the sample who wished to divert the ideas into another area. To extend the metaphor, it can be said that they shunt the ideas along a track which is different to the one set by a director or senior manager acting in the role of Idea-Champion.

It is worth noting that the order in which these roles became involved is different from the order commonly described in the literature on the transfer of innovation. (Allen, 1977) and (Rosenfeld and Servo, 1990). Instead of Idea Generator (Ideator) - Technology Gatekeeper - Champion - Sponsor; the order has been: Idea Generator - Champion/Sponsor - Technology Gatekeeper. The former order is more appropriate to the transfer of ideas within a company rather than for transfer into a company, but this distinction has not been highlighted previously in the literature.

6.3. Responses at Senior Management level.

In the course of this study eight directors including one founder-director, and seven senior managers became involved. Of this group, six maintained involvement beyond the acceptance stage while others delegated totally.

Initial receptivity was favourable in all cases, and there was unanimous agreement that the subject of fault diagnosis continued to be one of significant importance to the respective businesses. The idea of adopting a systems approach was also well received at this level. A favourable response was indicated in two ways; one was to offer field work facilities, and in the case of seven large companies the response was to contribute financial funding towards development of the open learning modules. The field work was conducted at the time of a recession, and Directors and/or Senior Managers had to consider very carefully the implications of becoming involved in this work; this applied especially to small companies in the sample. On average, each small company devoted two to three Director/Senior Manager-hours, five to six Supervisor-hours, and fifteen to twenty Technician/Operator-hours. The allocation of this 'non-productive' time presents a major problem to small companies when innovation of any kind is considered. There was no evidence of any formal costing exercises being undertaken, but during the initial meetings it was apparent from some of the questioning that the cost of lost time and possible disruption to production was being compared, in an informal way, with possible benefits to be achieved.

The following comments from Directors and Senior Managers reflect some of their concerns when presented with ideas that aim to improve fault diagnosis performance. Also, they have been selected because each can be said to have some relevance to the transfer of know-how into a company.

* 'We have little time for formal training these days but still need to up-date skills in areas such as this'.
* 'We can recognise good fault finders, the problem is in getting more like them'.
* 'The systems idea rings bells, we are altogether too narrowly focused, and not only in fault finding'.
* 'I noted the point about Troubleshooters who are too impulsive, we have that problem, but how do we get them to change?'
* 'Downtime continues to be a problem for us'.
* 'We are looking at total quality management at the moment and this seems to have a similar approach'.
* 'We all seem to be bad at listening, there is a need for some direction here'.

* 'Not too sure, could be too much theory for our people to digest, but can see some value'.
* 'We are busy at the moment trying to integrate design and test, the systems approach seems to have some relevance here'.
* 'Dealing with our clients is more difficult than fault diagnosis for our Technicians but there are parts of this training that can help in this, and which we can use'.

As to be expected, senior personnel are, in general, inclined to adopt a holistic approach, as outlined in Chapter 1, naturally and be ready to 'see the bubble'. In doing this it is mainly organisational benefits that are looked for from any new ideas. Referring back to the expectancy value theory at the beginning of this chapter it is the benefits that can enhance goals that will lead to a favourable response being given to the innovation. For Senior Managers these are predominantly organisational goals, as opposed to people at other levels in a company where goals are more likely to be departmental or personal.

6.4 Response at Middle-Manager and Supervisory level.

During this study, a total of twenty-six middle managers and fourteen supervisors, in both large and small companies, became involved. In the case of four small companies it was the middle manager who was the first point of contact following earlier contact with a director by telephone and correspondence. In the remaining four small companies the middle manager became involved after face-to-face contact had been made with a director or senior manager. As explained earlier, middle managers in all four large companies became involved only after initial meeting with directors or senior managers.

This contact with middle managers and supervisors provides the entry to a transfer channel, discussed in Chapter 5, and any problems encountered at this stage become difficult to overcome as the work progresses. For example in the case of two small sites, a middle manager (Training) was physically far removed from the supervisors and actors who had the task of implementing the ideas, and contact was infrequent (the actors seldom got any training). In addition, emphasis within training was upon competencies and not on the process of learning that was essential during the adaption to new technology. Two middle managers (Maintenance) did not become too involved because they referred all training matters to the middle manager responsible for training, and tended to adopt a Points-Controller type role, even towards the purely technical aspects of the material. The characteristics and behaviour of a technology gatekeeper were not in evidence at this level of management, and as a result the transfer became a difficult task. In retrospect, it was possible to identify one chargehand who could fulfil this role to better effect, but issues around status and job demarcation hindered this being done in a formal way. In another example, from a large company, a middle manager (Training) became involved after a senior manager had expressed a strong interest in the work. The senior manager saw relevance in the systems approach but the essential concepts did not transfer to the middle manager. The result was that only selected parts of the material were utilised to fit into an essentially reductionist view of fault diagnosis. This was well illustrated when the new re-designed course was entitled 'A Systematic Approach to Fault Diagnosis'. The important difference between systems/systemic approach and systematic is explained in the material, and was communicated to the manager, but despite this the new programme remains one that presents a narrow, and 'systematic', view of the subject.

These two examples provide an illustration of three types of problem that can be encountered at the transfer channel entry stage. this stage and its relation to other stages is shown in Diagram 9 in Chapter 5. One of these problems is the absence of what has been described as technology-gatekeeper characteristics and behaviour (See Tables 4 and 5), a second is an inability to either grasp or to accept essential concepts, and a third is the inclination of some people to shunt new ideas to a different track, away from their area of responsibility.

In contrast to the above examples, there were seven middle managers and four supervisors who could be said to follow the characteristics and behaviours that help facilitate the transfer of innovation. From observation of their activities during this time it is possible to describe four key tasks that were performed at this level of management when faced with the need to disseminate novel ideas. The description of these tasks, in part, helps to operationalise the characteristics and behaviours listed in Tables 4 and 5 respectively. The four tasks were:

* Hands over all relevant material that has been supplied in support of the innovation, i.e. background, aims, objectives, time and facilities required, and the innovative subject matter.

* Explains his/her own understanding of the ideas and concepts to the next-in-line in the presence of the Researcher to check that no serious misunderstandings exist.

* Makes it clear to all concerned the extent of his or her further involvement in the project, and where further involvement is planned the means of providing feedback are made clear.

* Emphasises his or her own view of the innovation, and as far as is possible states the benefits to be expected..

These four tasks are seen as a minimum requirement if novel ideas are to be transferred effectively from middle managers and/or supervisors to technicians and operators.

In contrast to behaviour that could be said to facilitate transfer, there were examples of receptivity and response from both middle managers and supervisors that served to hinder transfer. First in this respect was to neglect the four tasks listed above, and a further common response was to either adopt the Points Controller role, explained earlier, or to delay as far as possible any use of the material until influence was applied by the Researcher. Receptivity in these cases is best illustrated by quoted comments that also reflect some negative attitudes towards the innovation. Comments typically made in these cases were:

* "I do not really have the time to get involved with many of the wider things talked about here" (Maintenance Supervisor Referring to the modules).
* "I feel that R&D or Quality department would be more at home with this, have you discussed it with them" (Production Manager).
* "Maintaining fault records as you suggest is fine in theory, they do it at our place in Switzerland, but we do not have time for it here" (Maintenance Manager).

* "My main concern is getting the figures up at the end of the month, all else must take second place" (Production Supervisor).

There was a general tendency for managers and supervisors to quickly narrow down any application of the learning material to specific fault events. Having said this, there were five middle-managers who were able to demonstrate an early awareness of a more holistic approach, and of potential benefits from such an approach. One of the clearest indicators of this awareness was when they provided answers to the Researcher's questions that reflected what was contained in the learning material before they had a chance to study the modules. For example, the concept of causation is not always well understood, but these managers readily described examples where neglect of causation led to repetitive faults and wasteful servicing. In one case in particular, one of these managers had a group of widely dispersed field engineers and an on-going problem was how to feed back causal-type information so that each engineer had a broad overview of the service business.

It is important at this point to state that a holistic approach to fault diagnosis is not necessarily superior to a more reductionist approach. There are situations, such as bench-based fault repair work, and where engineers are solely dedicated to a specific process, that a narrower approach can be more beneficial. Television servicing is an extreme example of such a situation; the problems are clear and well bounded and can be solved using a narrowly defined approach. A less extreme example is of car maintenance; recent introduction of microelectronics has provided an increase in complexity but again the problems tend to be well bounded and are handled consistently by small homogeneous groups of Troubleshooters that serve to contain this complexity to a manageable size. These examples, where a systems approach can be seen as not applicable, are discussed in more detail in Chapter 10. In contrast to simple systems of this kind, which have been characterised recently in the literature, (Flood and Jackson, 1991), there are complex systems that have a large number of elements interacting in a loosely organised way. The attributes of these elements are not pre-determined, and tend to be probabilistic in their behaviour. Complex systems contain sub-systems, such as departments or small groups of people, that are purposeful and which generate their own goals. These sub-systems are in turn open to influences that cannot always be pre-determined.

In complex manufacturing or service industries, where many pieces of equipment and many people interact with different Troubleshooters, a systems approach begins to take on more meaning. It is important that middle-managers can also make this type of distinction between simple and more complex systems, and for them to advocate an approach that is appropriate to their context. Difficulties arise when particularly complex situations are treated by middle-managers and supervisors as though they were of the narrow well-bounded type; an example given earlier in this chapter of a manager, who operates in a highly complex system, using the material in a 'systematic' way fits this category.

There was considerable variance among middle-managers and supervisors in how they reacted and responded to the concepts and ideas put forward during this project; this variance applied both within and between companies. A homogeneity of response shown at the more senior level was not in evidence here. Two factors more than any other can be put forward as affecting receptivity and response to the transfer process. One was the amount of time, or 'slack' that a manager or supervisor could devote to the consideration of new ideas, and the second was an ability to grasp conceptual ideas which are not necessarily grounded in quite specific every-day events.

6.5 Response at Technician and Operator level.

During the field work there were fifty-seven technicians and twenty-nine operators involved. The term 'technician' is used here to describe people who have the task of troubleshooting. In practice some companies use the term 'engineer' or 'fitter' though in all but a few cases this sample consisted of people who were educated to at least ONC or BTech level, and a number were graduates but not professional engineers, so technician seems a more appropriate title than either engineer or fitter. Operators in all cases were classified as semi-skilled who follow a fixed set of procedures when operating machines and/or equipment. Unlike middle-managers and supervisors the two categories of technician and operator cannot be commonly referred to, therefore their responses will be treated separately.
With respect to technician response a vital issue was recognised from the start of the study; this was the fact that most of the sample would consider themselves to be

already skilled in the area of fault diagnosis. Further, any attempt to present the material as being training for improvement as opposed to training for new skills could be interpreted as a criticism of existing practices. This view of innovation as a challenge to accepted methods had to be accommodated at the beginning of the project. In retrospect it can now be said that these concerns were rather groundless; the initial questions to technicians in both questionnaire and face-to-face revealed that fault diagnosis had not been learned in any formal way, and that training was in most cases an option they were prepared to consider. Having said this, there was an almost universal response that skilled diagnosis comes only through experience. At no time was the view about experience being a necessary but not sufficient requirement voiced. The logic distinction between necessary and sufficient did not feature in their reasoning about how diagnosis skill is transferred either within companies or between companies. The outcome is that there is an an over-reliance upon 'experience' and the idea that training can provide a form of accelerated experience is not readily acknowledged. All technicians in the sample have learned to fault find by use of experience; new information about faults is gathered slowly over a period of time. Some could be said to diagnose as well as fault find, that is determine the actual cause as well as locating and fixing a fault. As a result of discussions and observation it has been possible to identify two distinct outcomes from technicians' exposure to experience of fault events and these are illustrated in Diagram 10. Here, experience divides into what can be called non-systematic on the one hand, left side, and systematic on the other. Little evidence exists of the systematic approach coming from formal learning; some Troubleshooterss adopt this approach as a result of their experience while others do not. Of those who do take the right hand route in the diagram very few go on to develop histories so that transfer of learning can take place, which in turn contributes to what has been described as organisational learning. (Argyris and Schon, 1978). The more common route is shown by the dotted line, that is to human memory alone. It was beyond the brief of this study to generalise this outcome to the transfer of other innovation either into or across a company, but it is interesting to speculate whether this reliance upon memory of experience can serve as a barrier to the absorption of new ideas that are not always to be found in concrete experience.

Like innovative ideas, some fault events can be novel and as such need to be transferred to as many people as possible. In the typical situation described here, this is unlikely to happen.

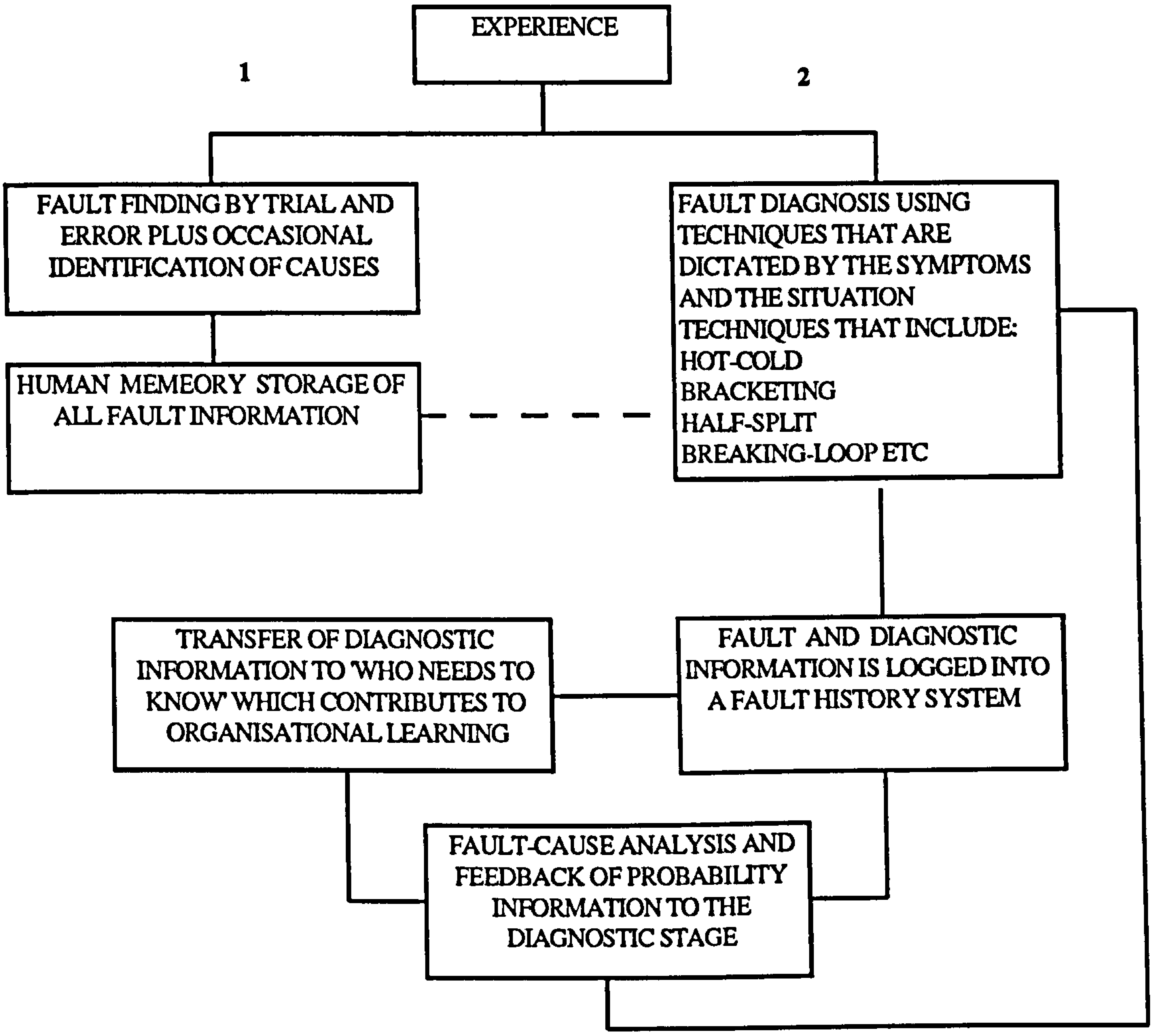


Diagram 10. Two approaches to diagnosis.

The lower half of Diagram 10, in which causal information is gathered together and analyzed, provides a broader picture of fault events and forms part of the systems approach. This proved to be one of the most difficult aspects of the systems approach to transfer to technicians, and to operators. Two main factors have been identified as relevant to what is a largely negative response to this transfer. One is that fault information provides technicians in particular with a form of expert power which exists only as long as the information is confined to relatively few people; it can also be said to provide some job security in uncertain times. Here there is a paradox, that at times when effective transfer of information is most needed there is least likelihood of it taking place. The second factor is that technicians as a body of people, with few exceptions, are reluctant to write in any detail; the briefest of notes is the most that can be expected, even when time is available to write more. Word of mouth is given as the most common means of fault information transfer, but this leads to very inconsistent results which are subject to who happens to be around at the time. Among technicians there is a tendency to specialise and to gain a reputation for expertise in a particular area, this, along with the rather protectionist approach described above makes the transfer of a systems approach difficult. These transfer-related factors will be referred to in the next three chapters when technicians' receptivity and response to the actual learning material are investigated.

The inclusion of operators in this study was not automatic; in practice the people who act as operators seldom become too involved in fault diagnosis. As a result of their inclusion some managers immediately recognised a link with current total quality management initiatives. This was that operators ideally should accept total ownership of their process, even to a predetermined level of diagnosis and maintenance. However, there were no examples of this level having been specified. Such an aim needs the support of more skilled technicians who would cooperate in providing basic information and know-how to the operator. Two of the small companies had done this with some success, and this is discussed in more detail as case studies in Chapter 7. In one of these companies an operator demonstrated an outstanding grasp of systems ideas in a quite spontaneous way, and was able to range across a wide area of causal events that was beyond the ability of technicians on the site. Where such operators exist they can make a significant contribution to the fault diagnosis being done by technicians, and there appears to be potential value in training operators to such a standard. Ideally this training or other means of learning ought to be done with technicians and operators in tandem, but to-date there is no known examples of this having taken place. The initial receptivity of operators is one of surprise and some suspicion about being asked to contribute to a fault diagnosis study. In a few cases the Researcher was tolerated in a good humoured way, in others there was real interest and a conviction that given the chance they could take more responsibility for diagnosis and maintenance. In terms of response there were only small sections of the learning material that could be applied in practice due to real restrictions upon their actions when a fault occurred.

6.6 Summary.

This chapter has considered how different levels of personnel have reacted to the transfer of this material into their respective companies. Prevailing attitudes to how information and know-how is transferred into and across companies needed to be taken into account. Examples from this study were compared with two attitude theories that are seen as relevant to this current work. After stating assumptions about peoples attitude with respect to receptivity and response, the roles perceived as critical to innovation transfer were described from the literature, and two further roles were added which have been based upon evidence from this study. Specific transfer-related behaviours, also taken from this study, which can be seen as linked to these characteristics were also presented. It was observed that the order in which these roles became active during this transfer was different from that given in the literature on transfer of innovation; a difference between transferring into a company as opposed to transfer within is offered as a possible explanation for this outcome. The generally favourable receptivity and response at senior level was contrasted with a more mixed reaction at middle-manager and supervisor level. The general response at technician level raised different issues, and direct comparison with management was less easily made. These were issues about expert power based upon fault information, and an observed general reluctance of technicians to write in any detail; both issues can be said to have a significant impact upon the transfer of innovation in this area. The receptivity and response at operator level was concerned more with potential, that is the potential of some operators to play a more meaningful role in the task of fault diagnosis.

Chapter 7 Receptivity and Response: Case Studies.

7.1 Application of the cases.

These case studies provide the first part of a research triangulation which has been described in Chapter 3, and they inter-relate with contents of the next two chapters.

Possibly the strongest reason for adopting a case-study approach in this context is that organisational issues form a significant part of this study. Case studies have been defined, (Yin, 1984), as 'an empiricist inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between the phenomenon and the context are not clearly evident, and in which multiple sources of evidence are used'. At the initial point of proposing an idea to be innovated a reasonably clear boundary exists between the idea (phenomenon) and the context. When the transfer channel is being used the idea becomes merged with influences from the context and boundaries are then much less easily defined. In these situations the influences can be seen as multiple sources of evidence that serve to give support or no support to the idea. The case study method can provide some structure to what can be a complex situation. Each 'case' in any study can be an individual, an event, or an entity. One of the most problematic tasks in case-study design is the choice of which unit of analysis to adopt. For this study it was decided to use as a main reference point the research questions taken from the framework in Chapter 1. To address these questions it became necessary to find a unit of analysis that would allow for the investigation of three broad areas: transfer of technology, transfer of learning and eventual outcomes from each company intervention. At first, the most plausible unit seemed to be working groups of people who form the sample, however not all subjects in the study worked in groups or had any group identity. Using each organisation as a unit was felt to be too broad an approach, and there is such a wide difference between people in their ability and their views in relation to diagnosis that an 'organisation' view is difficult to establish in this context. In these circumstances, the most appropriate unit was seen as the individual, and as a result it is how individual responses interact that provides a pattern of behaviour from each study.

The choice of a multi-case approach, as opposed to a single-case study, was made early in the project. There are advantages in the single-case method, in particular the opportunity for greater depth of analysis, and testing of results over a longer time span. However there are problems when trying to infer that findings can have implications for any but that one context, no matter how thorough and deep the research. A proposition is put forward in this study that a pattern of behaviour emerging from ten or more case studies will have some viable messages for other contexts where the same phenomenon is experienced.

7.2 Summary of the case-study firms.

The sample frame for this study contained eight small and four large firms. This was felt to be the maximum that could be accommodated in the research time available. Within this frame it was necessary to cover a range of industries and to represent both manufacturing and service processes. A small gesture was made here to redress the common trend, over the past ten years, to emphasise service and run down the manufacturing sector of industry; the emphasis here has been upon manufacturing. Another proposition in this study is that fault diagnosis issues and the skills necessary to tackle these issues share significant commonality across a range of different industries. Information from the research triangulation would help reveal to what extent this proposition can be supported. The eventual distribution of firms is shown in Table 6 by industry type and number involved in the case study research.

Table 6 Case study firms.

Small Firms	Number
Plastics Processing	(2)
Equipment Servicing	(1)
Instrument Servicing	(1)
Control Systems Manufacture	(3)
Transport Servicing	(1)

Large Firms	
Chemical Processing	(1)
Pharmaceutical	(1)
Equipment/Computer Servicing	(1)
Radar Systems Manufacture	(1)

One common feature shared by all firms was that people are employed as troubleshooters on machines, equipment or processes. These Troubleshooters do not perform the same functions across firms but normally have troubleshooting as an intrinsic part of their work; a range of job titles are used to reflect these functions such as:

* Technician
* Fitter (mechanical or electrical)
* Engineer
* Field Engineer
* Maintenance Engineer
* Craftsperson

Other jobs can include troubleshooting such as Process Engineer, Production Engineer, Project Engineer or Supervisor; but not necessarily as an intrinsic part of their work.

There are no standard definitions across industry for the terms of 'Technician', 'Engineer', or 'Fitter' so for the purpose of this project it has been necessary to state the distinctions that are seen as critical in this context. These distinctions are between electrical, mechanical or dual-skilled; between site-based and field-based; and between bench-based and operations-based. The case studies provide examples of these distinctions.

Referring now to the small-firm sample, two plastics processing firms were used to represent the two common sides of this industry; one of plastics extrusion and the other of injection moulding. Plastics processing provides a particularly interesting setting for the study of fault diagnosis. There can be a complex interaction between various causes of product, process, and machine faults, and the environment of the process provides a rich source of causal behaviour. The relationship between Troubleshooters and machine setters is also crucial for production performance and considerable scope exists for interventions to improve this relationship, training and improved information flow being two examples. The industry also operates on tight margins between capital expenditure, operating costs and profits.

The efficiency of Troubleshooter's work strongly influences pay-back time on machinery, see Figure 1, and in turn the profitability of each business. While this is true of all manufacturing industry it is highlighted here where nearly all plastics firms can be categorised as small.

Figure 1 Pay-back Time.

$$P = \frac{I}{C - E}$$

Where:
P = Pay-back time
I = Capital Investment
C = Labour Cost Savings (per-annum)
E = Maintenance Downtime Expenditure (per-annum)

Note: C Is subject to one,two or three shift working.
E Diagnosis can account for up to 90% of Maintenance Downtime.

Despite this situation, a holistic view of fault diagnosis and how it can influence business performance is not commonly found. Where capital expenditure has been made in new technology there has been a reduction in staffing levels but little real change in production practices; this leads to interesting questions about response to innovation and the transfer of technology. In some cases it can be argued that only technology in the form of hardware is being transferred into a company and not necessarily the means of full exploitation. For this sample one firm was chosen where significant investment has been made, and one where there has been little investment. An ideal research scenario, in this case, would have been to have an example of injection moulding with and without investment, and extrusion with and without investment. In the circumstances it was felt that two out of eight firms was the most that could be devoted to plastics operations.

Three of the small firms are listed in Table 6 as 'control system manufacture', however they do have significant differences between them. One manufactures sensing devices of various kinds from hazardous fume to explosives detection, and also provides the control systems for these devices. Another firm manufactures and commissions control systems for variable speed pumping operations. The third is concerned with the assembly and installation of control systems. These small firms are quite typical of manufacturing in this sector of industry, where they supply and are dependent upon larger companies. At the time of this study all three firms shared the difficult trading conditions experienced by their larger customers. A main area of interest within these firms is how a systems approach can be applied to the site-based manufacture compared to the subsequent commissioning and servicing out in the field, when the two operations are performed by the same firm. There is also, in each firm, an emphasis upon systems, that is the putting together of various units and components to behave as a system that in turn must control other systems. Whether this feature of the business serves to prompt systems thinking, compared with, for example, the batch products of plastics processing, offered an area for investigation.

Three servicing firms have been included in the sample and represent very different different aspects of fault diagnostic practices. One installs and services point-of-sale terminals in retail establishments of all sizes. The particular interest here was how field engineers transfer information about constantly developing technology use and about novel fault situations, when they operate quite autonomously in their designated areas. The transfer of innovation presents particular problems in this situation.

The function of the second service-based firm is to diagnose and repair various types of measuring instruments; this involved bench work alone as opposed to any site-based work. In these circumstances, the transfer of knowledge about innovation comes largely from customer feedback. How this transfer process operates in practice can be said to have implications for any other transfer of innovation into the firm.

The third service-based firm was split between two sites where omnibus faults were diagnosed and repaired. In this area of work a significant feature of diagnostic work is the increased reliability of crucial units leading to the use of extended warranty periods offered by manufacturers. This warranty work may or may not be done by the operating firm. The de-regulation of omnibus operations has also had a significant effect upon diagnostic work at the service sites. The ability of the sites to accommodate these innovations in the environment will largely determine their survival. The climate within the sites is one where the learning of fault events is achieved entirely by experience and memorising and where, in the past, there has been a secure and stable environment. This innovation came at a time when the method of learning was having to change, and this made the eventual response of particular interest.

The large-firm sample consists of a one-off systems manufacturer, two types of process manufacture and a service provider.

The manufacture of radar systems demands a high level of integration between R&D, design, production and testing. The emphasis in this study was upon the organisational system, as opposed to the system consisting of hardware and software components though these are taken into account when investigating the approach of various people to fault diagnosis. In practice, it is the organisational issues that are currently of most interest to management. One area in this respect was relevant to this study, and that is the transfer of diagnostic information between design, production, and test.

The two process operations are represented by chemical processing and pharmaceutical. The pharmaceutical industry in particular offers a rich source of examples for research into diagnosis. There are complex manufacturing and packaging processes that are subject to rapid technological innovation. In operation, the causes of faults or the failure of systems can be found across a very wide range of processes both within and outside the company. In such circumstances a reductionist approach to diagnosis appears difficult to defend; in this respect the setting offered a good opportunity for the testing of a systems approach.

The chemical processing shares many of the above features with two main exceptions that are relevant to this study. One is that problems with high speed machinery is not a preoccupation in the chemical industry, and the other is that unlike pharmaceutical manufacture the chemical processing operates on a continuous cycle of production. In both cases however a crucial part of site operations is the relationship between Troubleshooters and production operators, and both industries ponder from time to time about how this relationship can be made more effective.

The one large firm representing the service function installs and services office technology, which includes reprographic equipment and computer networking. There are some similarities with the small firm in the sample that services point-of-sale terminals; the main differences are in size of equipment serviced and range of customers. The large firm has a much wider range of customer-types from education to banking, and larger items of equipment to service. However as retailers invest in more computer networking systems there will be greater similarities between the two firms. The issues raised above, with respect to the small firm, about transfer of innovation-related knowledge among field engineers applies equally to this larger firm.

7.3 Small firms' receptivity and response.

Case Study A - Plastics Extrusion.

In this firm the main product is in the form of sheet plastic which has been profiled to provide covers of various shapes; a typical use is for diffusing light from florescent tubes in office buildings. In contrast to the injection moulding process in which items can be produced in under three minutes, one faulted item in this process can waste up to 30 minutes of production time. The setting of the machine, and of the process parameters to avoid faults is crucial to business performance.

There are two areas of the process where diagnosis is used, one is the detection of fault causes related to the actual product, and the other is the detection of fault causes on machinery. The product faults can have causes outside the boundary of the machine, such as quality of raw material, mixing of materials or even ambient temperature and humidity. When machine Setters were asked how many symptoms triggered off the search for faults there was a wide variation in answers, from 'around thirty' to 'fifty' then 'around a hundred' to one estimate of 'thousands'. This was found to be a common response among Troubleshooters even when it has been established that a common definition of 'symptom' exists. This vague idea of symptom, fault and cause frequency matches to a certain extent the commonly given statement that 'something different happens every day', when in practice, novel fault events are quite rare.

Product faults can also be caused by machine disfunctioning. In this case it was the improvement of machine fault diagnosis that offered the greatest scope for tangible benefits. After reflecting upon this diagnostic material, management came to the conclusion that with improved diagnosis money could be saved by not having to use a number of outside service engineers. Currently, the firm is charged around £30 per hour for labour, plus travel at 35p per mile, plus the cost of spares, with little control over the engineer who may diagnose by substituting spare parts or units, whether defective or not. With improvements made to in-house diagnosis it is estimated that service costs of up to £500.00 per fault event are now made.

Following an initial interview with the firm's Managing Director to gain support for the project, two members of staff acted in tandem as the gatekeeper role, though not acknowledged as such by the people concerned. In practice, and unconsciously, they fulfilled the requirements of the role extremely well. One person was the Production and Development Engineer and the other was New Product Development Technician who also had responsibility for the firm's training. To satisfy one of the requirements of this study, explained in Chapter 5, the transfer channel had to be that of training. As with nearly all small firms in this sample training in this firm had a very low profile to the point of being almost non-existent. In this case the diagnostic material was seen as an opportunity to give a spur to the training function.

Learning about fault events was achieved entirely through experience and memorisation, see Diagram 9, there were no means of keeping fault histories for the benefit of organisational learning. Only one person, the Production and

Development Engineer, did any diagnosis; all shop floor personnel simply did fault finding and repair. If a symptom could not trigger memory of what had happened before, and trial and error failed, the next step was to call for outside assistance. At times when the Production and Development Engineer was available this cost could be avoided.

In addition to the Production Engineer and the New Products Technician three Machine Setters and one Inwards Goods and Dispatch Controller gave feedback on the use of the open learning modules. The Inwards Goods person was more responsive than the setters, like the Engineer and Technician he could relate some of the systems concepts to his own work. For example, he recognised many diverse causes of poor quality as he experienced it both as inputs from suppliers and outputs from his own firm. He recognised the use of feedback but could not provide this adequately due to lack of stored information. Unknown to management he maintained his own records at home on a personal computer because there was no access to one at work; this he said made his job much easier. For this person the second module on diagnostic techniques was of limited value due to the nature of his job. The first module on listening and questioning was greatly appreciated, and the fourth module on record keeping he valued most. The management were reluctant to let this person have the modules because they felt they would not get them back; this seemed to be a compliment to the Inwards Goods Inspector even if not meant as such. Of the three Setters, one had a strong belief that his work could be learned only from experience and never from books. This belief is common throughout these cases, and there appears to be no questioning of this experience, that just possibly it is not the most efficient way of working in this context. In other words, if an alternative way of doing things is to be presented (innovation) then presentation needs to be through experience. This assumes that learning comes through a gradual approach over a period of time. This and similar cases is relevant to the discussion in Chapter 6 on beliefs driving attitudes and subsequently behaviour. The practical negative response would only be changed if the underlying belief about how learning can be achieved was also changed. The other two Setters did not express strong feelings about preferred ways of learning and expressed both favourable and less favourable views about the material. The module on fault records was followed up and used, and these Setters became involved in the improvement of shift change-over transfer of information; they could also recognise the records as good diagnostic aids. Listening and questioning for diagnosis was new to them as learning material but they felt that any benefits from this would take time to show and be difficult to demonstrate clearly. At the time the material made them more aware of their approach to machine operators when faults occur. The module on systems thinking was not seen as relevant; there were no 'messages' for them here. At this shop floor level, only specific points from the learning material that are of value will be applied, and have been applied. Taking a more holistic view has been recognised by an engineer at middle- management level, by a technician who was difficult to place at a level, and by a shop floor person acting outside the actual production process.

Case Study B - Plastics Injection Moulding.

The Senior Works Manager listened to the aims and objectives of this project and agreed with the approach but was less than hopeful of any real outcome. This feeling was due to a realisation that there was little they could achieve through training because there was no longer any slack in terms of human resources to allow for formal training to take place, by whatever means. There had been staff reductions and this had included a Training Officer; there was no overall responsibility for training. In these circumstances, the transfer channel had to be through production, and upon reflection a Gatekeeper role proved difficult to locate. Despite the fact that considerable capital investment had been made in new technology, this was only in the form of hardware and related software. Technology, in the form of 'ways of doing things' to match the hardware was not easily accessible; transfer of knowledge and ideas into the firm continues to be problematic.

In this firm injection moulding is used to produce a wide range of plastic products, and this can involve up to seventy tool changes in one week. The logistical control of these changes largely determines the extent of faults on both machines and on the products. Apart from predictable faults due to machine wear, there are faults due to frequent interchange between nozzles and mould. Unlike some parts of this industry there are few faults due to material mixing; only virgin plastic is used as the raw material.

One consequence of the high capital expenditure is that electrical and mechanical engineering skills become predominant in the production process. Unlike in the last case study, all engineering problems are solved on-site. Four personnel gave feedback on the systems approach to fault diagnosis, though not as thoroughly as in the extrusion process due to the pressure upon their time. A Senior Process Technician, a Setter and two Fitters (one electrical and one mechanical) gave their views. In all four cases there was agreement that the use of listening and questioning in training would be of value. The most common reason given for this was that when machine Operators can be questioned for fault information it greatly speeds up the diagnostic time. Unfortunately, few Operators are in a position to give this information. Training of Operators to supply more relevant information about their machine would be of value but this cannot take place for reasons given earlier.

The standard of fault history keeping was much higher than at many other sites visited, but there was still the intention to use parts of module four in improving what is in use. A quite reductionist approach was adopted towards module 2, the technique of half-split was known to the Fitters, and the serial nature of this process means that this is a particularly appropriate technique; however it was difficult to integrate systems thinking from module 3 to help them see the machines as having sub-systems and types of feedback which at times made the use of half-split misleading. The module on techniques was being used to reinforce current practices rather than introduce new ideas. These comments applied to the Fitters and to the Process Technician but not to the Setter. Of all the Subjects seen during this project, the Setter was exceptional. In previous employment this person had a background of computer numerical control (CNC) work, and was the only one of the four to recognise the statistical process control (SPC) on site as a diagnostic tool that helped provide a holistic view. In discussing module 3 and systems thinking he was able to link some of the concepts to pareto analysis, probability of faults and cause-effect relationships. He appeared to be the only person to make use of diagnostic pages provided by the machine controls. For this person the job involved tapping various sources of information and he was active in building up a record of fault events. Although there was general agreement among Technicians and Operators that causes from a number of systems in the firm can account for costly faults, only one person fully embraced the systems thinking ideas, and has been putting many into practice already, The open learning material prompted a range of causes to be supplied. These involve some detailed explanation and are covered in Chapter 9 on critical incidents; it is sufficient to point out here that causes were related more to logistical control of the process than to any lack of reliability of the machinery. This situation has systems approach implication in terms of the various interactions between personnel in the planning of the process sequencing, tool changes and related transfer of information. This approach can lead to consideration of logistically-driven faults that are not immediately obvious because they do not involve sudden machine breakdown. The Setter referred to earlier, made the point that two seconds over cycle time on each product is a loss making fault, and pointing to module 5 on costs said that cost appreciation at the shop-floor level could help reduce such faults. In the circumstances this statement has to be more in hope than in reality. In this firm the person senior enough to be a Champion of the innovation, as discussed in Chapter 5, was sympathetic to the ideas but due to the pressures caused by difficult trading conditions was unable to act in the Champion role. The Setter was a ready-made Champion for these ideas, and could be seen as a potential Gatekeeper for other innovations into the firm, but was not in a position to perform either roles. At the time of writing a new Senior Maintenance Engineer has been appointed, and the Works Manager says that this diagnosis project will be on his agenda when he is settled into the position.

Case Study C - Point-of-Sale Terminal Servicing.

In this firm a number of Field Engineers are employed to operate from their home base within a designated area. Their task is to service and to diagnose faults on Point-of-Sale Terminals. The overall purpose of the Engineer's work can be quite clearly stated, 'to service terminals in such a way that a high level of reliability is maintained with minimal call-backs, and to represent the firm to the customer in the best way possible'.

Point -of-Sale use is a constantly developing technology, and the result is that only certain Engineers can diagnose on the full range of Terminals. There are retail outlets where older manual tills are in operation, while some supermarket chains are using fully integrated computer networks linked to electronic fund transfer (EFT) systems. Managers expressed doubts about the ability of some Engineers to adapt to the new technology, and the ability of the firm to transfer the necessary skills and knowledge in turn hinders their ability to exploit fully the service opportunities offered by growth in this technology. In the area concerned here, the South East, there was a shortage of time-served personnel, and the alternative methods of providing skills were not able to satisfy this firm's needs. There are three areas of skill required by these fully-skilled Field Engineers; one is the diagnosis and repair of electro-mechanical equipment, i.e. dual-skilled; second is the programming and re-programming of the machines, and third is customer relations because they represent the firm in the marketplace. This last area of customer relations provides the greatest number of problems in terms of fault diagnosis. This is an aspect of the work that an Engineer who adopts a machine-centred approach would tend to ignore. Poor relations between the customer and an engineer frequently leads to a series of 'blame stories' being exchanged on both sides which further hinders diagnostic work and leads to more downtime, which then creates worse relations. If this situation is represented by the use of a systems diagram there can be improved awareness of respective problems on each side.

For an establishment of this size the commitment to training was impressive. A training room has been established where point-of-sale terminal work can be simulated, and engineers new to the firm get extensive training before field work begins. However a proven training system is still some time away. With respect to the progress that has been made in training the firm was an exception in this small-firm sample; there was the thought that being Japanese-owned may have had some influence in this respect, but this area of inquiry was beyond the brief of the project. In these circumstances, training could be used as a transfer channel with some confidence that the mechanism for absorbing and disseminating ideas was already in place within this firm.

A Director who responded to the initial request for support acted as Champion in promoting the ideas but was never seen by the Researcher. The next-in-line, a Training Manager performed the Gatekeeper role extremely well. This person was called upon to diagnose particularly difficult faults, and although employed at base in a training capacity he did not display the more common reactive behaviour of Trainers and had access to the latest information about developing systems. It was this person who arranged for five Field Engineers to become involved in this project and brought them specifically into the Centre for sessions with the Researcher. Overall, this manager's behaviour followed very closely that summarised in Tables 4 and 5 in Chapter 6. The result was that rapid dissemination of the ideas was achieved. That not all ideas were accepted is a separate issue from transfer; the main point here is that innovative ideas became readily available for discussion.

Two modules were of special significance to the Engineers seen, the most meaningful was module 1 on questioning and listening. Here there was a potential pay-off in avoiding wasted journeys due to the inadequate collection of fault information. The need has been recognised to introduce elements of this module to non-technical clerical staff who process fault details which have been phoned in by the customer. The skills introduced in this module were also relevant to the field engineer in encouraging more cooperation from the customer in terms of giving possible causes of failure; a significant proportion of faults are caused by Operator-maltreatment. Module 2 raised major discussion about different approaches to diagnosis among Engineers, and has led to a review of practices. The discussion revolved around whether to diagnose a printed circuit board (PCB) to component level and then repair on-site or replace the board which for many still in use involves re-programming of a machine which can take two or three hours, often longer than it takes to repair at component level. The Engineers who favour the component level approach do so largely for the interest and satisfaction this gives to the work; board changing is seen as being less skilled. However the time is rapidly approaching when all boards can be pre-programmed thereby removing the justification for component level diagnosis. This discussion led to the implications for costs created by the choice of techniques, and then reference to module 5 material; the Engineers saw relevance of this material to their work. Upon reflection, the Engineers saw the relevance of module 2 on techniques becoming much less in their context as time passes; the changing of units and boards can be done at a semi-skilled level and requires little use of techniques. The subject of fault record keeping, module 4, has generated ideas for change in the way they work. In particular, the way that customers maintain fault histories and can follow a simple algorithm to locate problems in advance of the Engineer's visit; from the firm's point of view this has to be seen as an increase in service to the customer, giving them a competitive edge over other service companies. In terms of pay-off from this innovation the Engineers identified two areas where benefits can be achieved. One is the confidence that increased diagnosis skill can give an Engineer. Typically, Engineers are now faced with technology that is not totally familiar to them and any show of hesitation leads the Store Manager to say something like, "you're the Engineer, you should know"; this can undermine confidence. The knowledge that an Engineer can apply a systems approach that includes a range of techniques from which to choose helps avoid any initial hesitation and this loss of confidence. The second area is more measurable than 'increase in confidence', this is customer turn-around time. The use of the material contributes in three ways to reducing this time:

* Shorter customer contact time due to more accurate information gathering (modules 1 and 4)
* The use of fault probability, from records of past events, to reduce diagnostic time. (module 4)
* Reduction of symptom-to-cause time through use of techniques. (module 2)

As explained above it is only the first two of these that are likely to have any long-term effects.

Case Study D - Transport Servicing.

Fault diagnosis with respect to passenger carrying vehicles in this firm can be divided into two areas. One is concerned with fault detection done during periodic inspection after forty-two running days, and at MOT test preparation done annually. The other is concerned with in-service fault events.

For the purpose of skill utilisation in the garage a vehicle is divided into, electrical, mechanical and bodywork sub-systems. However it is becoming increasingly difficult to divide a vehicle conceptually in this way. For example there is now a significant electrical/electronic input into traditionally mechanical areas such as transmission and gearboxes; personnel who are responsible for bodywork cover wipers which are pneumatic and rely upon mechanical compressor use for operation. Although there has been significant innovation of technology in this industry the Fitters in this sample were expected to accommodate these changes without any transfer of extra know-how into the firm. This provides a further example where a gap can exist between the innovation of hardware and the means to utilise this to the full. The on-site Fitters had a further influence to consider which has led to considerable uncertainty. This is the trend towards much longer warranty times being offered by the manufacturers. This is made possible again by innovation in technology leading to increased levels of reliability for units that are installed into each vehicle. For each innovation of this kind there needs to be a thinking through of implications for the various people involved. In this case, the implications remain unclear and lead to uncertainty, which in turn tends to influence performance on the job. It was against this background that this innovation took place.

Although a training establishment existed at a nearby centre there was no obvious responsibility for training on-site. The main reason given for difficulty in adapting to the new technology was lack of adequate training. An interactive video designed to cover the workings of a new gearbox was available in the training department but was unknown to the Fitters in the sample. Discovery learning was the most appropriate term for the way Fitters adapted to new equipment. The poor transfer of fault information between shifts was given as one of the main reasons for ineffective diagnosis, in a way very similar to the plastics extrusion case study. There is a computer-based fault recording system in place but this provides little opportunity to record diagnosis information; it calls only for symptom, spares used but no information about what was wrong, the cause, how it was rectified and whether the fault was repetitive and could have been avoided. In practice it was difficult to use training as a channel; the existence of a Training Department within an organisation is no guarantee that training mechanisms are in operation. In this case the mechanism appeared to exist only at the management level, and in particular with regard to competency identification; there were no obvious on-site mechanisms for technical training that could serve as a transfer channel.

The ideas were discussed with two managers, one on each site and four Fitters on each site had access to the material. The opportunity for the Fitters to relate the modules to the job were limited but five did provide feedback and some evidence of learning was available. There was a universal response that fault diagnosis was gained from experience alone, also that some otherwise 'good' fitters could not be effective at diagnosis. In this respect one Fitter, who was a good craftsperson, had the name of 'check-check' because he needed regular help in checking through fault problems. Despite this situation there was no recognition that these weaker Troubleshooters could improve their diagnosis ability through training. Unlike the Point-of-Sale case study it was not possible to identify benefits to the firm from gains in individual diagnostic ability. This was surprising because during consideration of costs (module 5) figures were given of repair sessions being sixteen hours long and involving £500.00 worth of spares and equipment compared with one hour and £30.00 worth. It was pointed that the difference is often in how fault diagnosis is done. The implication from this is that while fitters all learn from experience it is either not the same experience, or the experience is interpreted differently. There was not the time on site to explore this observation. The small benefits that could be achieved were through changes in procedures, such as the method used to collect fault information from Drivers and/or Inspectors, and the new design of the on-site computer fault recording system. The overwhelming belief among Fitters was that for learning to be effective it had to be practical, manufacturer's courses off-the-job with a minimum of text-based material. Given these requirements and the restrictions upon access to this type of course, (one available place was filled by fitters throwing a coin), the ability of the firm to transfer into the workplace knowledge and skills related to innovation is severely limited. The customised fault diagnosis module, produced as a result of this work on two sites, was based upon the use of modules 2 on techniques and module four on fault recording. One aim was to increase vehicle availability through improved diagnosis, and the other aim was to increase the quality and quantity of information gathered from Drivers by introducing basic fault symptom/cause awareness into driver training. At the time of writing the chances of these being implemented are weak.

Upon reflection it appears that any innovation in the form of concepts, ideas, and skills delivered through text-based material and the spoken word would meet with a similar response. In comparison with the last case study, it was the lack of a Champion and in particular Gatekeeper role characteristics that made initial entry difficult in this case. It can be argued that the absence of such characteristics was one reflection of the current climate in a firm in which hands-on doing is the only form of learning possible, and where any learning activity, such as training, must be done off-site.

Case Study E - Motor Control Manufacture.

In this firm Engineers and Technicians are employed to design, manufacture, install, commission and service systems that control motor drives under variable speed conditions. The systems consist of complex hybrid operation of mechanical and electronic functions. A Middle Manager (Training), two Field Engineers and three factory-based Test Engineers were involved in the project.

There are two areas where fault diagnosis is practised, one is during the manufacturing and test process, and the other is during on-site servicing of installed systems by Field Engineers. It is the Field Engineers who have the most demanding fault diagnostic tasks; their primary discipline needs to be that of electronics, and they must understand something of the host process in which the firm's control systems operate. The host process varies widely from car manufacturing to newspaper production, in fact anywhere that variable speed motors need to be controlled. As in a number of diagnostic situations, the fault information-gathering and in particular the interactions with users of the technology presents these Engineers with problems. In manufacturing industry there tends to be a time lag between the innovation of new technology and full appreciation of its requirements on the part of Operating staff who are not normally from an engineering background. One of the most obvious examples of this was described by two Field Engineers. They said that it was possible to diagnose from experience on older plants because there were clear clues from the less complex operation of components, such as mechanical relays; now it is necessary to stand back and consult manuals and diagrams. Operating staff, whether Operators themselves or Supervisors and Managers, seldom appreciate this change in how diagnosis now needs to be done and expect Field Engineers to perform as before. Effective interpersonal skills are needed in order to overcome this problem; in this respect module 1 on listening and questioning made a valuable contribution, but did not fully satisfy the interpersonal-skill requirements of the Field Engineer in this

situation. The two Field Engineers found that plant Operators were normally more reliable providers of information than resident Maintenance Engineers; the latter can be defensive, feeling that they have failed if Field Engineers have been called in to troubleshoot. In these circumstances it is not unknown for a Field Engineer to give the impression to production personnel that the fault was indeed complex when in fact it had been quite simple; this was done to 'save-face' for the on-site Engineers. There was universal agreement among the Engineers that listening, questioning and additionally building customer relations was a vital training need in their work.
All Engineers recognised the need for training in diagnostic technique use; one young Engineer in particular compared the techniques in module 2 with the total lack of diagnostic training at a Polytechnic which he recently attended. This comment was repeated a number of times during the study, that, in effect, concern in both further and higher technical education is with how things work, rather than how they do not work. Given that diagnosis was the central part of this young Engineer's job he felt unprepared for this type of task. In this firm the task of diagnosis is also essential during immediate post-manufacture testing, and the above comment applies equally to young Engineers in the test area.

All Engineers made the point that the speed of technological change over the past few years has put considerable demands upon their ability to diagnose effectively. In a way similar to the point-of-sale service Field Engineers, the issue of going to a client's site where technology has changed can put them into a vulnerable position, and possibly create a loss of confidence. Knowledge and skills in diagnostic techniques can reduce the adverse effects of this experience.

This was one of the few firm's where module 3 on systems thinking produced some positive feedback. The Test Engineers were not able to establish full functional reliability of a system; this could only be achieved on-site when the control system became a sub-system of the wider system in use. When Field Engineers have to deal with faults on-site it can be difficult to establish whether the cause could have been located earlier by the Test Engineers. A lack of systems thinking in this way and a corresponding lack of feed-back from field to the Test Engineers at base leads to some on-going problems. It was reported that similar difficulties are not experienced at the parent company in Switzerland where diagnostic recording in systems terms is more effective. This mirrored the report of a UK hotel Engineer who said "they maintain very much better fault records in our Swiss hotels but we do not have time for that here". Both module 3 and module 4 on fault recording has prompted the Middle Manager to review this aspect of their work, and to investigate the use of a bulletin called 'Closed Loop' which provides feedback to Engineers in their American factory. The use of laptop PCs was also being considered in this respect.

There was general agreement among Engineers that knowledge and awareness of costs should not be confined to management, and they saw the relevance of module 5 (Costs) to their every-day work. They needed an awareness of cost implications for their customers that arise from repetitive call-back of field Engineers, and of the potential cost implications to their own firm from the creation of a detrimental image that can be caused by too frequent call-backs.

This was one of only two small firms where receptivity and response to the material and ideas was universally positive across the sample group of people; the other was the point-of-sales service firm. The firm, like all others in the sample, wish to increase their commitment to training in this and other subject areas, but like others there is at present too little human resource 'slack' to allow for new learning to take place. In this case the training mechanism allowed for an effective transfer channel to function, which in turn contributed to an appropriate climate for receptivity. The Middle Manager fulfilled the roles of both Champion and Technology Gatekeeper very well.

Case Study F - Instrument Servicing.

In this firm, measuring instruments of various kinds are diagnosed, repaired and calibrated. All work is factory-based and confined to laboratories and laboratory-type workplaces. Six people became involved: a Technical Director who followed progress closely and on visits was the first point of contact, a Section Manager who still performed instrument diagnosis and repair work, and four Electronics Technicians.

In this situation, only module 2 on diagnostic techniques was fully responded to. As in the previous case study, the Section Manager and Technicians pointed out that graduates in electronics from Polytechnic or University are unable to do the work required of them because they have no diagnostic ability. The present approach to learning diagnosis by experience means that two years or more can elapse before a Technician is fully operational; the ability to teach diagnosis was seen by the Director and one Technician as valuable, and both said that the modules fulfilled this role. The Section Manager and the remaining three Technicians were doubtful, even after working through the modules. They were still convinced that experience offers the one way to becoming skilled in diagnosis. The one Technician, who responded positively, acted as the firm's key Troubleshooter, even though he had less experience than many other Technicians. However when difficult faults were brought to him he simply solved the problem and did not work through the diagnosis with the Technician who originally owned the problem. When reflecting upon the module contents he could recognise ways that he could be in a Tutor role as well as a 'fixer' role. This example was repeated a number of times in this project and indicates that people already skilled in diagnosis and able to conceptualise about symptoms, faults and causes are more likely to respond positively to this approach than less skilled Troubleshooters who, paradoxically, can be said to need the approach most.

From observations and face-to-face interviewing it was possible to identify the need for a more holistic approach to the service work, however apart from the Technical Director the overall response to the modules was, with the exception of module 2, negative. There was no evidence of any means whereby new ideas or skills could be transferred into the firm, and work was conducted according to well practised activities. Despite inconsistent fault reporting by their customers, little value was seen in improving listening and questioning for fault information. All Technicians agreed that diagnosis accounted for the highest proportion of instrument downtime (between 75% and 90%) and that actual repair time was relatively short. Information about the cost of downtime to the customer and the comparative cost of diagnosis and repair or new replacement of an instrument, is typical of the service that an effective Technician could give to a customer. Despite this, the contents of module 5 were not recognised as relevant by most Technicians in the sample.

There was some justification in rejecting module 4 on fault recording; the firm had an effective microfisch system in place for the recording of faults and spares used. The system was essentially one of stores control, and could have been further utilised as a diagnosis aid as opposed to simply fault recording.

There were no examples of formal training, therefore this transfer channel was difficult to utilise. The Champion, who was the Technical Director, was not directly involved, and was about to retire, and a Technology Gatekeeper was not available, although one Technician could have fulfilled this role. The Section Manager was an electronics enthusiast and tended to be naturally reductionist and focused upon bench-based problems. The current trading climate, in which the armed services, a main client, had reduced the flow of work considerably, hindered any moves towards training or learning initiatives. From this situation it is possible to speculate that where transfer of innovation is made difficult within a firm, the replacement of key customers when they are lost can also be made difficult. In this case, set ways of operating did reflect a situation when the firm was accustomed to performing within a relatively stable environment. Now that this environment is much less stable the ability to absorb new ideas has become a current need. On the evidence of this study some form of mechanism to transfer and absorb new ideas is required.

Case Study G - Process Control Manufacture.

This firm designs builds, installs and services control panels in various parts of the process industry. There is some planned expansion into the fabrication of the actual panels instead of assembling bought-in units. The design function includes both software and hardware development. There is a very close interaction between design and production, and any faults that can be design-related are quickly detected and rectified. There is a high level of cross-fertilisation between people and few skill demarcations. Overall a systems approach comes quite naturally to the firm, but they would not describe their work in this way; there is a strong emphasis upon practical experience. Five people were involved, An Owner-Director, factory Manager and three technicians.

Although training is listed as a possible service to the customer there is no formal training within the firm. Up to one year ago a Training Manager was employed who also had responsibility for marketing and sales. The new person is concerned with marketing and sales, but not with training. The main reason for lack of training is the one common to other firms in the sample, that past human resource 'slack' is no longer available. In these circumstances it was difficult to recognise how new ideas or innovations get into the firm. It was during the visits that the close link between design and production became apparent. In retrospect it would have been more beneficial to work with design rather than production because the normal entry point to a transfer channel would most likely be found within the design function. The overall outcome from this study, in terms of benefits to the firm, was unsatisfactory. Only one area of significance to the learning of techniques concerned the totally novel fault event. This means that when a customised new-design system is working for the first time it is possible to get faults that can be called novel, i.e. not experienced before, and there is no opportunity to use the technique of comparing with a similar or same system. This issue was a key feature in the next case study, and as there, it makes a case for learning a diagnostic strategy that normally consists of using two or more techniques. One opportunity was identified for the firm, and although acknowledged by the Technicians and the Manager there seemed little likelihood of it being implemented. This was the chance to utilise the material as a means of offering systems and diagnosis training to their customers as part of the marketing and tendering processes. The need for manpower and time were the main considerations here, and neither were readily available for this task.

During the period of this study the firm was going through particularly difficult business conditions, and the time given to this project showed that the readiness to consider new ideas was not lacking even in adverse circumstances.

Case Study H - Sensing Device Manufacture.

The main emphasis in this firm is on leak detection (if there is a hole we will find it) and involves the design, building and servicing of equipment to cover the following areas:

* Image Analysis
* Gas Chromatography
* Cable Fault Detection
* Robot Vehicle Detectors

The skills of fault diagnosis does not form a major part of the overall workload but has a significant influence upon business performance, particularly in the service area. Seven members of staff were involved in the project: the factory Manager, Test and Service Supervisor, and five Technicians; the manager was involved only at the beginning and did not work through the modules.

There was no formal training structure in the firm, and no person with any direct responsibility for training. However, there was a mechanism for learning and for transferring skills and knowledge into the firm. This could be described as a demand-led system in which anyone in the firm could request the opportunity to attend courses, seminars or buy-in suitable learning material. Recently a whole section had attended a one day presentation about a new process. Also the firm was sponsoring Technicians through programmes of further and higher education. In this climate it was possible for a group of Technicians to work together on the modules and have time to study alone. The Manager was in this case the Champion of the ideas, and the Supervisor was a very effective Gatekeeper to the extent of being a 'model' for this role. In this situation it can be said with some confidence that any failure experienced in delivering the innovation lies within the innovation itself and not in the effectiveness of the transfer mechanism.

Two modules were seen universally to be of value. These were module 1 on questioning and listening and module 2 on Techniques. The first was used to rectify a situation where Technicians wasted time on customer sites because inadequate or misleading fault information was given to them. The idea of fault questioning as a skill to be learned was new to them and opened up a fresh line of enquiry. This material was also recognised as relevant to the contact between design, production and test departments. In this firm these three functions are fully integrated but there are still difficulties of understanding between the disciplines. The module on techniques helped emphasise what was needed to overcome an on-going problem in dealing with novel faults. This type of fault occurs more often in firms of this kind where prototype equipment is being built and tested. In other industries, 'novel fault' normally means novel only to the Troubleshooter on the job but will be known to one, or other, Troubleshooters but simply not shared and made known. Each Technician in this firm had particular approaches to this kind of fault but contact with this module encouraged discussion, and this generated learning more than the actual material. The fault record system in this firm was, when compared with contents of module 4, defective in a number of areas yet was still the most comprehensive of all in this small-firms sample. The record system was largely the work of the Supervisor and he was keen to develop it in the light of the module material. Even in this case where Technicians work closely together there is a strong tendency for them to store important fault information in memory alone. When a technician leaves, the firm loses a valuable source of data, and the Supervisor aimed to rectify this situation. The cost of spare parts and the purchasing of less reliable spares was an on-going problem; sections of module 5 was relevant to this situation, but only highlighted their situation, it was not possible to offer any quick solutions in this respect. The purchasing function did not fit into the close working of design, production and test/service. In this respect the section in module 3 on organisational systems and in particular the idea of department boundaries acting as barriers to transfer were seen as relevant. The Supervisor and the Technicians were familiar with most of the concepts used in systems thinking and as a result module 3 added little to their knowledge. Their descriptions of how they diagnosed did however provide useful examples of systems thinking in practice; in particular the use of Sub-System identification, causal links and feedback.

This firm was maintaining levels of production during this recessionary time, and recently recruited a technician to replace one leaving. In these circumstances it was possible for time to be allocated for learning to take place. There was also a recognisable transfer channel in use that is better described as a learning system rather than 'training'.

7.4 Large Firms' Receptivity and Response.

Case Study I - Radar Systems Manufacture.

This firm designs and builds customised one-off radar systems. The organisation is divided into three main functional areas of design, production and test. It is at the system test stage that the skills of diagnosis are used most extensively. First contact and subsequent Champion was the Design Director, but this Champion was lost mid-way through the project when he was promoted to an executive position; interest was maintained but not overall control. With the pressures of a new post the succeeding Design Director, was not able to fulfil the Champion role in the time available. This situation was recorded as yet another independent variable to be considered during any transfer process. The ideas were discussed in general terms with two senior managers in addition to the new Design Director, and in more detail with a Test Department Manager who studied the material at some length. Four Test Engineers then became involved in the work.

The subject of diagnosis has been recently identified as a critical area in the whole production process. This identification came out of a study to locate what has been called 'causes of excess'; a brainstorming session led to the realisation that most major causes of excess involved issues around the subject of diagnosis. It has been possible to put cost values against these causes, so that any new initiatives designed to rectify problems can be evaluated.

Although the intention was to use training as a transfer channel there was general agreement among all persons seen that the level of training was poor, and that other methods of learning had to be adopted on site, mainly through questioning. There are acknowledged weaknesses in this system, one Engineer said "some people will not question because they will not admit to not knowing". Test Engineers learn about new systems only through diagnosis of faults. In this situation some Engineers will escalate a difficult problem to another Troubleshooter in hours, some will spend a day or two days before escalating. In the absence of any formal training system it appeared that some of this diagnostic time needed to be costed as learning time as opposed to downtime. One area emphasises the gap between technological innovation in hardware terms and innovation in terms of knowledge;

the transfer of one outstrips the transfer of the other into the firm. This problem of transfer involved the use of test equipment during the process of diagnosis. Test equipment is now extremely complex, one Manager said, " the designers of this equipment have been carried away by the technology at their disposal, and there is a need to appraise the actual needs of Test Engineers". Having said this, the Manager pointed out that few Engineers are able to fully exploit the capabilities of the new equipment while they are diagnosing. In this respect the limited available training was criticised as being concerned only with how equipment operates rather than how to use it. The Manager made the point that time to gather experience of use was no longer available to them, there had to be concentrated learning sessions. This example highlighted problems of transfer; part of innovation can be satisfied through the use of capital expenditure but without complementary innovation of knowledge and know-how the capital expenditure is under-utilised. In the circumstances there was no identifiable transfer channel for the further dissemination of the open learning material beyond the sample of people seen. As in the small firms there had been reductions in staffing levels and personnel were too 'stretched' to allow time for learning or innovative activities.

There was a full appreciation of systems thinking concepts among the Engineers and the Manager. They identified three types of fault as either design-related, production-related or buying-related. In systems terms, if diagnosis was to be done effectively there had to be a close relationship between these three areas; a major pre-occupation in the firm is how to bring design and test closer together. It was design-related faults that were the most difficult to solve. For example, in radar systems two functioning components may not behave as expected when they are linked together; this inability to predict behaviour presents major problems when diagnosing. It is only recently that Test Engineers discovered that in the Design Department a computer-based model existed to help compare predictions with actual behaviour. Possibly the greatest problems are caused by the different emphasis between Design on the one hand and Test on the other. Design Engineers are highly specialist and have difficulty in taking a holistic view, while Test Engineers must take a broad view. With respect to production-related faults, two Test Engineers made the point that what is found to be wrong here is what is normally wrong, which suggests that little account is taken of repetitive faults and their root causes. Buying-related faults can cause very costly dismantling of systems.

Buyers are given a free hand to save costs at the point of procurement, but while components may pass procurement specifications they may not have the necessary characteristics for a particular system. An Engineer said that the normal response in these situations was to bawl down the telephone at someone in the Buying Department when what was necessary is a broader systems view of the problem.

In all cases the receptivity and response to the modules were positive. Having said this there were feedback comments about there being no substitute for experience; this was yet another example of seeing experience as both a necessary and a sufficient cause of diagnostic ability. This feedback was surprising in a situation where technology changes at a rapid pace and leaves little time to build up experience in any one area. The Test Manager was able to see value in all the material and could recognise how it related to their attempts to integrate Departments, remove barriers and generally take a broader view of the systems design, build and test. The Test Engineers were more inclined to select only key messages and had difficulty in seeing how the firm could find time to make use of the ideas. This was a reasonable assessment of this situation because the opportunity to utilise the ideas are at present severely limited.

Case Study J - Pharmaceutical Products Manufacture.

This firm researches, develops and manufactures a range of pharmaceutical products. Fault diagnosis occurs at two main stages in the production process, the first is during the actual mixing and forming of the product; at this stage there is a tendency to look first for equipment or machine faults before checking other areas for faults such as the actual mixing process. The second stage concerns the packaging of the products where high speed complex machinery is in use. It is this second area that has been considered in this study. One Senior Manager acted as a Champion for this project, and has maintained an involvement in the work. One Middle-Manager with responsibility for training who acted as the Gatekeeper, and six Technicians provided feedback on the methods and ideas.

Information and data from these processes, gathered during research field work, were incorporated into the open learning modules. Changes made in this firm to the manufacturing process provided examples of systems thinking in use; there is an on-going attempt to remove barriers between departments, and to recognise that inter-related multiple causes need to be understood before production downtime can be improved. One of the most significant changes has been the integration of maintenance personnel into the production process. Skilled maintenance Technicians are part of a production unit, rather than based in a remote workshop on-site. In this situation only a small central core of Technicians are based centrally to cover major problems, and some to cover routine factory maintenance. The emphasis is upon mechanical fault diagnosis; electrical/electronic Technicians are fewer in number and operate across a wider area. Taking a broad view of this change it can be sen that it is not without possible disadvantages. One of the most significant is that current line-dedicated Technicians have the flexibility to diagnose across the plant but as new technicians are recruited to operate in a line-dedicated way this flexibility will be lost.

A significant feature of pharmaceutical packaging is that over the period of one shift it may appear that no major downtime has occurred, however actual packaging up-time may be as low as 60% due to the occurrence of a number of failures that result in short stoppages. In this situation there can be an on-going attention to symptoms, the correction of faults but little consideration of causes. The presence of Technicians does increase the attention given to causes but the idea of adopting a broader view of the production process is not common. In terms of process failure and downtime the boundary drawn around the production system needs to include the sub-systems of packaging design, material supply and inwards goods control; all three areas produce significant factors which help explain reasons for packaging failure. In most cases there is little feedback to one of these areas when it has been found that a failure is caused either by a design-related fault, a material-related fault or is due to poor quality of the raw material being used.

With respect to open learning module use, some of the changing practices on this site prompted ideas for the presentation of the learning material, but in practice it was difficult for the Managers to conceptualise in systems terms the increased interaction that was taking place, such as that created by the removal of boundaries between production and maintenance.

The first module on listening and questioning has been universally accepted, and both Managers and Technicians questioned why this aspect has not been included in Technician training until now. The main reason for this response is that the relationship between production Operators and Maintenance Technicians is one of critical importance to the pharmaceutical business, and this aspect of training is recognised as making a contribution to the effectiveness of this relationship. The role of the Operator is particularly important to diagnosis. This has been highlighted where Research Chemists use machines as part of their work and where few of these casual'''Operators'' have any machine-sense; the result is that Technicians are busy rectifying faults of which some can be very costly. There was a more limited use of techniques from module two. In this firm the emphasis is upon mechanical faults in a mainly linear process and it was only additional information about the half-split technique that registered clearly. Refining the use of visual search which is used frequently, and known comparison, i.e. checking with an identical line that is working well, were the other two techniques of value. Fault history recording is of enormous benefit to this firm, yet the systems in use are limited in their effectiveness. This is generally acknowledged among Managers, Technicians and Operators; despite this recognition of weakness there is a reluctance to invest the time in improving the situation. The material in module four served to increase awareness about the potential pay-off from adequate fault histories but response in this respect has been slow. There were examples of line-dedicated Technicians maintaining their own record systems but these are not generally accessible to the firm. The overall attitude to costs, in module 5, was that this is a Management issue, and the dissemination of the ideas in this module to the shop floor would be difficult. Only one reason was offered for this view, and this was the nature of the production process; there is a need to concentrate totally upon the behaviour of the line, and there is little time to consider other issues such as costs. The broader approach is however being applied to diagnosis by recognising the need to consider a wide range of causes, and to improve feedback about fault events.

The transfer of innovation is critical to the research and development area of this firm and ultimately determines the business success in a highly competitive market. In the production area of the firm the need for and access to innovation are much less clear. On the evidence of this investigation, the firm shares with some of the small firms the tendency to invest in new technology hardware without the complementary transfer of knowledge and know-how to fully exploit the new hardware available. A training system was in place that could serve as a suitable channel, but this had a low profile in the firm. In these circumstances transfer was best achieved by working alongside the changes that were being instigated in the Production department. However the Middle-Manager with responsibility for training was himself trained in the use of the open learning modules so that he can incorporate the material into current training programmes.

Case Study H - Equipment/Computer Servicing.

This firm services both reprographic and computer systems in a wide range of client premises. A Senior, headquarters-based Manager acted as Champion for the project and a Middle-Manager with responsibility for training acted as Gatekeeper. As in the previous case study, this manager was trained in the use of the open learning material in order to develop the ideas further in the firms Training Centre. In addition to these managers two Field Engineers provided feedback, and a full day was spent with each in client's premises diagnosing faults. This firm has a well well established system for training and here the training function worked effectively as a transfer channel.

In this case the cost of diagnosis and how the use of various techniques can influence costs provided input to module 5. With respect to both reprographic and computer servicing there can be a tendency for Field Engineers to use the technique of substitution. Here, printed circuit boards (PCBs) and other component or units are replaced as a means of locating faults. The outcome is that thousands of pounds worth of spares are being transported in service vehicles which can include used parts that are not faulty but are unlikely to be used again. The Engineers seen had full awareness of these cost implications while diagnosing which indicated that through training this firm was encouraging a broad view of the diagnosis process. For this firm it was important to merge the module 2 material on techniques with the module 5 material on costs. The fault recording system was the most comprehensive to be encountered during this project, however the firm was still dependent upon Field Engineers for its effective use, and their response in this respect differed widely. Where Engineers did use the full recording system it was possible for the firm to learn a great deal about causes of failure, and allowed a comprehensive analysis to be made of fault events. From this analysis came details of various ways that faults can be caused, and also identified the probability of different types of faults in various contexts. Many of the examples gathered during this field work helped generate ideas for sections of module 4 on fault recording, therefore the production of this module added little to this aspect of the firm's work. As with other firms in this study the ideas behind listening and questioning for faults were novel and have been utilised in the training of Field Engineers. The ability of Engineers to gather information from a wide range of people is vital in all the diagnosis that is done. This range is from school administration clerks who operate reprographic equipment to research scientists working on computer networks. Apart from listening and questioning for fault information, the work demands a high level of multi-type client relationships but in this respect the material did not go beyond listening and questioning. Techniques from module 2 were drawn upon extensively, at any one client visit three or four techniques could be used, most typically: Half-Split, Visual-Search, Bracketing, Known Comparison, and at times Substitution! The module on systems thinking was not acceptable to this firm, the main criticism from both Managers and Engineers was that it contained too much theory that was difficult to relate to practice. Managers also said that a tendency towards de-skilling in some areas of the work, i.e. basic board changing, had led to fewer time-served and fully technically competent Engineers in the field, and this in turn has led to an inability or unwillingness to accept ideas that are not strictly practical and job-related.

This firm, which has a strong commitment to training provided an opportunity for this function to be tested as a transfer channel. On the evidence of this study the ideas have been absorbed into the firm; in some cases they have served to reinforce current practices, and have served also to introduce new ways of conducting diagnosis; there has also been rejection of ideas where they are perceived as serving no useful purpose.

Case Study K - Chemical Processing.

This firm produces a range of chemical-based products under continuous-operating conditions. In this case the responsibility for fault diagnosis is shared between the plant Operators and the electrical or mechanical Troubleshooters. The liaison and communications between production and engineering is crucial to the success of plant operation. Initially, two senior Plant Managers, a Plant Manager, four Shift Supervisors, an Instrument Engineer, a Maintenance Engineer and two Maintenance Supervisors were involved at various stages in providing the opportunity to collect information about fault diagnosis. Some outcomes from this field work were used in the design and writing of the open learning modules. Subsequently, the modules have been used in a Training Centre that services the requirements of the chemical plant. For this part of the project a Senior Manager (Training) and Manager of the Training Centre became involved. It is this latter part of the project that is concentrated upon here, although there will be reference to information gathered from the plant to illustrate the typical needs of the firm.

In general it can be said that few faults are Operator-related, the shift members work very closely to well rehearsed sequences of operations. Whenever it is economically feasible duplication of units such as pumps and motors is introduced to avoid costly downtime. Many faults occur to instruments and to instrument sensors, and faults are recorded into an on-site computer system. The actual manual records, upon which the computer system is based, could not be described as fully diagnostic; there is still the tendency for critical causal information from diagnosis to be stored in the memory of Operators and Maintenance Personnel. However there are activities on the plant aimed at continuous improvement in this respect.

Given that a chemical plant represents one of the most complex systems of inter-related processes and inter-related personnel of different disciplines it could be expected that ideas which promote a holistic view would be fully utilised. The response of Engineers in particular is to reject the ideas as too theoretical. A five-day fault diagnosis course has been designed since the introduction of the open learning modules, but only selected parts of this material have been used. The outcome from this is a reductionist view of the diagnosis process. The Centre Manager said that this is in response to what the Engineers want; this raises an interesting point with respect to the innovation of ideas. If a firm responds only to felt needs internally, how does it tap into and use ideas from outside? In this case the felt need was for practising fault finding by the simulation of faults on a mock part of a chemical plant; this is seen as rapidly building up experience. The greatest need was felt to be knowledge of new equipment on the assumption that such knowledge is a necessary and sufficient requirement for effective diagnosis; evidence from research, summarised in Chapter 2, suggests that knowledge of a system is a necessary but not a sufficient requirement for effective diagnosis, and students taught diagnostic techniques have performed better than experienced Troubleshooters.

In this case there was an effective Champion, the Senior Manager (Training) but an effective Gatekeeper was lacking, that is someone who could conceptualise and assess systems ideas with respect to his or her context. Here, parts of the material have been recognised as useful, but the essential systems thinking ideas have not registered in a situation where at least they can be said to be plausibly appropriate.

7.5 Comparisons between small and large firms.

From the information gathered and observations it has been possible to identify significant differences between small and large firms in this sample, but overall the picture is one of many similarities.

One area of difference was to be found in the investigation of transfer as demonstrated through the introduction of knowledge and know-how contained in the modules. Individuals in these firms who become involved in the transfer of knowledge and know-how generally find these tasks easier to perform in the large firms. In particular, the person who acts in the Technology Gatekeeper role has more access to relevant information about new developments, whether in connection with new technology or with training which supports this technology. There are established links to Government and private bodies outside the firm such as Training Enterprise Councils, Colleges, Universities, Research Establishments and private Training Bodies. In contrast, not one of the small firms had any firm links of this kind, and the result is that no clear channels exist between the sources of ideas on the one hand, and possible recipients in the small firm on the other. Reading through the small-firm case studies, it will become apparent that some people do carry out the Gatekeeper role effectively, but mainly through the use of personal characteristics; the lack of transfer mechanisms can be said to make this informal part of their work difficult to perform, and in this respect it could be said that their potential is not being fully utilised. For example, the direct approach taken in this project of cold-contact with respective Directors was possibly the only means of transferring the learning material into these firms. Directors and Managers in all small firms made comments to the affect, that even where material in support of technology use is known to them they have no means of assessing its relevance, worth or potential benefits. All but one of the small firms had invested in new technology, but in all cases their ability to develop the people, who are needed to 'drive this technology is lacking. Apart from the problems associated with transfer of knowledge and know-how, outlined above, there is the difficulty of finding time for the introduction of training initiatives. In this respect there were no real differences between the small and large firms. All had reduced staffing levels to a point where slack in terms of human resources was not readily available. In the past, there was what amounted to an informal recognition that people could be made available from the production process for the purpose of providing new skills or for the up-dating of skills and knowledge.'

One observation that caused surprise to the Researcher, who had not worked in small firms previously, was that department boundaries acted as effective barriers to the transfer of knowledge and know-how in a way equal to that found in large firms. One of the large firms had chosen this phenomenon of departmental-barriers as a key current project, others recognised these boundary-problems, and in the small firms it was only individual Managers who expressed the need to overcome this type of problem.

The gap between more senior Managers and shop-floor personnel in terms of systems awareness was evident in both large and small firms. One person on the shop-floor in a small firm, who had more systems awareness than some senior Managers, served to contradict this statement, but in general the broader view of diagnosis was not in evidence below senior Manager level. This issue has been discussed more fully in Chapter 6 under Senior Manager response.

Inspection of the twelve case studies shows that receptivity and response to the open learning modules varied across firms without any notable differences between large and small. The large firms tended to be more preoccupied with organisation-related issues associated with diagnosis, such as deciding to have the maintenance function either centralised or line-dedicated, rather than with technique use or technical problem solving. The small firms tended to emphasise the influences that effective or less effective diagnosis can have upon the product being produced.

The first module on listening and questioning was universally received in a positive way; while some firms derived more tangible benefits than others the overall response was of positive acceptance. The third module on systems thinking was received in an almost universally negative way. A recommendation, made early in this project by Roger Seaton at Cranfield Institute of Technology, to integrate this material into the other modules at appropriate points has on this evidence proved to be correct. This will be done in any future re-writing of the modules. The second module on diagnostic technique use was frequently met with what can be called the experience syndrome, that techniques of diagnosis can only be learned from experience; this can be said to reflect a particular attitude towards learning. The discussion on attitude formation in Chapter 6 is relevant to this issue. The experience syndrome was to be found across all firms in the sample. However, there were sufficient positive responses in both large and small firms to justify further promotion of the techniques. The form in which the techniques were delivered, by written text with diagrams and exercises, was not acceptable to a number of people; for this reason there needs to be an exploration of alternative means of presentation. One part of this second module has been converted to interactive video and is in the process of evaluation, this is the logic reasoning exercises, see Appendix D in Volume II. Among Technicians in particular there appears to be a general reluctance to learn through the written word, but there is still too little evidence available to suggest that computer-based delivery is more effective as a means of learning. The fourth module that had the aim of producing fault records as a means of providing effective diagnostic aids was of benefit to only three small firms; one of the large firms already had a record system and here they noted from the module areas where improvement could be made. In the cases of the nine remaining firms, the benefits to be gained from effective fault recording and analysis were either not recognised, or where there was this recognition time was not available for implementation. One of the few near-perfect fault record systems encountered by the Researcher, outside this study, was in a Japanese-owned car manufacturing plant based in the United Kingdom. Again in a way similar to the large firm in this sample the Managers, on seeing module four recognised small improvements to be made. One of the two small firms in this sample to make full use of this module was also Japanese-owned. The module brings together what is known about valid recording of faults and their diagnosis, and is based upon research done in industry and upon contact with members of the medical profession. The general response to the ideas and methods in this module have to be reported as negative. The fifth module on costs was generally better received in the small firms, particularly at shop floor level. In the large firms the overall attitude was that this is a subject of concern only to management. The positive response in the small firms came mainly from Engineers who had regular contact with customers. In large firms there was not this identification with customers, and in the small firms where customer contact was not experienced the attitude that Management look after costs was prevalent.

7.6 Summary.

In this chapter, key issues arising from the twelve case studies have been presented. The chosen unit of analysis was of the individuals who were involved rather than groups, departments, organisations or events. In each case there have been three subject areas covered: the mechanism of transfer, the means of learning and response to five of the modules (module 6 is more concerned with administration of training). On the basis of this evidence it can be said that in both large and small firms training as presently functioning does not provide an effective technology transfer channel, either into the firm or within firms. The main reason gathered from this study is that too little slack in terms of human resources exists to allow time for training initiatives to take place; this observation applies equally to both large and small firms. The innovation-related roles, discussed more fully in Chapter 6, appeared easier to perform in the large firms due mainly to more developed channels of access to technology knowledge and know-how, which includes training technology. These roles were recognisable in some of the small firms, but more through personal characteristics of the individuals concerned and not as part of a technology transfer mechanism. Even in small firms where there had been significant investment in hardware and software (seven out of eight) there were major difficulties in transferring necessary knowledge and know-how, again this also includes training technology.

With respect to receptivity and response towards the learning technology, there were no notable differences between large and small firms; there was a common sharing of issues relevant to diagnosis. One module can be described as having failed in its aims and objectives, one only marginally acceptable, two recorded areas of positive response, and one was universally positive.

Chapter 8. Receptivity and Response: Survey.

8.1 Questionnaire design and delivery.

The questionnaire used in this survey, see Appendix A, had two stages of development. The first pilot testing of the questions aimed to investigate the Troubleshooter's perception of fault diagnosis, by using a set of open-ended questions. Some of these first questionnaires were answered during face-to-face contact, and others were completed independently. One finding from this exercise was that most Technicians and Operators were reluctant to provide long-answer responses by putting their thoughts on paper. Although useful information was collected at this time, which then guided the questionnaire re-write, it was decided to develop a semi-structured format. This approach allowed for the investigation of both measurable and non-measurable issues. Following discussions during the pilot stage it was decided to introduce a section that examined the benefits to be derived from training in fault diagnosis, and the questions used in this section have been based upon these discussions. The examination of benefits is also relevant to the outcome-related research questions listed in Chapter 1.

In designing the questionnaire, some rules were observed, (Bouchard, 1976), in framing and ordering the questions:

1. Is the question necessary? A large number of questions were eliminated in trying to avoid what Bouchard calls 'questionmongering'. Only questions that could be described as essential to this part of the research framework were used, and questions that 'could be useful' were eliminated. Repetition was checked to ensure that no two questions served the same purpose.

2. Can the respondents answer the question? A note was included in the introduction to the questionnaire to allow for the possibility that some respondents may not have the necessary information. This possibility was anticipated because the sample was not homogeneous in composition. The important point was that respondents put a line through the question to show that it had been considered and not overlooked.

3. Is each question clear? This rule was checked out in a pilot of the revised questionnaire, two nearby firms were used to provide only a small sample of seven respondents, but included both Operators and Technicians to check respective levels of understanding.
4. Are the items susceptible to an order effect? The items in each section were randomised; however in retrospect it was realised that question 2, on learning, did show some order effect.

5. Is one item likely to bias those following it? This effect was checked, and no obvious bias can be detected in this respect.

6. Is the ordering of the questions natural or reasonable? This refers to the sets of multiple-choice questions and open-ended questions, and not the order of items within questions as in rules 4 and 5 above. There was a conscious effort to present a 'logical' follow through of these questions, rather than a haphazard listing.

7. Does the sequence maintain motivation? The point is made by Bouchard that long series of closed-ended questions tend to bore respondents. However it was found in the pilot for this exercise that too many open-ended questions impose too great a demand upon respondents; for this reason it was decided to present a mix of open and closed type questions with the open-ended questions interspersed at intervals.

8. Is the opening appropriate? This, the most critical part of questionnaire design, was thought through carefully. Upon reflection, the fourth question on issues could be threatening or could be treated with suspicion, and should not have come so early in the questionnaire.

There are a number of doubts and confounding effects associated with questionnaire use, and it is possibly the weakest link when used in any research triangulation, and much weaker when used alone; for this reason it was felt necessary to present the rules that have been used in the design and development of this questionnaire.

Delivery of the questionnaire was done by leaving six copies with each firm, to be returned later. From a possible sample of 72 there was an eventual return of 53 (73.6%). Large firms, 17 (70.8%) and small firms, 36 (75.0%). Expected return for effective questionnaires is between 75 and 95%, (Williams and Wechsler, 1970).

To assure respondents of confidentiality the inclusion of their name was optional, and it was stated that no reference would be made to named persons or companies.

8.2 Interpretation of the results.

This interpretation contains three elements: a sequential reporting of the results, question-by-question, an inter-question comparison, and a comparison with case-study results where relevant. In reading this section it would be useful to have the questionnaire to hand; Appendix A in this Volume (1).

Question 1. Types of fault diagnostic work.

One respondent did not answer this question, n=52. Those who did, recorded altogether 124 responses as shown in Table 7, from most frequent type to least frequent.

Table 7. Types of fault diagnosis work.

Electronic Digital	34
Electronic Analogue	27
Mechanical	23
Hydraulic/Pneumatic	19
Instrumentation-Control	12
Operator	5
Process Control	4

These types of diagnosis reflect a commonly used way of grouping skills in industry: single-skill, dual-skill and multi-skill. Analysis of this question shows the following:

Dual-skill	25 (48%)
Single-skill	19 (37%)
Multi-skill	8 (15%)

Where a respondent gave 'electronic digital' and 'hydraulic/pneumatic', this was recorded as dual-skill. 'Mechanical' and 'Instrumentation-control' was also dual-skill. The only double combination not treated as dual was 'electronic digital' and 'electronic analogue'; when given together this was recorded as single-skill. Multi-skill was recorded when three or more types of diagnosis had been given.

In answer to the request for 'other' types, three respondents gave 'Electrical' (an omission in retrospect), one gave 'PLC software logic fault diagnosis' and another gave 'RF fault diagnosis'. These have been included in the above grouping of skills. In analysing the responses to this questionnaire this grouping has been considered as a variable.

Question 2. Learning of Diagnosis.
One respondent did not answer this question, n = 52.

There was a lesson here, on how questions are worded. When respondents gave 'by experience alone' it was anticipated that no other option would be given, logically! However five respondents did include other options with this answer.

The overall outcome of this question was as anticipated in that 25 (48%) of respondents gave experience alone as the method of learning.

There was a total of 93 responses to this question and these are shown in Table 8.

Table 8. Methods of Learning Fault Diagnosis.

By experience alone.	25
Experience, plus some instruction on the job.	26
Sitting next to Nellie.	17
FE College courses.	12
Off-the-job courses.	7
Planned on-the-job training.	3
Computer-based training.	3
Open Learning Programmes.	0
Distance Learning Programmes.	0

In answer to the request for 'other' only one response was given by one respondent, this was 'In at the deep end'.
When interpreting the responses to this question it can be seen that experience plays a significant part in the learning of fault diagnosis, and reinforces the responses given by additional people during the field work. For example, when Further Education College courses were indicated, experience was always included as well. In retrospect it would have been useful to ask for a ranking from most relevant to least relevant method. The low response to computer-based, open and distance learning also reinforces the discussions and observations made during the field work, and is reinforced again in question 6 when respondents were asked for preferred method of training. In both large and small firms there was a low level of awareness about the latest developments in training technology, such as multi-media and interactive video; this can be interpreted as a further example of slow or ineffective transfer of technology into firms.

In comparing these responses with the previous question, on type of fault diagnosis work, it is possible to make some observations. As was to be expected, the Operators gave experience only, and sitting next to Nellie as responses. The methods other than experienced-based (12+7+3+3 = 25), see Table 8, came mainly from large firms. Of the 12 FE College course responses, only 4 came from small firms. All other non-experience based methods (10) were reported from large firms. When these results are examined using the variable of skill grouping, it is seen that of the 25 non experience-based methods only 3 were given by single-skill respondents. Dual-skill respondents accounted for 6, and the much larger number of 16 came from multi-skilled respondents.

Question 3. Skills of Fault Diagnosis.

All respondents attempted this question, but only the item 'listening to, and questioning, other people' was included in the ranking by all. The results are given in Table 9, in order of the most important skill (lowest mean score).

Table 9. Skills used in Fault Diagnosis.

	x	
Recognising correct symptoms.	2.48	n = 52
Gathering fault information.	2.68	n = 51
Reading drawings and diagrams.	2.88	"
Reasoning logically.	4.80	"
Interpreting manuals.	5.35	"
Listening to and questioning others.	5.83	n = 53
Using fault diagnosis techniques.	6.47	n = 51
Recording fault information.	6.50	"

Inspection of these results indicates that three skills are clearly recognised as important. Of these three it is the reading of drawings and diagrams that has not received adequate attention in the modules. Diagrams and circuit drawings were used in module 2 in order to illustrate the application of fault diagnosis technique, however the reverse process of using the skill of reading diagrams and drawings to aid the fault diagnosis process was not found possible at the time. This is not to say it cannot be done; further research would be needed to make the links between the respective uses of these skills, possibly with the use of protocol analysis to record thought processes as Troubleshooters transfer their knowledge from the drawings and diagrams to the fault event.

When asked for 'other' six respondents gave six additional skills:

	Rank.
Understanding how equipment works.	1
Understanding how components function.	2
Passing fault information to others.	4
Avoiding fault re-occurrence.	4
Intermittent fault finding.	9
Customer relations.	9

The first two on understanding the process is frequently confused with skills of diagnosis. Knowledge of this kind is a necessary requirement before fault diagnosis is performed but is not a sufficient requirement, and is not an intrinsic part of fault diagnosis skill use; it is complementary. The concept of causation and the attendant logic of necessary and sufficient has proved difficult to transfer to the shop floor. In contrast, the third skill of 'passing fault information to others' is quite valid and has been noted for any future revision of the modules. Avoiding fault re-occurrence and intermittent fault finding are part of diagnostic technique use. The skills of customer relations has been noted already, from the case studies and from critical incidents described in the next chapter. This is an area that needs more attention, particularly for Field Engineers but also for those within firms where the concept of 'internal customers' is in use. One predictable item among these responses was the low importance given to the recording of fault information. This reinforces results from the field work, and from earlier work done on this project, that Troubleshooters do not readily recognise a need for the recording of information. Closer analysis of this item shows that the highest ranking given was 4th, and this by only three respondents. The highest ranked skill of recognising correct symptoms is fully covered in the modules. This does not apply to the skill ranked second; although the reading of drawings and diagrams is included in module 2 on technique use, it is not given specific attention and needs to be considered further. The other skills are covered by more than one module. On this measure it was not possible to identify any significant relationships using variables from the previous two questions.

Question 4. Issues.

Overall the issues recorded in this section reflected five main concerns:

1. Problems concerned with the buying-in of equipment and spares; this was repeated often.
2. Lack of skills in certain areas and lack of suitable training.
3. Lack of policy or plan for standardisation of machines/equipment/parts.
4. Poor availability of technical information (relevant to technology transfer).
5. Poor attention given to the prevention of faults.

Listed below are comments taken at random from this section of the questionnaires, and copied exactly as written.

* 'Poor reliability in some areas (bought-out and in-house) Quality of build has got worse, lack of communication'.
* 'Lack of training in complex equipment'.
* 'Inability of some engineers to diagnose particular types of circuits, i.e. n-wave

or RF. Inability of some engineers to use particular items of test equipment as fault finding (as opposed to test) tools'.

* 'Tendency for buying office to procure cheaper/lower quality items causing reliability problems which can far outweigh the cost saving'.
* 'Complexity of equipment and therefore time taken to diagnose and repair manually can be more costly than new replacement item. Engineer's skills are being lost by this policy'.
* 'Pace of change, i.e. new plant and processes. Poor standardisation of kit, i.e. up to 5 different PLC types'.
* 'Availability of spares. Up-to-date drawings and manuals'.
* 'Old out-of-date packing equipment in some areas'.
* 'Information regarding the original fault is not passed on to the appropriate personnel sufficiently'.
* 'Steps are not taken often enough to prevent faults re-occurring'.
* 'Training could be done on Friday afternoons, when a lot of the time people can't carry on with their jobs'.
* 'Technical information is not always made freely available. Lack of a positive standardisation plan to keep the variety of equipment to a minimum'.
* 'The real problem lies with production time taking priority over every other aspect, especially preventive maintenance'.
* 'Bought in items tend to be the weak points'.

* 'Modifications to product cause numerous faults but are soon cleared'.

Question 5. Relevance of training in fault diagnosis.
One respondent did not answer this question, n = 52.

The responses to this straight-forward question were as follows:

I could benefit from training in fault diagnosis.	23
I see no need for training in fault diagnosis.	7
I am prepared to consider the need for such training.	22

The responses to this question have to be considered in relationship to the responses given for how diagnosis is learned, question 2; also in relation to comments below from question 6, and to the amount of training available in this subject area as reported in the case studies. The apparent willingness to be trained in fault diagnosis is not being matched by any training currently available.

Question 6. Type of training.

Nine respondents did not answer this question, n = 44, which included the seven that feel no need for such training (question 5) and the respondent who did not answer question 5.

Eighty three preferred methods of training were indicated, as shown in Table 10.

Table 10. Preferred methods of training.

Working through training modules with a Tutor in support.	27
Formal, off-the-job training course.	22
On-the-job formal instruction.	13
Informal, next to Nellie instruction.	10
Working through the training modules on your own.	9
Computer-based training.	1
Interactive video.	1

In response to the request for 'other' methods, only one respondent gave 'hands-on with an experienced engineer'. This is worthy of comment because so often in this project 'experience' has to be read as possibly meaning a number of things, the engineer in this quote has to be taken as an effective Tutor as well as being effective at fault diagnosis. There is often a problem is in getting people to acknowledge that experienced people can also be ineffective as Tutors, at diagnosis or in both. Inspection of these results shows that, among this sample, there are two clearly preferred methods. The lack of contact with computer-based methods, shown in response to question 2, is reflected here when a choice of methods is made. It is not easy to make comparisons between question 2 and this question, although they ought to be related; one asks for type of learning and the other refers specifically to training. Possibly there should have been an additional question about preferred method of learning.

Question 7. Training in general.
Fourteen respondents did not answer this question, n=39.

The main reason for asking this question was to set the other responses to this questionnaire in context. In other words, whether responses were given against a background of varied training, a specific type of training or generally limited training.
In response to asking about training of any kind in their organisations, the respondents showed evidence of little more training than was indicated when asked about fault diagnosis training specifically. Formal or informal training with manufacturer's representatives was the most commonly used method. There was only one reference to computer-based training, and none to open or distance learning. The overall picture is one of the traditional next to an 'expert' approach.

The following list of responses has been selected at random, and copied exactly as written.

* 'Lectures, purely listening, little interaction'.
* 'Work shadowing, watching and aiding engineers'.
* 'Hands-on learning through experience, aided by Trainer/experienced personnel'.
* 'Virtually none'.
* 'Usually by working with Design Engineers on first-off equipment, or when you're totally baffled by fault and have called-in Design Engineers'.
* 'Short on-site courses, working alongside service engineers'.
* 'Multi-skills training at college'.
* 'All training is done with formal off-the-job courses'.
* 'On-the-job training (only one or two days)'.
* 'There is a facility for OBS training but at present training consists of adhoc sessions agreed with various manufacturers, normally at part their costs. There are moves to have a more planned approach but with the recession biting deeply, I fear this will be shelved'.

Question 8. Planned training.
The reason for this question was to discover to what extent the range of modules could be considered as comprehensive. When asked if anything is missing there

were six additions to the subject areas covered:

* Common failure modes.
* Uses of drawings and diagrams.
* Awareness of fault diagnostic testing equipment and its use.
* Understanding faults from poor production technique and Operator error.
* Customer relations.
* Practical training.

The full use of module 4 on fault recording aims to help the understanding of common failure modes and poor production technique and Operator error. The introduction of many exercises within the modules aims to promote practical training. The other subject areas in this list have been discussed above, and do need further attention.

Question 9. Use of the modules.
Eighteen respondents did not answer this question, only those in this questionnaire sample familiar with the modules responded, n=35.
Modules 1, 2 and 4 were recognised as valuable by a majority of the respondents; modules 5 and 6 as not valuable by the majority, and the remaining module 3 gets a mixed response with 20% of respondents seeing it as valuable and 30% as not valuable, and the balance seeing some value. The results from this question are shown in Table 11.

Table 11. Responses to the use of modules.

Module.	Valuable	Some Value	No Value	n=( )
1	28 (82%)	6 (18%)	0	(34)
2	28 (82%)	6 (18%)	0	(34)
3	7 (21%)	16 (49%)	10 (30%)	(33)
4	21 (64%)	12 (36%)	0	(33)
5	2 (6%)	14 (42%)	17 (52%)	(33)
6	1 (3%)	6 (19%)	25 (78%)	(32)

The very positive response to module 1 reinforces the face-to-face responses given during the field work. The field work responses to module 2, while being positive were not given to this extent; there were more who expressed doubts about learning techniques in this way, but they did see some value in the module. Again, on the evidence from field work there could have been a greater negative response to module 3 than is shown above. The poor positive response to modules 5 and 6 are as expected. The subject of costs related to fault diagnosis is generally recognised as only of concern to management. Module 6 was designed primarily for Trainers or Training Managers, given that fewer people are to be found in these positions, especially in the small firm, it may be necessary to produce an equivalent module for the shop floor that deals more with learning to learn in a practical way.

The responses to this question can be compared with the skills seen as important to fault diagnosis, question 3. Given that, in question 3, recognising correct symptoms, and gathering fault information were seen as most important, there is a consistency here in recognising module 1 on listening and questioning (gathering information) and module 2 on techniques (recognising symptoms/causes) as valuable.

There is some apparent conflict between the little importance given to the skill of fault recording in question 3, and the generally positive response given in this question to module 4 on the subject of fault recording. During the field work it was discovered that a number of Troubleshooters, and some Operators, recognised the value of fault recording but time was not available for this function. The overall response is to relegate it to a low order of importance, which in turn can be said to have relevance to reducing dissonance between what is believed and what happens in reality, discussed in Chapter 6. Also relevant in this respect is that the purpose served by a function influences its perceived importance. A primary purpose of fault recording is the opportunity for analysis and longer-term planning, and this does not satisfy the more common purpose found in fault diagnosis work of day-to-day fire-fighting.

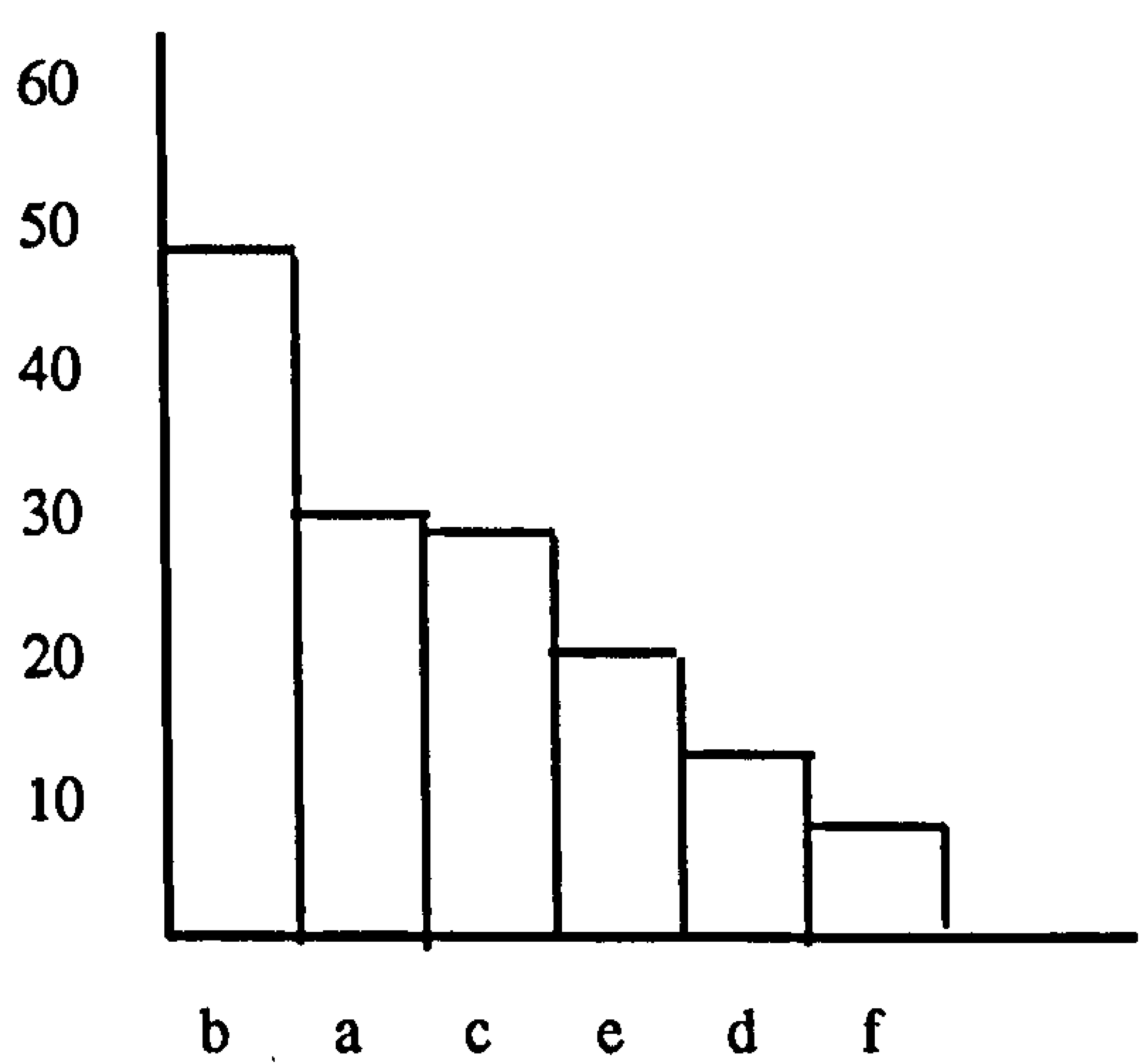
Benefits Section.

The benefits that can be perceived as possible as a result of training in fault diagnosis have been examined in two ways. One was to ask which benefits, in the opinion of the respondent, could be achieved, and the other was to ask the respondent for a level of confidence for each benefit chosen, given the circumstances in their company. A four-point scale was used between absolutely confident (1) to not confident (4); confident (2) and doubtful (3) were the other options. Each question in this section was answered according to this scale. Questions one and two were are related to measurable benefits, and questions 3 to 5 are more subjective in response.

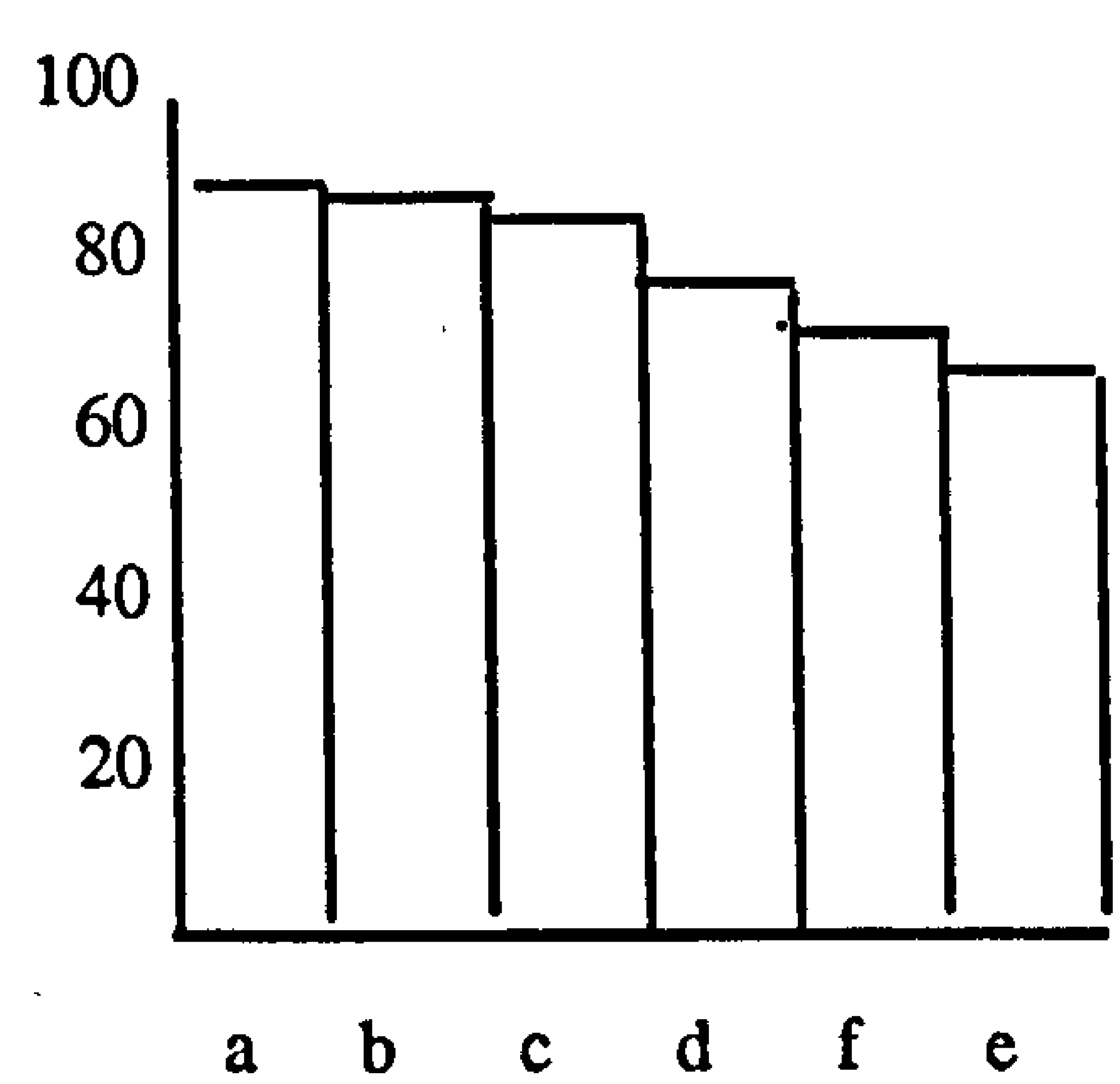
Question 1. Time related benefits.
One respondent did not answer this question, n=52.
These benefits can be called the 'bottom line' of fault diagnosis, that is, gains in production and service time as a result of reduced down time on machines and equipment stemming from increased effectiveness of the diagnosis process. Results from this question are shown in Table 12.

Table 12. Time-related benefits.

	Confidence Level			
Benefits.	1	2	3	4
a) Improvement in time taken to respond to a fault.	16	9	1	2
b) Improvement in time taken to diagnose a fault.	17	25	6	1
c) Improvement in down-time caused by faults.	12	10	3	1
d) Improvement in time between same (repetitive) faults.	4	7	3	1
e) Improvement in time taken to raise spare parts.	5	6	6	3
f) Improvement in time taken to report faults.	5	1	3	0



Frequency of benefits.



Level of confidence %.

Two benefits, (b) and (c), that record a high number of responses and which are seen as possible to achieve are closely related. Changing technology has led to the situation where the act of diagnosis can, and most often does, account for close to 90% of downtime caused by faults, in both production and service industries. Response time, (a) , also strongly influences downtime. The lower confidence in (c) as compared with (b) is understandable because there are difficulties in always separating and defining the many possible causes of downtime.

The low confidence in (e) and (f) could be said to reflect the low involvement of stores personnel and Operators respectively in the issues surrounding fault diagnosis and downtime. The general neglect of fault recording is reflected in (d) because it is only through the analysis of fault records that moves can be made towards improvement in this area of repetitive faults.

Question 2. Benefits related to cost saving.
Four respondents did not answer this question, n=49.

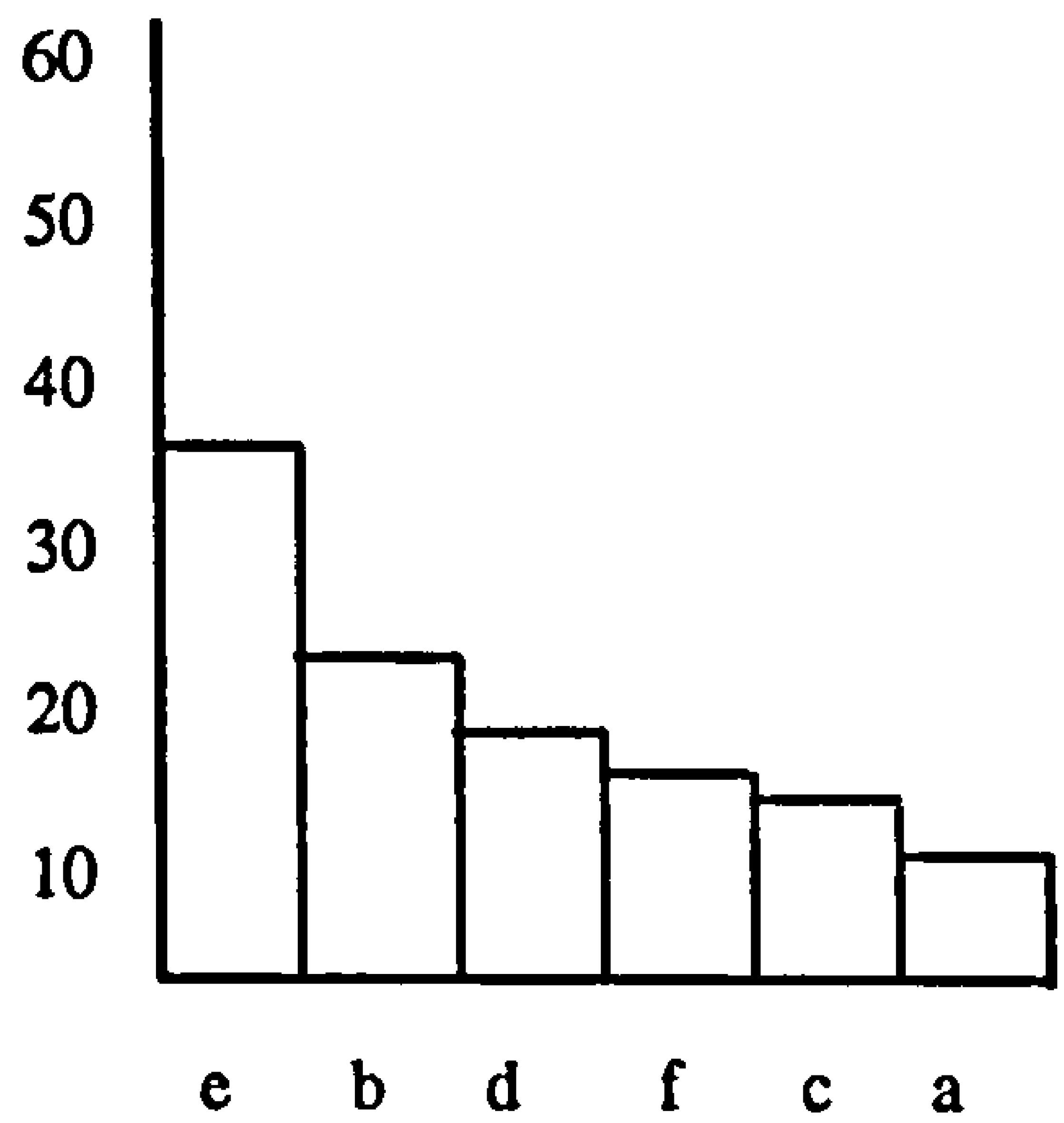
Two benefits were recognised as most possible here, a reduction in maintenance costs and a reduction in the cost of unnecessary call-outs. Overall there was a lower level of confidence than in the other measurable time-related benefits question. The results are shown in Table 13.

Table 13 Cost-related benefits.

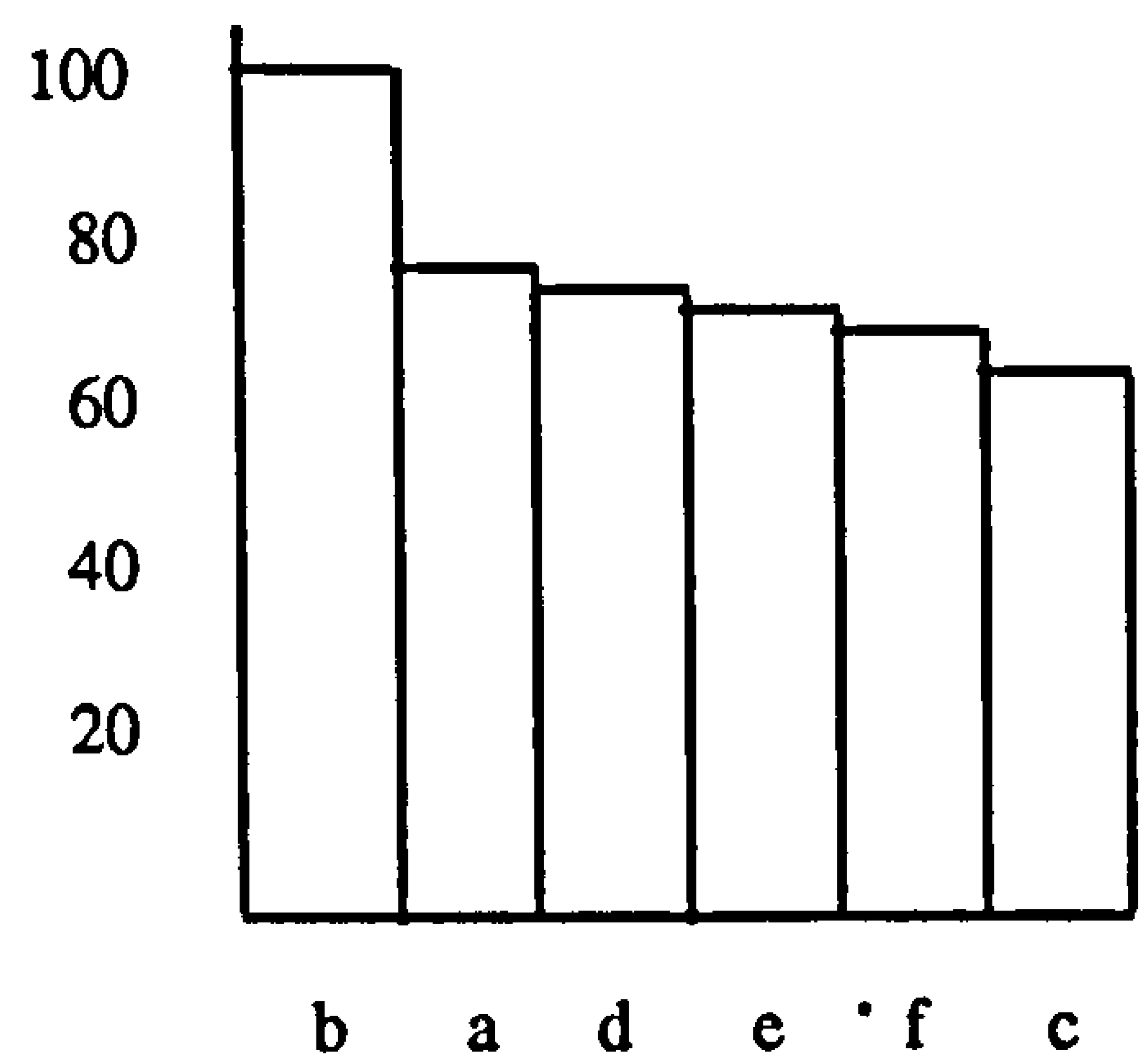
	Confidence Level.			
Benefits	1	2	3	4
a) Reduction of the cost of spare parts held in stock.	3	4	2	0
b) Reduction in the cost of unnecessary call-outs.	17	5	0	1
c) Improvement in equipment/machine pay-back on capital.	2	6	3	1
d) Reduction in quality costs as a result of greater reliability.	7	6	3	1
e) Reduction in maintenance costs.	10	17	7	3
f) Reduction in the cost of outside contractor services.	5	6	2	2

Two further benefits were added in response to 'other':
Lower production test excesses, given level 2.
Understanding of staff undertaking modules, given level 2. (Difficult to interpret in terms of cost-related benefit).

(Table 13 cont.)



Frequency of benefits.



Confidence levels %.

Question 3. Customer relations related benefits.

Ten respondents did not answer this question, and six of these recorded not applicable (na). This response was given despite the note provided at the start of the question to define what was meant here by 'customer'. n=43.

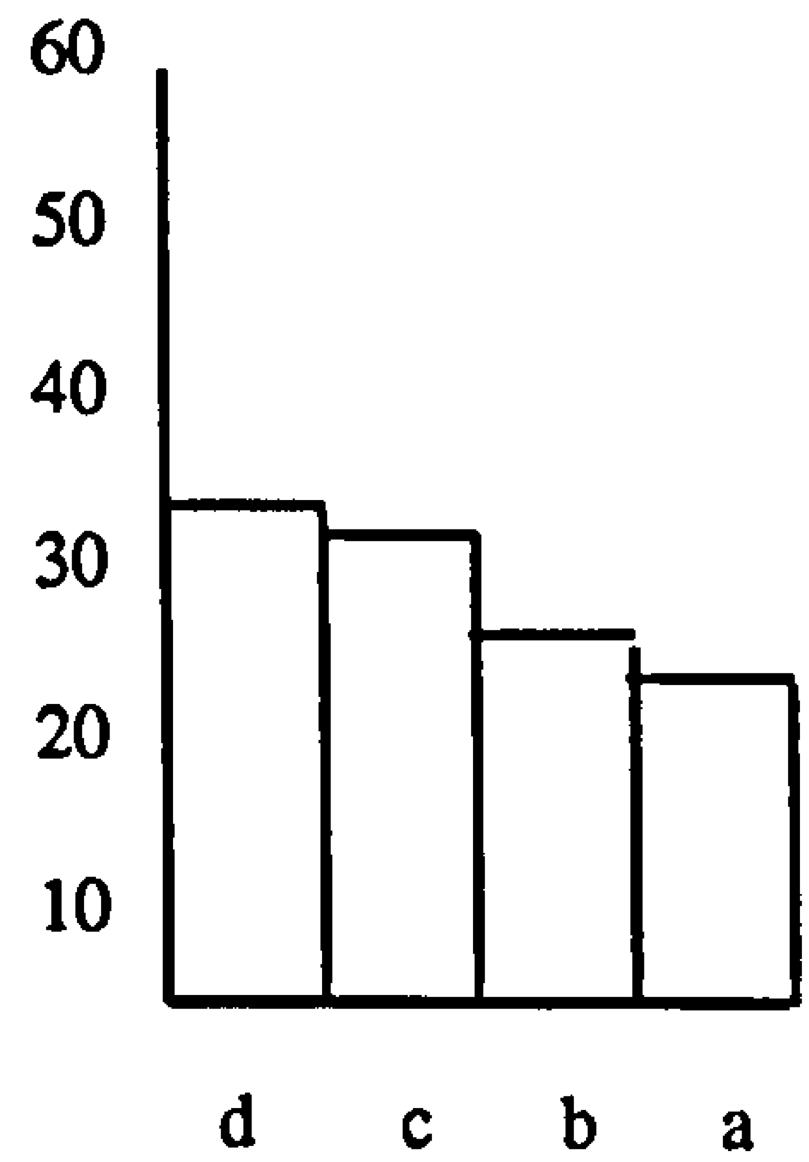
The results from this question are given in Table 14.

Table 14. Customer relations related benefits.

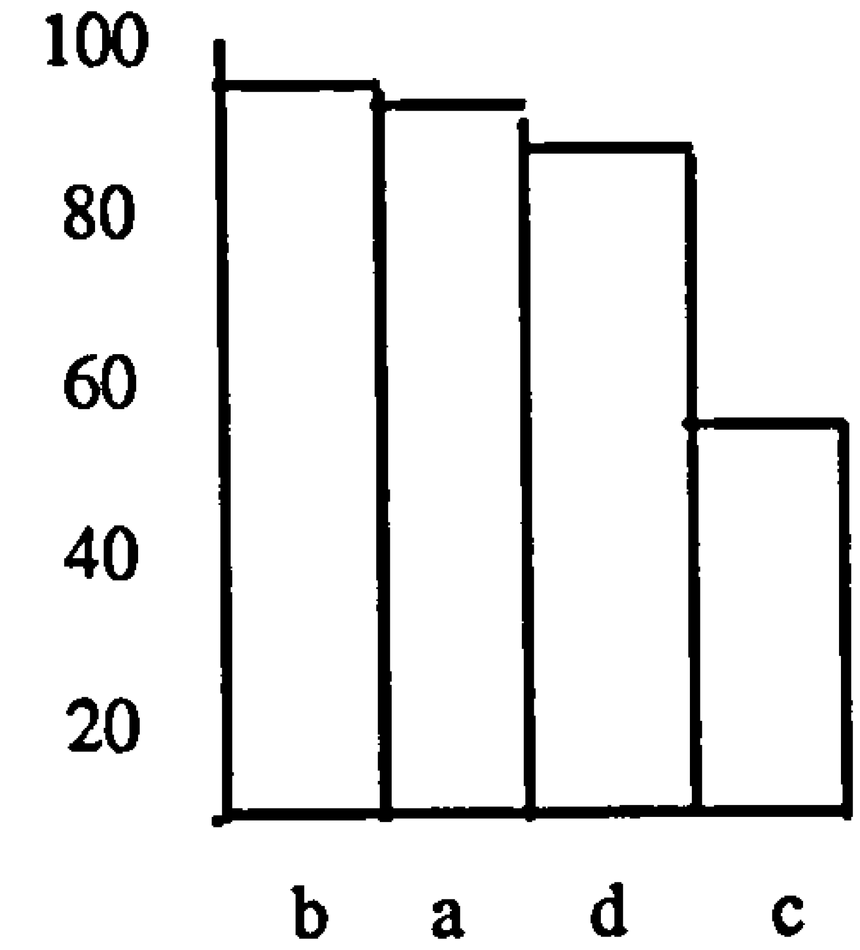
Benefits.	Confidence Level.			
	1	2	3	4
a) Increased customer confidence in machine reliability.	12	9	1	0
b) Greater customer satisfaction with service on equipment.	14	10	1	0
c) Greater customer involvement in fault diagnosis.	6	12	10	3
d) Improvements in customer satisfaction with feedback.	10	18	4	0

In response to 'other' benefits:
Customer confidence during trial-acceptance of equipment, given level 2.
Improved team work, given level 2.

(Table 14 cont.)



Frequency of benefits



Confidence level %

Overall there was a positive response to this question. Improvement in feedback of fault diagnosis information to the customer was seen most often in this sample as an achievable benefit, followed closely by greater satisfaction with service, and confidence in reliability. The remaining benefit, greater customer involvement, was indicated as having considerable possibility, but for many in the sample the confidence in this being achieved was low.

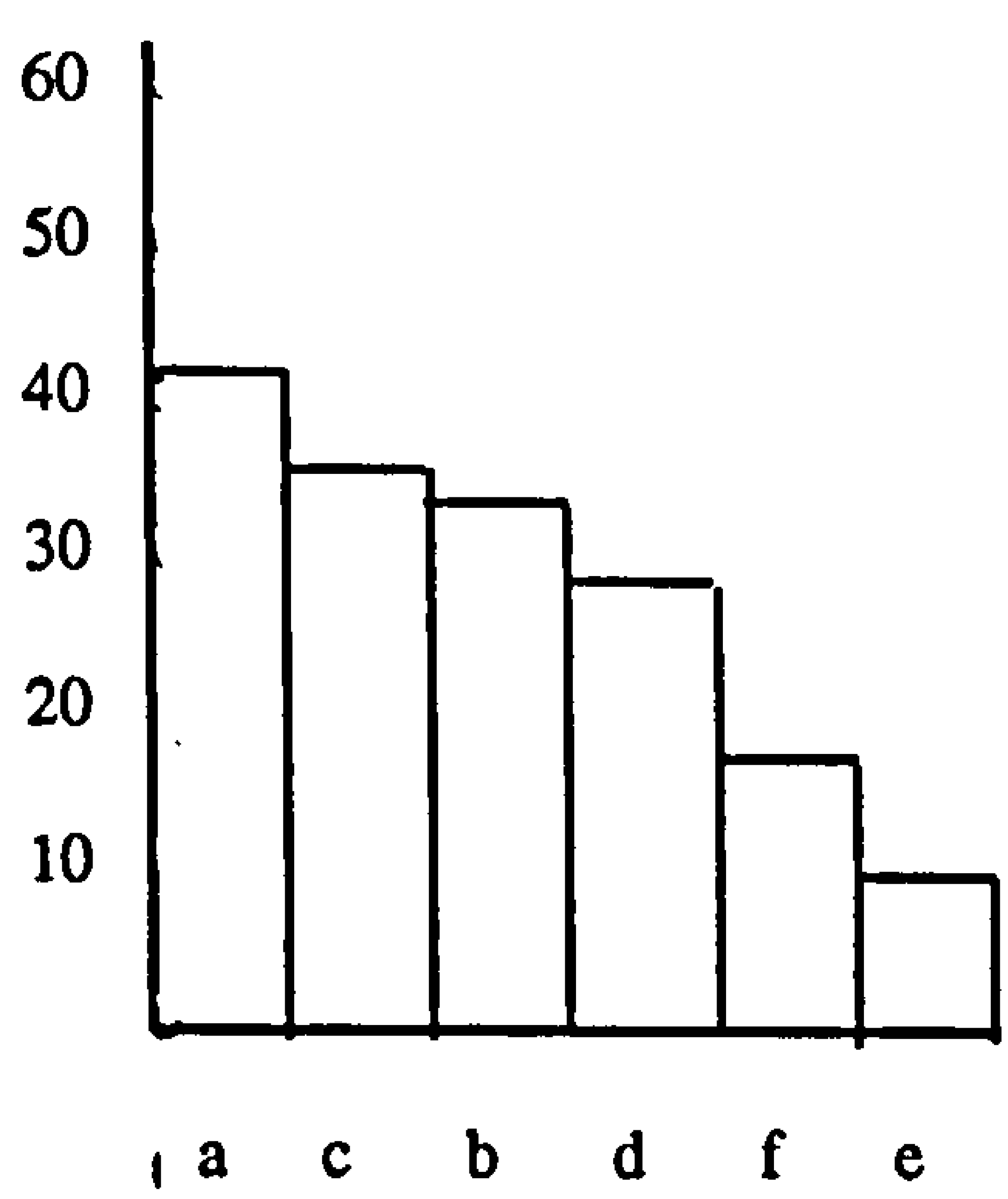
Question 4 Fault information recording related benefits.
Three respondents did not answer this question. n=50.

In contrast to the field work-based responses to fault recording this question raised a significantly positive response. The results are shown in Table 15.

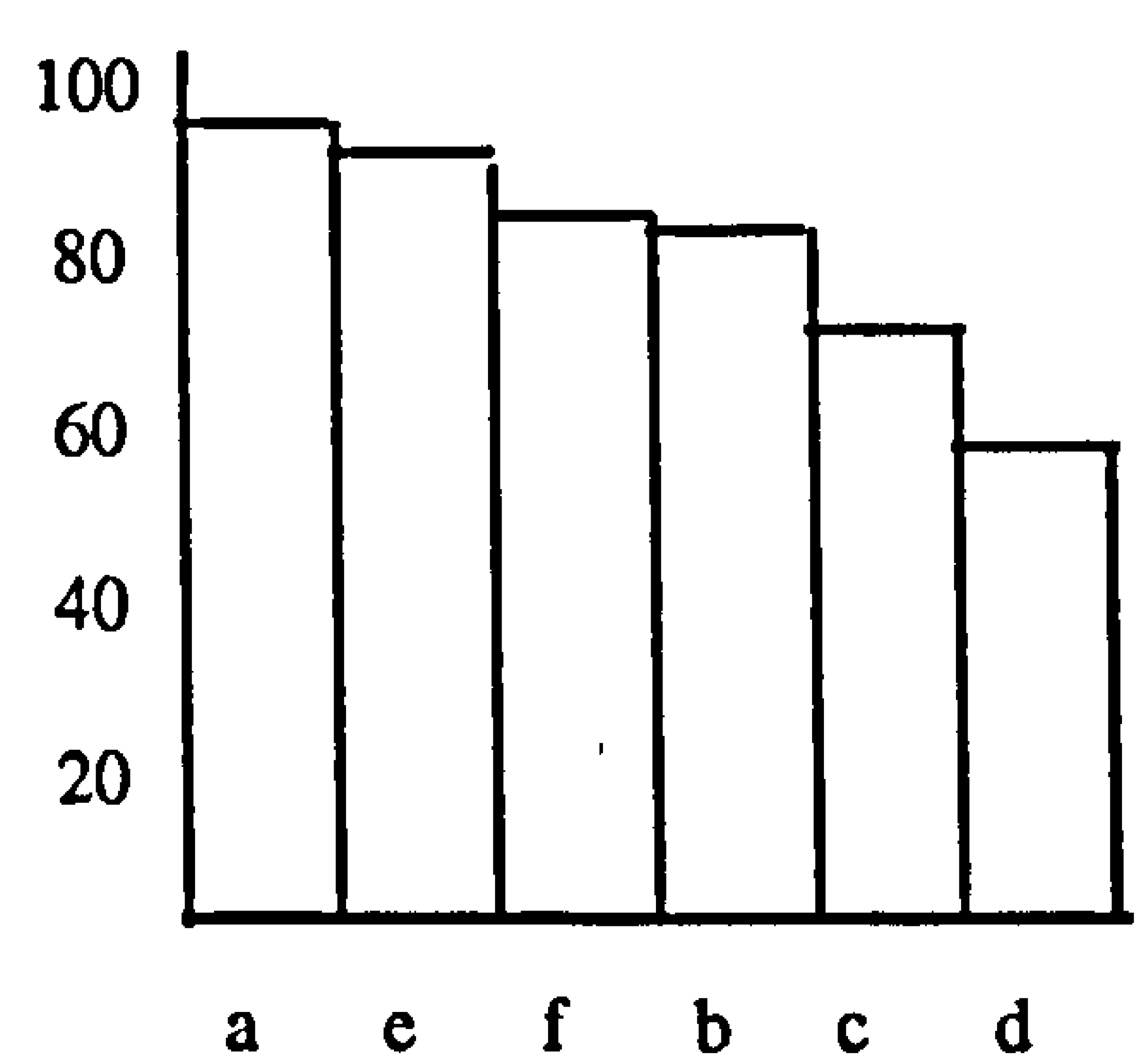
Table 15. Fault recording related benefits.

Benefits.	Confidence Levels. 1	2	3	4
a) Improvements in the amount and quality of information shared between those who diagnose.	29	10	2	0
b) Improved design features as a result of giving better feedback about design-related faults.	14	14	5	1
c) Greater prediction of faults as a result of improved fault recording.	12	14	12	1
d) Improved flow of fault information between departments.	10	4	10	1
e) Improvements in stores control as a result of analysing improved fault records.	3	6	1	0
f) Improvements in fault information from customers.	8	6	3	0

In response to 'other' benefits, two were provided:
'Better data bases for storage of fault information', given level 3.
'Between-shift information improved', no confidence level given.



Frequency of benefits



Confidence levels %.

Three benefits, (a) (b) and (c) were given as achievable by the majority of respondents. Again, as in previous questions, the possibility of achieving stores control improvements is low. While a systems approach to diagnosis embraces the stores function, there is less likelihood on this evidence, which is reinforced in the field work, of this being the situation in practice. The problems in transferring information across department boundaries within a firm has been a recurring theme during this project; this is reflected again in the response to question, (d), that a number of respondents see this as a possible benefit, but also a number have little confidence in it being achieved.

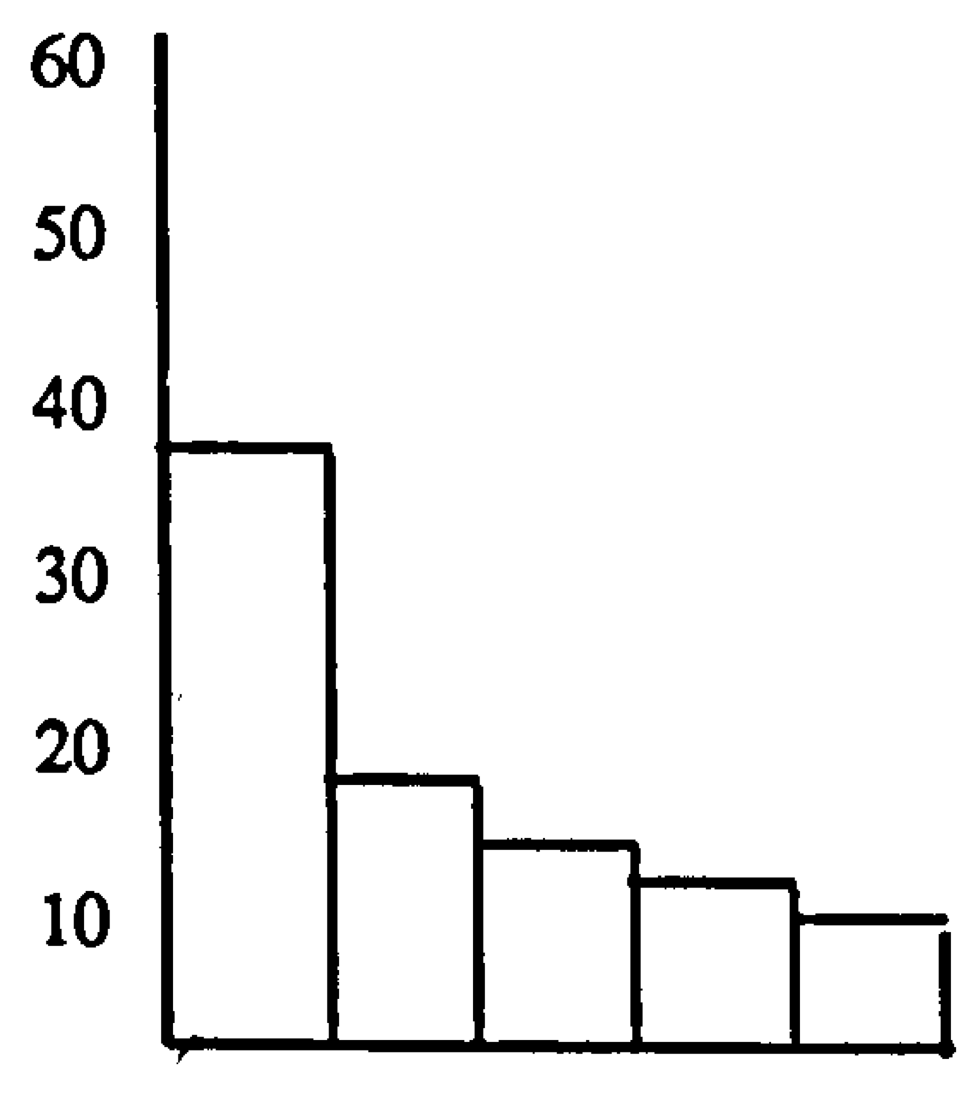
Question 5. General attitude-related benefits.
Twelve respondents did not answer this question, n=41.

Only one of the potential attitude-related benefits was given as achievable by a majority of the respondents; this was, (a), that more listening and questioning can lead to more analysis and less 'diving in'. This is closely related to the cognitive style of Troubleshooters, and in particular to impulsive - reflective approaches to diagnosis discussed in Chapter 2. The results are given in Table 16.

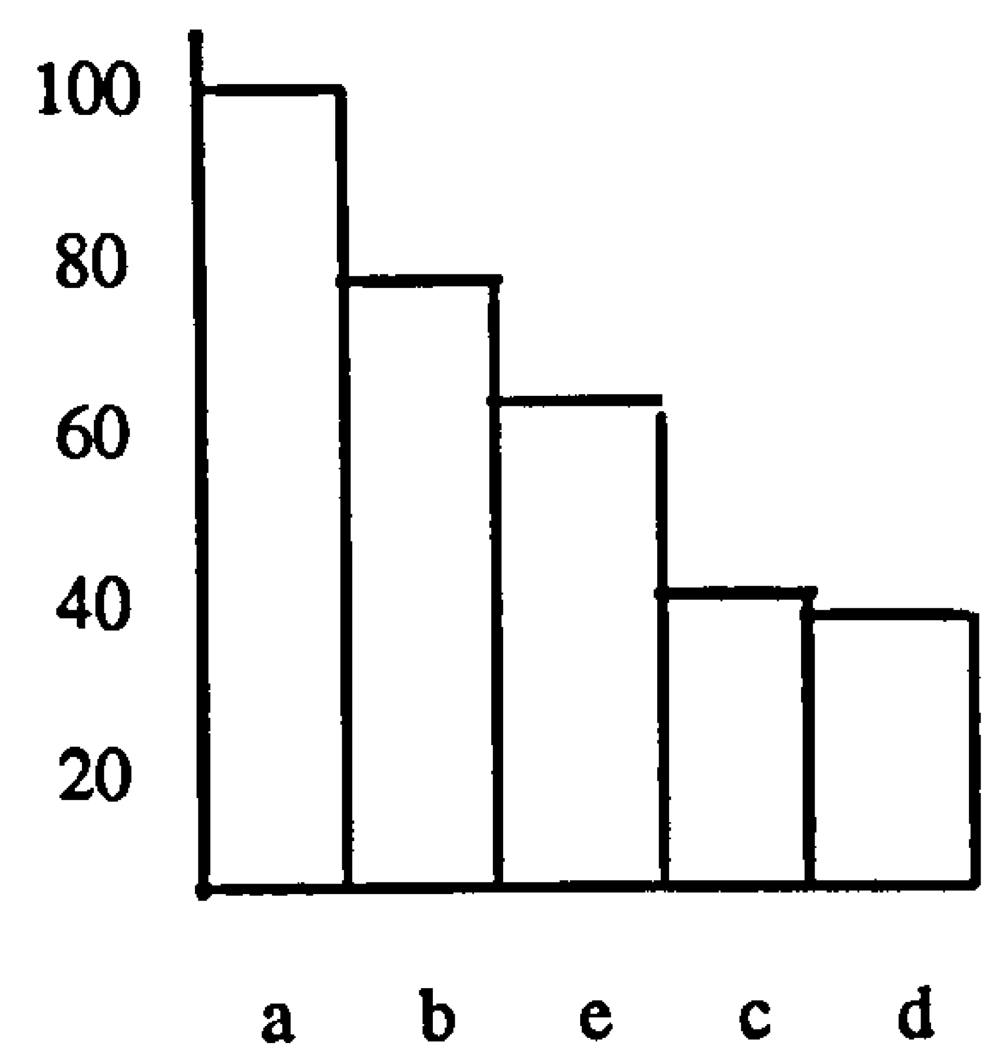
Table 16. Attitude-related benefits.

	Confidence Level			
	1	2	3	4
a) More listening, questioning and analysis, and less 'diving-in' shown by those who diagnose.	21	12	3	0
b) Fault recording is now seen as a vital part of diagnosis.	10	5	4	0
c) Signs that maintenance personnel now work **with** rather than **for** production.	3	3	5	4
d) Greater 'ownership' of equipment/ machines is indicated from Operators being more involved in fault diagnosis.	3	1	3	3
e) Technicians and Operators now recognise fault diagnosis as a set of skills that can be improved through training.	3	5	3	2

(Table 16 cont.)



Frequency of benefits



Confidence levels %.

Of the other attitude-related benefits only, (b), was given a positive response, but only 37% had any level of confidence in it being achieved.
The idea. picked up during the field work, of maintenance personnel having the attitude that they are part of production, working 'with' rather than 'for', received a much less positive response. The next question,(d), reflects another aspect of maintenance and production functions working closer together and again a low positive response was given; the four respondents who did recognise this benefit as possible were dual and multi-skilled personnel in large firms, rather than Operators themselves. The last question can be compared with question 5 in the first section in which 87% of the respondents were at least prepared to consider training in fault diagnosis. Here there is much less confidence when asked about attitude in general among Technicians and Operators.

8.3 Summary.

The results from this survey have been interpreted by using between-question comparisons, and by relating to findings from the case studies and from the critical incidents. There is confirmation that the learning of diagnosis comes essentially from experience, which has implications for the receptivity of knowledge and know-how that originates outside firms.

The low response given to forms of training other than those conventionally used over many years has also been experienced during the field work, and can be said to represent another aspect of technology transfer; in this case how training technology transfers from origins to intended points of delivery.

There is also confirmation that fault information plays a significant role in the process of diagnosis, whether in gathering, processing or feeding-back to customers. Despite this finding there is low priority given to the skill of fault recording, unlike in the medical profession; however positive responses are given to possible benefits to be achieved from recording. There is here a paradox between being able to recognise benefits, but not being able to recognise the importance of the fault recording function.

A high proportion 87% of respondents were prepared to consider training in fault diagnosis, and half of these felt they could benefit from such training. This finding was contrasted with the current dearth of training in this subject in the UK. The use of modules and off-the-job courses represented the dominant choice of training method. For this question the options of computer-based training and interactive video were given to check preference for less conventional methods but again, as in response to the question on learning, such methods were virtually overlooked. These computer-based approaches to training are increasingly being used as a means to disseminate knowledge and know-how related to new technology, and it can be speculated that low take-up of these methods may provide a further restriction on technology transfer.

There was a positive response to three of the open learning modules, a mixed response to one and a negative response to the remaining two. In the case of module 3 on systems thinking, which was given a mixed response, the field-work based results were more negative. Overall, there is justification in merging this material into the other modules at a later date. Module 1 on listening and questioning was given the same positive response as experienced during the field work. Module 2 on techniques and module 4 on recording were considered by the majority of respondents as of value. Module 5 on costs was given a negative response by the majority of respondents, and relating this to the field work responses the reason was mainly due to this subject being considered relevant only to management. The final module although designed primarily for Training Managers was felt to be of value to the learner, however this has not been the case. The aim of introducing the idea of learning to learn needs a more direct approach to the learner in any set of training programmes.

Chapter 9. Receptivity and Response: Critical Incidents.

9.1 Critical Incident Technique (CIT).

This technique emerged out of an investigation performed during World War II. The initial task was to discover the reasons for certain failures in United States Air Force bombing missions over Germany. The key Investigator, John Flanagan, had to find a way of overcoming the tendency of Pilots and Navigators to speak in general terms when describing their behaviour during these missions. This tendency however is not confined to US Air Force personnel, it can be said to be widespread. Whenever people are asked to describe events or behaviour the result most often is a statement of generalities. The method that was eventually developed with this problem in mind became known as the Critical Incident Technique, (Flanagan, 1954), which in the United States has been used in over seven hundred research programmes. (Fivars, 1980). The technique, when used skillfully, enables respondents to focus in more specifically upon events and upon behaviours, in a way that helps them describe situations more clearly than without the use of such a technique.

The reason for including this technique as part of research methodology, see Chapter 3, was that it offered respondents the opportunity to give spontaneous views about issues related to fault diagnosis. In using this technique there are no direct questions to guide the respondents along a line of thought chosen by the interviewer, only an invitation to talk about fault diagnosis. see Appendix B for a description of the technique in use. One disadvantage with the technique is that descriptions in answer to this open-type approach must be listed and categorised into subject areas, which can be time consuming. An advantage is that the issues fall into categories that reflect the interests of the respondents, rather than issues pre-determined by a Researcher, which is common in questionnaire application. The aim in using the Technique was to contribute to a pattern of response which includes case study and questionnaire responses.
Around fifty incidents were selected at random from the raw data, being the number that could be reasonably accommodated in the space available here, and analysed by first categorising them according to key themes suggested by the contents.

9.2 Categorising the Incidents.

The incidents were initially summarised on 3M post-it pads, then grouped into areas of roughly common themes. At this stage there was no clear indication of how many categories could emerge from the exercise. At the end of more detailed sorting there were eight categories, listed below in order of the highest incidence frequency first.
Where it has been necessary to add further comment to the incidents as reported, these have been put in italics.

* Learning Difficulties.
* Organisational Factors.
* Fault Information Handling.
* Design Influences.
* Operator Influences.
* Buying Decisions.
* Cost Implications.
* Customer Relations.

Learning Difficulties.

'A Centre Lathe which we use to machine plastic developed a clunking noise. Inspection of the gears showed one of the teeth missing. A new replacement wheel did not cure the problem, it became worse and a costly second diagnosis session showed a more serious problem. If we had learned the proper use of that visual search technique it could have been used when the machine was dismantled and would have saved us this cost'.
This incident contains technical detail and can be described as a machine-centred view of diagnosis; there may have been wider issues around this fault that were not mentioned.

'We had Operators working to templates placed over monitors to simulate running conditions as a means of learning about faults; this is no longer used. We need a similar idea to encourage Operators to discuss ways of fault finding with

Engineers'.

This also reflects a need for some means to transfer knowledge and know-how within the firm.

'One fault happens quite often, this is when a thermocouple comes loose. This seems to be corrected frequently without any attempt to learn about what could be causing this to happen'.

Here there is a request for some means of going beyond the symptom and the fault to a broader view that includes causation.

In this work, the recent technological developments of surface-mounting and of wire-wrap boards presents new difficulties in learning to find faults. Some Engineers eventually arrive at a strategy for solving these problems, but there is no proper means of disseminating what they have learned. "As long as there is no means of enhancing information there is no method for me to feed back information". The Test Engineers need to be Systems Operators, Developers, Discoverers, and Tutors'.

Although there is some reference here to technical detail, the description reflects needs that go beyond the machine issues. There are implications too for transfer of information within the firm, and for relationships between people.

'The main faults seem to be on control parts of these machines, problems are caused where these new logic-based systems are in use. Most of us on the electrical side are more used to power and installation, and have to learn about this new equipment by trial-and-error and self-teaching'.

The emphasis here is upon a machine-centred issue of how to cope with one aspect of control. The implication is that learning is difficult in this situation, and transfer of know-how from outside the firm is also difficult.

'When we had any fault on rigs in practical work at the Polytechnic, we were sent to do theory while the maintenance Technicians diagnosed and fixed; I feel we ought to have been involved in this fault finding as a learning exercise'.

This was from a young graduate in a small firm who felt ill-prepared to take on diagnosis which was a key part of his work.

'When I get a fault I say to myself, "how many ways could I make this fault happen?" This immediately gives me a likely area to work in and I learn to extend the range of possible ways each time'.
This reflects one way, not included in the techniques module, of overcoming difficulties in learning diagnosis.

'There are so many incidents, and thousands of possible symptoms, faults and causes, it takes a number of years for the various combinations to be learned'.
This incident was repeated many times during this project, with many different estimates given, and can be said to reflect the view that diagnosis is difficult to learn, and learning can only be achieved through experience.

Organisational Factors.

'One of the most critical incidents to cause faults is when Process Engineers attempt to shorten the cycle-time of the production process. We explain that this can be short-sighted because faults can be caused on the product and more time is wasted in re-setting and correcting the fault, but such comments seem to fall on deaf ears'.
This incident reflects two issues, one is of interpersonal relations and the other concerns the need to take a broader view.

'When I attend to a fault in this place the main problem is in finding out who is responsible for the equipment, who to talk to is a problem. A main cause of their difficulties is in how they store their paper, this causes machine faults, but nobody seems to listen'.
Totally unrelated to the previous incident, but again shows concern about interpersonal issues and taking a broader view beyond the equipment. There are also implications here for transfer within the firm, and for transfer of necessary knowledge and know-how into the firm.

'Here in this incident is an example of the same fault being fixed a number of times because there is no dedicated Engineer to follow through to find a cause of the problem. Service is organised so that different Engineers diagnose and do not talk to each other'.

Interpersonal issues and internal transfer feature again here.

'The eyes in these springs need regular re-bushing, this is a design fault but the main problem is that when information is passed to the R&D department we get no feed back, so eventually we give up reporting these faults'.
Although design-related, it is how people overcome organisational barriers that seems to be the real issue here. There are also implications for interpersonal relations and the internal transfer of information.

'Mechanical incidents are quite different to electronic incidents. When an Electronics Engineer finds no fault and passes over to a Mechanical Engineer he has to fully justify that it cannot possibly be an electronics fault; elaborate explanations have to be given. However when passing over in the reverse direction, the Mechanical Engineer need say very little, and normally nothing'.
This more general comment about incidents reflects an aspect of how respective organisational departments relate, and about interpersonal relations.

'This incident of fixing a wiper mechanism is done regularly, but normally the cause is some distance away from the wiper in the compressor that provides the air to make the wiper work. There is often oil in the air, or air in the oil as we jokingly say. Because the compressor is outside the area of the Fitter's responsibility he goes on fixing wipers without dealing with the cause'.
Here there are implications for boundary-setting, and reflects a broad view of this process.

Fault Information Handling.

'One incident involved over two hours downtime, we could not find the fault on this packaging machine. When a Technician arrived for the PM shift he asked if we had checked the packaging material, this we had done because a new batch had been introduced when the machine stopped so this fact provided an obvious clue, however we saw nothing wrong there. On closer inspection the newly arrived Technician pointed to a small change in the package design and said that he had experienced this before. The line was soon in operation again'.

Changes of this kind are not communicated to those who need to know, either from the source of the design change or from Technicians who have knowledge of such change. There are implications here for the internal transfer of information, interpersonal relations, and the need,at times, to look well beyond the machine in order to locate causes.

'An incident occurred, that shows the problems at shift change-over. At the change-over, one Fitter said that he had replaced the levelling valves but that one air bag was not inflating. However he did not say that he had also stripped the equalising valve. This valve had been re-assembled wrongly and re-piped wrongly. The fault took hours to locate because indications were that the equalising valve had been functioning well and had not needed attention'.
One cause of this fault was poor workmanship, but a root cause was the lack of clear fault information transfer between Fitters in the form of a diagnosis history. There are also interpersonal issues involved.

'One of two pumps in tandem was reported as, "making a strange noise" by an Operator. One pump handled a reduced load while a new pump was fitted. This fault is picked up by listening to or feeling the pump itself. This is a design problem and happens roughly every 80 to 90 days'.
In such an incident this fault diagnosis is not followed through to those who need to know. As presented, the incident reflects a machine-centred view of this event.

'A rare symptom on this machine was linked to a tool fault, but after nearly an hour of trying to find the fault it was discovered that the lifting of a cover had knocked a control button which is not normally touched, and this affected the tool cavity monitor'.
This incident was talked about by those involved at the time, but was not recorded and did not become part of general fault knowledge. There are also implications for internal transfer of information.

'We had not seen this service Engineer before, and when he fixed the lid mechanism on the machine it was discovered that another part would soon fail but he had no replacement. This information was not given to the regular Engineer as we expected; failure of this part occurred at an inconvenient time, and we feel the problem could have been avoided'.

Internal transfer of information, and interpersonal relations are the issues, in addition to the handling of fault information.

'This fault does not influence downtime because this machine is not being currently used for production, but the record system will not show this fact and any analysis of records can be confusing'.

Lack of confidence in the reliability and the use of data is one reason given for a reluctance to maintain fault histories.

'This incident of cycle-time on this machine being longer than necessary, although only two seconds, ought to be recorded as a fault; over the year this can amount to considerable downtime on all the machines where this happens'.

Within this incident there are implied implications for productivity and for costs; there is also a recognition that fault records can be extended to include this type of information.

'Fault incidents are not well recorded here, mainly because people are reluctant to admit to any errors, or where Technicians take longer than necessary to fault find they will not record accurately'.

This reflects a difference between a learning and a non-learning organisation, that is to what extent the climate can be called blame-free. Strong implications for interpersonal relations and includes organisational factors.

'This is an example of not being able to link documentation to a machine because we cannot find sufficient information on the machine to identify the correct documentation. Also, there are times when we cannot read the German on the only documentation available that would help us diagnose faults'.

Implications here for transfer of knowledge from the firm's environment to the shop-floor.

Design Influences.

'A solenoid controls the holding of this plastic body while another controls the insertion of a screw, the two operations are difficult to synchronise and causes a good deal of downtime, but we simply have to cope with it because it is a design fault'.
There are cases where the cost of repeated resetting is justified because the cost of changing the design would be greater, however the true costs of either decision are often not available due to poor record keeping and analysis. As stated the incident can be said to reflect a machine-centred view.

'This incident of replacing wire looms happens often because the loom is too close to a source of heat, it is a design problem'.
'Happens often' suggests a lack of internal transfer of information, and, to a certain extent, a narrow view of the situation.
'See how much time it has taken to get to the fault because these machines are not readily accessible to the Engineer who has to service them, this is a design problem'.
This, and the next incident, reflect two different aspects of the same problem. In both cases there is a rather narrow resigned view taken of the situations. No attempt is made to take a broader view by feeding-back such information to 'those who need to know'.

'This room is far too small for this equipment, an Engineer cannot work effectively when a fault is reported; the Designers do not consider maintenance and servicing of technology when planning the lay-out'.

'The standardising of parts and units on these vehicles would greatly reduce time spent in fault finding'.
Some appreciation here that decisions in other departments can have an influence upon fault diagnosis.

Operator Influences.

'On this machine, how well an Operator can describe a symptom is critical. The other day an Operator said about an oscillating reading, "Oh it is always like that" I could take the word 'always' to indicate normal running but in fact it was a sign of a slowly developing problem; it is a great advantage if Operators can be trained to be aware of such signs'.
Interpersonal relations are critical in such a case, and the observation at the end goes beyond the machine situation.

'The Operator was able to describe a noise that led to an intermittent fault as a dry rasping noise, I was then able to reproduce this noise, and make it worse, by moving the cooling fan around on its mountings, this led to a quick detection of what could have been a difficult fault to locate'.
This was particularly relevant to the module on listening and questioning.

'The labelling reel on this machine is controlled through the use of this sensitive probe which comes into action when the reel is nearly empty. A simple act of the operator failing to reset this probe can bring a technician out to a supposed fault. The problem is that the Operators rely upon memory for most things on the job. If they were asked what the probe or that 'rod' did they would not be able to tell you'.
There are implications for learning difficulties, and for relationships on the shop floor.
'On these office machines where we have dedicated Operators there are far fewer faults than on machines where casual Operators are used'.
The main issue here, apart from Operator performance, is related to organisational factors.

'Most Operators work by rote on what is familiar. This week an Operator just returned from holiday reported a fault that was difficult to find; after much checking we found a switch at 'off' which this Operator never changed but which the relief Operator had moved'.
Perception was a critical factor here, the Operator saw what he expected to see when checking the panel. Fault history recording was also an issue because this incident was known only to the two people concerned and the Researcher.

'This fault we are dealing with now is an example of an Operator making adjustments on the machine which are beyond his ability, and then keeping quiet about what had been done leading up to the fault'.

An alternative to questioning the Operator's ability in such situations is to check how clearly Operators understand what can and what cannot be within their control. This also reflects learning difficulties, how can people and the organisation learn in this situation? There are interpersonal issues and organisational factors included here.

Buying Decisions.

'In this case the Buyers have changed the source of some components and of fabricated cabinets from those that performed well to those that produce faults. At our stage in production these faults are very costly to find and to rectify. This problem comes about because Buyers work to different criteria and use a system of open-loop control, they take no account of any feedback'.

This was a common type of incident to be reported during this project. Interpersonal relations, organisational factors, transfer of internal information and cost implications are included here too.

'In fixing this fault we have had to drill a larger hole and re-tap to take a bolt that we do have in stock. This problem in buying spares added greatly to the downtime but appears only as machine fault downtime rather than caused by buying deficiencies'.

There is here a need to take a broader view of the organisation; as stated the incident did reflect a broad view of the situation.

'As builders of complex control equipment we need some influence over the buying of parts and units, but client sales and marketing people dictate the choice of suppliers. We would not have specified this type of switch because it will lead to faults'.

This, and the next incident, reflect organisational factors, and interpersonal relations.

'This fault repeats a number of times, simply because they chose to buy cheaper crimps'.

Cost Implications.

'As Contractors, we need to be very clear and precise about the cause of this fault and not just the fault itself because we need to be able to allocate costs to other parties in the contract'.
This incident provided a use of cause identification not previously given in the modules. Technique use in the identification of causes, customer relations, and cost implications also need to be considered here.

'The recent introduction of profit centres has influenced the way we now fault find. When money was easier we used to substitute parts a good deal to help find faults. Now we are charged for parts going for repair even if not faulted; we need to use other methods for finding faults'.
There are indications that learning difficulties could be experienced in finding alternative diagnostic methods.

'The practice of 100% sampling at point of production avoided many faults at our test stage. Now that a sampling system has been introduced faults at test are more frequent, and the cost of fault finding and rectification at our stage goes up by a factor of ten'.
Cost implications and organisational factors have to be considered here. There is too a 'looking beyond the site of the fault'.

'One incident can lead to three hours diagnosis by one technician, and the same incident to thirty minutes diagnosis by a second Technician. The estimates for time and cost are largely dictated by the diagnostic ability of our Technicians; fixing is now a relatively short exercise in most cases'.
Learning difficulties are also implied here, in this incident the technicians had similar experience, so according to the common view held about learning from experience they ought to have been at a similar level of diagnostic performance.

Customer Relations.

'A customer phoned in to report a fault, and the initial symptoms given indicated that it was a hardware problem, but after further interrogation on the telephone it was realised that the fault was in the software and caused by someone 'playing around'. A third party located near to the customer was called who quickly diagnosed and solved the problem. We did not waste Engineer-time, and the service was good for customer relations'.
This is an example of an on-going problem for service firms; where skilled Engineers are on hand to deal with customer calls of this kind an effective service can be provided, but normally such calls are handled by office personnel who cannot be expected to provide the same diagnostic service. How far office personnel can be trained to 'bridge this gap' is a current issue. There are organisational factors, interpersonal issues, Operator, or user, performance issues, and cost implications to be considered.

'One recent incident was of an annoyed client phoning up to say, "your Engineer arrived and spent nearly half an hour just looking at a manual", there seems to be no appreciation of how complex this equipment has become'.
This incident reflects a gap between the rapid development of technology, and the user's perception of how Engineers ought to behave. The functions that allow the user ease of use when working well provide particular problems when not working well. A key issue here is, how knowledge and know-how, relevant to new technology, is transferred from the environment; also learning difficulties and interpersonal issues need to be considered.

'Some customers are very good at giving us clues that can help in our diagnosis while others can tell us very little, this does make a difference'.
This is an example of reactive behaviour on the part of a firm. Some firms are far more proactive in this respect and seek ways to help their customers provide more information about symptoms, and in some cases faults,which then leaves them the task of diagnosing cause and rectifying. Again, as in the previous incident there is the issue of how firms transfer information from the environment. Fault history recording, and interpersonal relations are included here too.

9.3 Interpretation of the Incidents.

Although these incidents do fall into discrete categories that reflect current issues in this area of work, there are a number of inter-relationships between them. Any one category of incidents includes a number of features related to other categories; this inter-relationship is best shown by the use of a matrix, see Figure 2.

Figure 2 Category Matrix.

	LD	OF	FH	DI	OP	BD	CI	CR
LD	*	0	2	1	1	0	1	0
OF	1	*	4	1	0	0	0	0
FH	2	3	*	2	1	0	1	0
DI	0	0	1	*	0	1	2	0
OP	2	3	2	0	*	0	1	0
BD	0	1	1	0	0	*	3	0
CI	2	1	2	0	0	0	*	1
CR	1	2	2	0	1	0	2	*

CODE: Learning Difficulties (LD) Organisational Factors (OF) Fault Histories (FH) Design Influences (DI) Operator Performance (OP) Buying Decisions (BD) Cost Implications (CI) Customer Relations (CR)

Note: Figures refer to number of incidents , e.g. four incidents in the Organisational Factor category include features related to Fault Histories.
One Incident can appear more than once in a single row of the matrix.

From this matrix it can be seen that fault histories, cost implications, organisational factors and learning difficulties feature strongly in that order, while the remaining

four categories feature much less strongly. However, each category does relate to at least three other categories.
This provides further evidence for saying that on the subject of fault diagnosis it is difficult to focus narrowly upon one area to the exclusion of others.

On closer inspection of the incidents it is possible to recognise features that have implications for this thesis. One concerns the issue of transfer; the concepts of technology transfer or knowledge transfer are not commonly used within industry, and it is not surprising that neither emerged as a category of concern to the respondents. However, it is possible to recognise implications for transfer in a number of the incidents. A distinction needs to be made here between transfer of knowledge and know-how internally within the firm, and externally from the environment of the firm. There were 15 (33%) incidents that can be said to have implications for internal transfer, and 6 (13%) for external transfer. There were no significant differences between large or small firms in this respect, the transfer related incidents split equally between them on both internal and external transfer. These transfer implications are referred to in the comments (italics) at the end of the respective incidents.

Another feature to be recognised in this way, is that of a machine-centred or reductionist view of fault diagnosis. There were incidents of this kind, but not as many as could be anticipated from the claim in this thesis that shop-floor personnel adopt largely a reductionist view of this subject. There were 12 (27%) of incidents that contained detail of this kind, and which could be said to be narrowly focused. In contrast, there were 16 (36%) of incidents that reflected a concern for issues beyond the immediate area where faults occur. Just under half the incidents could not be classified as typically holist or reductionist in approach. Large and small firms split evenly in reporting reductionist views, but of the sixteen 'broader' incidents, eleven were in the small firms. Despite being asked to focus upon 'incidents' some respondents have, in their description of the incidents, reflected a broader view than was anticipated at the beginning of this project. On this evidence it can be suggested that shop floor personnel may be more responsive to a systems approach if a way can be found to present the ideas in a more appropriate and acceptable manner.

A third and last feature to be examined here is related to an early statement made in this thesis that fault diagnosis is essentially a social process that takes place in a technical context, rather than technical problem-solving in which people take part; this was described as a shift in perception. This perception is also central to the adoption of a systems approach in this area. There were 24 (53%) of incidents that included interpersonal issues; that is essentially about how people interact over fault diagnosis problems. This does not reflect the picture presented by much research in this field of the lone Troubleshooter preoccupied with fault finding. There was an almost even split here between large and small firms in this respect.

9.4 Contribution of the Incidents to the Thesis.

The main contribution has been that a random selection of spontaneous views can be compared with the more structured data collection provided by the case studies and the questionnaire data. The categories and the sub-categories that emerged as a result of the analysis provide a pattern of concerns held by the respondents. One question to ask is about the extent to which the other two research methods either reinforce or contradict this pattern. A key factor to come from these incidents is that an assumption made at the beginning of this project about the amount of reductionism to be found on the shop floor can be called into question. The statement that fault diagnosis is a social process in a technical context is largely supported on this evidence, and so too is the the point that fault events have many interacting factors.

9.5 Summary.

A brief background to critical incident use has been provided, together with a rationale for its adoption in this study. The incidents were then grouped into eight categories by using the key issue raised by each incident as a guide. From inspection of these categories it could be seen that many inter-relationships exist between them; no one category could be described as discrete. A category matrix was produced from further analysis to show where the relationships occurred most often. This pattern of relationships, between issues seen as critical to fault diagnosis, adds support to the proposition that diagnostic activity takes place in a complex situation in which a number of issues interact. Finally the implications that these incidents had for technology transfer, and for the machine-centred versus holistic view of fault diagnosis was discussed.

Chapter 10. Contribution and summary of results.

10.1. The Transfer Model and the contribution from the Thesis.

In this section the contributions, made to the subject area are linked to the Transfer Model which was introduced in Chapter 1, (Diagram, 6).

The two assumptions, and their related issues as shown in the first part of Diagram 6, were without exception reinforced by the findings from the fieldwork. The reinforcement of the issues, through evidence from the research triangulation, is given as a contribution to the subject of fault diagnosis practices and to the transfer of technology that aims to facilitate those practices.

As part of the initiative taken, in response to these issues, six open learning modules were produced, Appendix C, Volume II, in disseminating the material there was the possibility that this would prompt someone to reveal alternative fault diagnostic training programmes yet uncovered by the research which has been done for the project; this has not happened. For example, in one important area of fault diagnostic work, railway signals and telecommunications, there has been a recognised need for such training for some years. Now, British Rail have drawn up specifications for two training programmes to cover signals and telecommunications which have been based entirely on the six learning modules produced during the project. The research and development of the learning modules is seen as a contribution to the subject area.

At the beginning of the thesis a shift in thinking about fault diagnosis was proposed, from seeing the subject as a technical process in which people take part, to a social process that takes place in a technical context. A contribution has been made to our understanding of the subject by providing spontaneous qualitative data that lends strong support to this proposition. It has been demonstrated that an inherent part of fault diagnostic work involves a complex interaction between people in a number of diverse roles, and that this feature of the work is not adequately reflected either in the preparation of people for the tasks or in their on-going training.

Another contribution, that can be described as novel in this context, is the application of systems thinking to the subject. The contribution here has emerged from the fieldwork results; evidence has been provided of a distinction between the receptivity to the ideas when presented in a descriptive way, as opposed to actual application on the shop floor when delivery has to be prescriptive. A problem raised in Chapter 1 about the possible need for people to unlearn the practice of using 'system' as a label in order to grasp the conceptualising requirement of systems thinking, could help explain some of the difficulties of applying the concepts. In this respect, the Troubleshooters who tended to resist the broader approach in favour of more direct focusing on fault problems did offer examples of broader thinking about these problems when they were asked to be descriptive, particularly when asked to provide critical incidents. The highlighting, with evidence, of the distinction between descriptive receptivity and prescriptive receptivity can be seen as a contribution to the subject.

A contribution has been to highlight, through the medium of fault diagnosis, that technology transfer mechanism can be poor in the small firm. It has been possible to describe, through the behaviours of certain people, that the essential role of Technology Gatekeeper can be fulfilled in the small firm; it was the transfer channel, as defined here, and the necessary links to outside sources of technology that were lacking. Factors that either hinder or facilitate this process have been identified, and also some essential behaviours of the Gatekeeper role have been described which serve to complement the characteristics identified in earlier research, (Allen, 1977). The exploration of training as a technology transfer channel has led to the identification of channel characteristics and in particular the use of transfer-related roles that can be adopted by people who attempt to facilitate transfer. Two further roles have been identified, and these, together with the transfer-related roles identified previously by Allen, have been operationalised in this particular context by describing examples of behaviour that facilitate transfer and when absent, tend to hinder transfer. A contribution has been made here through the identification of behaviours that can facilitate the transfer of a technology. At the beginning of the thesis, training as a function was said, intuitively, to be a potential technology transfer channel. Unfortunately it was not possible to gather sufficient examples of the training function working well in order to test this idea fully. This led to a further contribution by adopting the concept of 'slack' to describe a *human* resource situation as opposed to the common meaning in relation to materials and information. When Directors and Managers were given this concept they readily recognised it as contributing significantly to a lack of necessary training initiatives, but, in the current economic climate, were unable to correct the situation. The lack of slack human resources also leads to less time for innovation or the transfer of new ideas either into the firm or within the firm. The idea of actually allocating time to innovation and transfer, (Rosenfeld and Servo, 1990), could not be readily adopted by firms in this sample.

The identification of factors which can inhibit transfer, (Section 11.2), provides a contribution. The factors arose from only two parts of the research triangulation. The lack of evidence from the survey method comes from a problem in planning the methodology. As explained at the beginning of the Thesis, (Section 1.8, page 18), a reorientation became necessary at the stage of the project when the learning modules had been introduced; transfer-related issues arose that needed to be accommodated in the study. The survey had been conducted at this stage, primarily to provide data to aid the learning module construction. A lesson had been learned that when using a triangulation of methods, the sequencing and timing of the methods needs to be planned very carefully and some forethought is required.

Finally, in terms of contribution, it has been possible to identify critical aspects of the cognitive skills now required by Troubleshooters. These have been highlighted in modules one, two and four, Appendix C, Volume II. This information is currently being used at the Department of Employment to assist in the development of level 3 NVQ competency statements for maintenance technicians. The use of cognitive skills in troubleshooting has been, and still is to a certain extent, very difficult to articulate clearly. There has been a contribution to the subject by relating the behaviour of skilled Troubleshooters in a range of situation and then making common links between them. The result is that a core of generalisable techniques has emerged that transfers across different firms. In the case of the small firms, a customised module was produced for each one that introduced supplementary material that was unique to the firm; certain core material was common to all. Benefits have been highlighted, (Section 8.2), and in some cases have been demonstrated, (Section 7.1). It was important to emphasise benefits when attempting to gain access to firms and win their cooperation for the research; at the early stages of the fieldwork this was difficult because the benefits that were eventually identified were not then available. In marketing terms, firms do not want training modules; it is the benefits to be gained that are required. The description of achievable benefits from fault diagnostic training is a contribution that ought to make the future proposing of such training more readily acceptable. The identification of certain aspects of fault diagnostic work, (Section 11.1), where a systems approach is not appropriate or certainly less relevant than in other situations is a contribution that can help guide future application of systems thinking to fault diagnosis.

10.2 Conclusion from the research questions.

In this section the results from the project are summarised by addressing the original research questions that were presented at the beginning of the Thesis, (Section 1.8, page 18).

How the initial issues prompted a debate that led to the formulation of research questions has been described earlier in Section 1.8, and after some deliberation the questions were grouped under three categories relating respectively to transfer, learning and outcome from the initiative. The questions fit also into the research framework, (Diagram 7, page 16), within the stages from systems thinking, through the development of the learning material and application of the transfer channel, leading to outcomes in the workplace.

Transfer-related questions.
It was the case study and critical incident methods that produced results most relevant to the area of technology transfer. The questionnaire survey method could be referred to here only through inference rather than by pointing to specific evidence. The reason for this has already been discussed in Chapter 3 and concerns the respective timing of the research methods used when three methods are being used in combination. If the survey had followed last in sequence, then transfer-related questions, based upon the issues that emerged from the other two methods, could have been included.

The Questions:
Are some innovation-related roles more significant than others in facilitating this learning technology ?

The roles referred to here as innovation-related, were discussed in Chapter 6, in particular the roles of Ideator, Technology Gatekeeper, Champion and Sponsor. From evidence in the case study material, a number of examples emerged where people, through their behaviour, displayed characteristics of the Technology Gatekeeper role, and it was this role that had the most influence upon the eventual transfer of the learning technology. It was noticeable that in firms where such a person was difficult to locate there was greater difficulty in making an effective transfer. The Champion and Sponsor roles were confined to senior management positions, and once their support had been given any further impact upon transfer was, in most cases, limited. The Ideator role was taken largely by the originator of the open learning material who was looking for Champions, Sponsors and Gatekeepers to facilitate the transfer. However there were Troubleshooters who did come up with ideas to extend the application of the material which have been noted for inclusion in any further re-write, as indicated in Chapters 7 and 8. During the field work it was observed that people with these characteristics found it easier to perform the role in the large firms than in small. In all cases, the small firms had very limited access to sources of knowledge and know-how either within their own immediate environment or further afield. The larger firms had more ready access to sources such as Universities, Government bodies, Research establishments and local/national/international networks.

The contribution of the critical incident results served to reinforce the situation described above. The roles were not offered spontaneously when providing incidents because most people in industry do not readily recognise the concept of transfer-related roles. However, many of the characteristics are operationalised through the behaviours presented in these incidence. Inspection of the incidents listed shows that there are a number of implications for the transfer of ideas, knowledge and know-how, both within the respective firms and from the environment. In a number of these incidents it can be inferred that a link is missing between ideas, knowledge, know-how and someone to champion the transfer; in most cases this is best served by a person with the characteristics of the Technology Gatekeeper. A strong indication that this link is missing is that the incidents are normally presented as on-going recurring problems that lack the means of being resolved at source.

As explained at the beginning of this chapter, the survey used was of limited usefulness in exploring transfer-related questions. With regard to this particular question it is possible to relate the emphasis upon experience found in the survey results, to transfer-related roles and in particular to the critical role of Technology Gatekeeper. By implication the industrial climate that emphasises experience, values most that which can be learned from practical in-house events over a lengthy period of time. This aspect of a firm's climate can hinder people who have the potential to act as Gatekeepers, and who wish to resource knowledge and know-how by means other than relying upon experience.

Are there significant differences between people at the same level in an organisation in how they accept and respond to the innovation ?

From the case study material and the critical incidents it was possible to identify differences at both Operator and Troubleshooter levels, however there were no significant differences between particular groups of Operators or Troubleshooters. Where differences did exist they were to be found between a small number of individuals and the remaining part of the sample. The majority acted in a positive way only towards selected parts of the learning material which were seen as satisfying quite specific requirements of their work. The effort involved in seeing a broader view was not readily forthcoming. A smaller part of the sample did recognise the concept of a systems approach and were able to respond to the interactions between parts of the learning material, such as between information gathering, technique use, and fault histories.

Overall, the responses from Operators showed how limited was their involvement in the diagnostic process, despite management statements that Operators ought to play a stronger role in this respect.

There was a consistency too in the responses to the survey questions; among Troubleshooters at the same level it was the variable of single-skill - dual-skill - multi-skill that provided one significant difference with respect to the methods used in learning fault diagnosis. There were fewer examples of methods other than by experience or experience-related; where these methods were given it was from dual or multi-skilled personnel.

Are there significant differences in how people, at different levels within an organisation, accept and respond to an innovation ?

Evidence from the case-study material points to a significant difference between levels of the workforce, and in particular between senior and middle manager levels. Without exception the senior mangers responded positively to the ideas and the content of the material; all acted as Champions, and in some cases as sponsors in support of the project. The responses have been described in Chapter 6, and from discussions during field work, reported in Chapter 7, it is possible to identify two explanations for this observed difference. One is that the role of the senior manager demands a more holistic approach, and any ideas which are seen to promote such an approach are likely to be welcomed. Beyond this initial reaction it is necessary to have what senior managers recognise as valid subject content in support of the ideas, before full acceptance will be given; and this they did. In contrast, most of the the post-holders at middle-manager level and in particular at supervisory level found little time for such an approach, and if they did see value in the ideas would quickly focus attention on only specific items within the material. Paradoxically, the research on transfer-related roles, (Allen, 1977) and (Rosenfeld and Servo, 1990) state that the Gatekeeper role is most often found at the supervisory level. On the evidence from this field work the fire-fighting nature of Supervisory work leaves little time for the Gatekeeper-type functions to be performed adequately.

Another explanation is that the ideas were presented in different ways to the respective levels within any one organisation. At the senior manager level the presentation had to be in the form of description; aims, objectives and how the ideas could be implemented which included logistic details about time and resources that would be needed. There was also discussion about systems thinking and its relevance to current fault diagnosis practices. From this approach it was universally recognised that the ideas ought to make a significant contribution to business performance. At the middle-manager and supervisory level the presentation had to be in the form of prescription rather than description; although some description was necessary it took second place to the job of actually transferring the ideas to the shop floor. It was at this point that some of the essential ideas about interactions between people, between processes, and between failure events could be lost.

Most responses from Troubleshooters and Operators followed a pattern similar to that of their immediate managers, and overall it appeared that the very practical orientation of their work precluded any conceptualisation of issues beyond immediate concerns. However, inspection of critical incidents, in Chapter 9, shows that when given the opportunity to reflect upon their work, the categories thrown up by the incidents reflect a much broader view of diagnosis. From this it can be reasonably inferred that failure-related problems are viewed in a holistic way while actions taken to resolve them are most often highly focused and reductionist.

Is training, as a transfer channel, more likely to facilitate or to hinder the adoption of novel approaches of this kind ?

Here it was possible to draw directly upon evidence from all three research methods.
In all the cases studied, the support given to training was restricted to such an extent that the answer to this question has to be given with qualifications. Given one example of an effective and efficient training system it would have been possible to assess more reliably the scope of training as a transfer channel. No firm in the sample would claim to have such a training system, and no individual was found who could claim to have received effective training beyond apprenticeship. In the circumstances and on this evidence it has to be concluded that training was not a suitable channel for the transfer of this learning technology. In a number of cases, it was the production function that had to be used in the absence of any proper training resource. At the beginning of this thesis it was stated that training, given that it is normally related to learning, ought to provide a suitable channel for the transfer of knowledge and know-how, both within a firm and from the environment; on the evidence available there appears to be little reason to change this view. Examples from all three research methods provide evidence that both Troubleshooters and Operators express the need for training in many aspects of their work apart from fault diagnosis. There is a recognised gap between the capital expenditure on new technology and the

support given to individuals so that this technology can be fully exploited.

Are there identifiable characteristics about people who either accept or reject a systems approach ?

Upon reflection, at the end of the field work, this question could be seen as too ambitious, and almost justifying a thesis alone. There are major difficulties in identifying characteristics that could be used as variables to help explain the observed differences in response. For example, do people become senior managers partly because they are receptive to a more holistic approach or do they become more receptive as a result of being in the position ? What can be said about characteristics is that middle managers, supervisors and Troubleshooters/Operators who were receptive shared some of the characteristics listed in Table 4, Chapter 6, in particular the reading of work-related literature, links with people in other departments, and others turn readily to them for information. From the survey results it can be observed that dual and multi-skilled people responded more positively to the ideas, however there were negative responses among these categories too.

Are there significant between-company differences in receptivity and response to this innovation ?

There were no significant differences to be found in what firms see as critical to the learning of fault diagnosis; the issues and concerns about achieving effective diagnostic practices were shared across all firms. On this evidence, a generic fault diagnosis programme is a valid aim. One qualification to this is that in addition to what can be called core generic material there are needs at times for some specific bolt-on sections where firms do have unique requirements. For example customer relations training is ignored in the current programme, but for field-service firms this ought to be integrated with diagnostic training rather than be seen as a separate exercise; the sample personnel in one large firm and the four small firms involved in field work all shared this view. A critical training need has been identified in firms where specialist testing instruments are used, the current programme does not address this subject adequately but for some firms it must be an added requirement.

In terms of overall response to the innovation being positive or negative there were differences between firms. In the case of small firms, four responded positively and four negatively. There was a positive response from the four large firms to the ideas but in practice the systems approach was accepted in three. Factors that can help explain these differences in response have been discussed earlier, and are summarised later in this chapter.

Learning Related.

The Questions:

What evidence exists for the proposition that fault diagnosis is learned mainly through experience ?

There is strong evidence within these results that 'experience' is the main, and in some cases the only, means of learning the skills of fault diagnosis. The evidence is contained in the responses to survey questions, and in behaviours revealed during the case study work. Also it is the accumulation of incidents, such as revealed during the critical incident exercises, that largely accounts for what is described as personal experience. Of interest in this respect is that training is often discussed as being either of some use or of no use depending upon the course or programme followed; at no time during this project did anyone question whether experience could be of some use or no use as a means of learning. The quite valid idea that experience can be a conveyor of bad practices, can be a hinderance to effective learning, and can block the transfer of new ideas was not acknowledged spontaneously, but some people did appear to begin the adoption of this view after these points had been discussed. Overall the view is that learning by experience must be effective. From inspection of the issues raised during this project, this emphasis upon learning by experience has to be recognised as a hinderance to both individual and organisational learning. The pace of change is now so rapid that the time-consuming practice of learning by experience is rarely possible. The possible reasons for this reliance upon experience have been discussed already and are summarised later in this chapter.

To what extent can people at operator level become involved in the process of diagnosis ?

This question raises issues that are fundamental to systems thinking in the area of fault diagnosis; mainly that the interaction between all those involved and between people and machines needs to be understood and fully exploited. However, although there is, on the evidence from the critical incidents and from the case studies, a perceived need for

Operators to be more involved in this area of work the survey response in this respect and the field work observations suggest that Operators still have a low profile when considering their involvement in fault diagnosis. The evidence from this project suggests that there is a considerable pay-off for firms from the greater involvement of Operators. During this project, Troubleshooters described how they question Operators who can be relied upon to provide information that will aid diagnosis, and will ignore Operators who they feel cannot provide this information. Often the success of a diagnostic session, and consequently the amount of machine downtime, will be determined by which Operator happens to be on duty. Despite awareness on the part of management that this situation exists there is little evidence that Operators are being encouraged to become more involved.

Are there significant differences in how organisations learn from failure events ?

In this sample, only one large firm and one small firm made a serious attempt to analyze failure events as a means of learning in order to guide future actions. As a result of involvement in this project, two of the small firms and one large firm are making moves towards the development of a system that will aid learning in the future. In the majority of cases the concept of the learning organisation, (Argyris and Schon, 1978), goes largely unrecognised. From evidence in the case studies it can be seen that so-called 'novel' faults can often be novel only to the Troubleshooter faced with the problem, they are not necessarily novel to the organisation, but because the organisation does not learn. i.e. in a corporate way, the fault information is not shared. Given that novel faults can account for considerable periods of downtime, this failure of organisations to learn from failure events can be costly. As pointed out earlier, the writer has experienced only three examples of firms where adequate fault recording, analysis and learning has been observed as a result of contact with twenty-six firms. Of these three firms, two are included in this project, and all three happen to be the only firms in this sample of twenty-nine which are not British-owned; two are Japanese-owned and the other is American-owned. Although beyond the scope of this project, and with results that could be accounted for by chance, there is a temptation to suggest that there could be a cultural dimension to the recording and analysis of failure for the purpose of organisational learning.

Outcome Related.

The Questions:

Can the adoption of a holistic approach to the learning of fault diagnosis provide tangible benefits to a company ?

The criteria that would allow for the assessment of effective fault diagnosis has, over the years, been difficult to establish. From inspection of the benefits section in the questionnaire survey, see Appendix A, it will be noted that only two broad areas of tangible benefits could be established, one of costs and the other of time. For each broad area six measures are applied; all other benefits in this section of the questionnaire are subjective and cannot be described as tangible. The invitation to respondents to add to this list did not produce further measures of any significance. Previously it has not been possible to answer this question because there were no criteria for the measurement of benefits in this area of work. At this stage it is reasonable to assume that the twelve measures provide for the first time a means of measuring tangible benefits that could be gained from a broader approach to fault diagnosis. They serve also as the first tangible criteria of fault diagnosis performance. The critical incident results also pointed to events where a more holistic approach is needed in order to save time and reduce costs. The same two areas of measurement occur in the case studies.

In answering this question it is important to consider that some of these benefits could be achieved by improving fault diagnosis skills, say from the use of module 2 or from another form of training. The benefits that need to be highlighted here are those which could not be achieved without the application of a systems approach. The simple answer to this question is 'yes' for the reasons given below.

The first of these benefits is the one of reduction in maintenance costs. To achieve this it is essential that all aspects of fault diagnosis activity are assessed, from stores and design practices to the skills of Troubleshooters. For example the cost of repeatedly diagnosing and fixing a design-related fault can only be reduced as a result of taking into account the interaction between cost of spares, cost of lost production and cost of any possible re-design. In one firm in the sample it has been realised that maintenance costs can be reduced by including Operators in the diagnosis process, and by diagnosing faults more accurately there is a saving on the unnecessary call-out of contractors. The Troubleshooters in another firm, by intervening in the buying process can reduce maintenance costs by using more reliable spares; here it is only through the maintenance of fault histories that Buyers can be convinced of the case for different spares, again an aspect of the systems approach.

Another benefit that requires a broad approach for its realisation is the reduction in pay-back time for capital intensive processes. There appears to be a general lack of appreciation that diagnostic time can account for a significant proportion of downtime, and as a result of pay-back time on the capital spent. A number of elements from a systems approach can contribute to a reduction in the time spent diagnosing: greater involvement of Operators, analysis of recurring faults, sharing of fault information across departments and between

Troubleshooters, intervention in spares buying procedures, 'cause' rather than only fault identification, and improved 'wider-scope' documentation.

A systems approach to fault diagnosis can be seen to have close links with the current trend towards total quality management, in particular the control of processes from the input rather than from the output. When Operators are responsible for their own quality, at the input, it becomes necessary for them to have more control over the reliability of the machines or equipment being used; this in turn means working closer with the more technical Troubleshooters, with stores personnel, and even at times with those who design machines and processes. The cost of maintaining quality can be reduced by effective working in these areas. All this demands that people adopt a broader view of their workplace.

The benefits of cost reduction and time saving are not discrete measures; although cost saving is emphasised above, time saving is also featured. There are more specific time-related benefits that can only be realised as a result of a broader approach being taken:

* Improvements in time to respond to faults; for service firms a number of variables need to be considered, and for manufacturing firms there are organisational issues to be considered.

* Improvement in time between repetitive faults; to take action in this respect it is normally necessary to begin by recognising the concept of causation. Then, to broaden the area of operation to include all possible sources of cause, and to maintain and analyze fault histories in order to establish that repetitive faults have been eliminated.

* Improvement in time taken to raise spare parts; here a number of variables need to be considered which can exist outside the normal area of diagnosis. One is the accuracy of feedback from Troubleshooters about the probability of failure for critical parts which can aid accurate parts procurement. Another is the extent to which Troubleshooters adopt the technique of substituting parts when diagnosing, and thereby put a strain on parts provision. Also, attempts to introduce just-in-time methods and reduce capital held in stock needs to be compared with cost of downtime caused by waiting for spares. The above time-related benefits can be seen to require a broad view of organisational working if

they are to be fully realised.

What advantages and/or disadvantages come as a result of applying a systems approach ?

Advantages:

The tangible benefits listed above can be considered as advantages to a firm, and in addition it is possible to identify other non-tangible advantages:
One advantage is being able to have a diagnostic system to which new information can be added quickly and disseminated widely, thereby helping groups of people to be more responsive to changing processes.

From case study and critical incident results it has been possible to identify a particular advantage for Field Engineers as a result of using a systems approach. This is related to the advantage given above because it concerns adaption to changing processes. Field Engineers can experience a loss of confidence when faced with a rapidly changing technology that they have not had time to fully absorb. In such situations the knowledge of systems-based strategies can be drawn upon when experience and what is contained in memory is no longer sufficient. Part of this strategy includes client-relationship handling to avoid the possible confidence sapping criticism from those being served. There is also confidence to be drawn from an ability to conceptualise complex systems in terms of boundaries, sub-systems feedback and causation. In other words there has to be less reliance upon 'what happened before' when faced with a complex system.

The realisation that fault diagnosis activity is interdependent with many other activities in determining business performance can encourage greater cooperation between departments, and can lead to more multi-discipline team working.

Introduction of the systems concept of boundary to the shop floor can help in the understanding of increasingly complex systems at work, in particular being able to trace causes of failure across either systems boundaries or across department boundaries.
Disadvantages:

Earlier it was described how people tend to salute every time systems thinking is run up the flag pole, (Checkland, 1978), but there are some disadvantages to be considered. There are situations where a systems approach to fault diagnosis can be considered to be inappropriate, and this is discussed in the next section. In situations where the approach is said to be appropriate there are still disadvantages to be recognised.

First there is a risk of Troubleshooters becoming too indecisive when a broader view, involving multiple causes, is being taken of fault events. There has to be a balance between the hasty solutions made on too little evidence on the one hand, and too long deliberations over possible causes on the other. When past research has pointed to reflective Troubleshooters being more effective than impulsive Troubleshooters, which has been discussed in Chapter 2, there was no consideration of performance from people who are excessively reflective. There are times when rapid decisions based upon experience, or even intuition, are appropriate.

Another disadvantage concerns the possible costs involved in adopting a systems approach. For example, the fire-fighting modes of operation used by some firms in this sample can become costly to change to one where periods of analysis and planning have to be accommodated; a common response to the idea of analyzing fault histories was that, "we cannot afford the time or resources for all that". These managers need convincing evidence in the form of tangible benefits such as a 5% reduction in downtime. It is worth noting that a catch 22 situation has been observed here; without reliable analysis it is often not possible to establish what percentage of downtime is due to failure events, as opposed to many other causes not related to fault diagnosis. At present the case for a systems approach is not sufficiently strong to convince the management in some firms within the sample that allocation of extra time and resources will be worthwhile. In contrast, the management of the three firms where such an approach is used, discussed earlier, consider that they cannot afford to neglect recording and analysis of failure events as an aid to planning. However for firms already in a fire-fighting mode the time and cost factor presents a disadvantage.

A further disadvantage, related to the above example, is any disruption that can be caused to organisational life by either weakening or removing the boundaries around departments. For a systems approach to be fully adopted a free flow of information must be possible between all departments in a firm. Also, status-barrier situations, in which Troubleshooters at a certain level find difficulty in communicating with people at a different level in another department, need to be removed. The disruption that can be caused by changes to department relationships and to the role of status in a firm has to be recognised as a possible disadvantage in adopting a systems approach.

Chapter 11. Conclusions and the way forward.

11.1 Appropriateness of the systems approach in this context.

From the evidence of the literature review in Chapter 2, a systems approach to fault diagnosis has been much less common than a reductionist, or what has been described here as a machine-centred approach. Evidence from this field work also indicates that in practice, as well as in research, the methods adopted tend to be reductionist. One reason for this situation could be that a holistic approach is inappropriate in this context. As a result of bringing such an approach to twelve firms, mixed in both size and purpose, it has been possible to report on the respective receptivity and response. Overall the results indicate quite strongly that when people are asked to reflect upon current issues relevant to fault diagnosis the responses range across a wide area of a firm's activities, and demonstrate the many factors and interactions that need to be considered when addressing these issues. On the other hand, when adopting methods to tackle these diverse issues there is a strong tendency to focus quickly to a narrow view of most failure events. In two small firms and one large firm where this tendency was less in evidence, they had lived with what has been called 'high technology' for the firm's life. In other firms they have lived through technology change, and it could be a case of old habits die hard, and that approaches relevant to the older equipment have not been adapted to suit the new technology. Before the 1970s, and the microprocessor, it could be said with some confidence that applying systems thinking to fault diagnosis would have been an example of over-kill. At this time, machines and equipment operated in a discrete well-bounded context; the mainly mechanical functions allowed Troubleshooters at that time to learn by experience. Since the 1970s this situation has been changing rapidly, and now many processes take place within complex systems. In terms of technology transfer it is conceptual thinking and problem solving skills that need to accompany the new hardware and software. The evidence from firms in this sample suggests that a gap can exist between introduction of hardware and software on the one hand, and complementary knowledge and know-how on the other; the outcome can be that current technology is being operated with an approach more relevant to earlier technology. On the evidence provided, in the form of current issues from case studies and critical incidents, it can be said with some confidence that a reductionist approach is much less viable than was the case twenty years ago.

There are still some areas of diagnosis where using a systems approach is difficult to defend, and highlighting them helps to emphasise the characteristics of areas where a systems approach is seen as appropriate. In contexts where a systems approach is inappropriate there is normally a series of well-bounded problems facing the Troubleshooter, and relatively few people ever become involved other than the problem solver. Situations that fit this description are to be found in the diagnosis and servicing of videos and televisions, motor vehicles, telephone switching and instrument servicing. Due to the introduction of more electronics on motor vehicles there have been discussions about a different approach being needed to diagnosis, but in practice the diagnostic tasks are well defined within the tin boxes on wheels, and the context cannot be described as complex. The development of telephone switching technology has had major implications for diagnostic practices. The old technology allowed Troubleshooters to learn through experience by gradually building up their senses of smell, hearing, touch and sight to detect faults. Now a conceptual approach is required, but the reliability linked to the ease of diagnosis by board changing has made this into a well bounded context that seldom requires systems thinking. It was for the reason just described that BT senior management, although wishing to be kept informed of progress on this project, could not recognise the ideas as relevant to the current use of technology now or in the future when very few engineers will be required to diagnose or service equipment. The area of instrument servicing was illustrated by a small firm in this sample, and while specific items in the learning material were of value to them the systems approach could not be described as relevant in that context.

There are contexts where fault diagnostic problems take place that are complex and unbounded. In these situations it is often difficult to confine causes of a failure to within a well known and bounded area. Eleven of the twelve firms in this sample reported issues that can be described in this way, and on the evidence available a systems approach or at least ideas from systems thinking can be recognised as appropriate.

11.2. Identification of factors that inhibit transfer.

First, a distinction ought to be made between those factors that can be said to inhibit acceptance of the ideas presented here, and factors that inhibit the actual transfer of these ideas. For example, a situation can exist where transfer is made effectively from research to the shop floor but various factors inhibit acceptance. On the other hand there can be acceptance of the ideas but factors act to inhibit the transfer. However, this distinction is difficult to make in practice, where there is a close interaction between acceptance and transfer. During this project it has been possible to witness examples of acceptance

together with effective transfer; some acceptance together with poor transfer, and no acceptance with poor transfer, but no example of acceptance with poor transfer. On balance it is the transfer mechanism and certain people within the mechanism that have been most critical to this innovation; on the basis of this experience it is difficult to visualise a situation where full acceptance can be achieved against a background of poor transfer.
Five major factors have been identified as inhibiting transfer, and thereby influencing acceptance of the innovation. The identification of such factors is given in Chapter 1, (Section 1.9) as a contribution to this area of study. The factors emerged as the field work progressed, and now towards the end of the Thesis it is possible to bring them together and to look for possible inter-relationships between them.

* Factor A - Slack Resources.

  A key factor of slack resources in terms of people availability emerged from the various attempts to transfer the learning technology into the workplace. The factor influenced the function of training as a means of transfer, and influenced the ability of some people to exercise transfer-related roles.

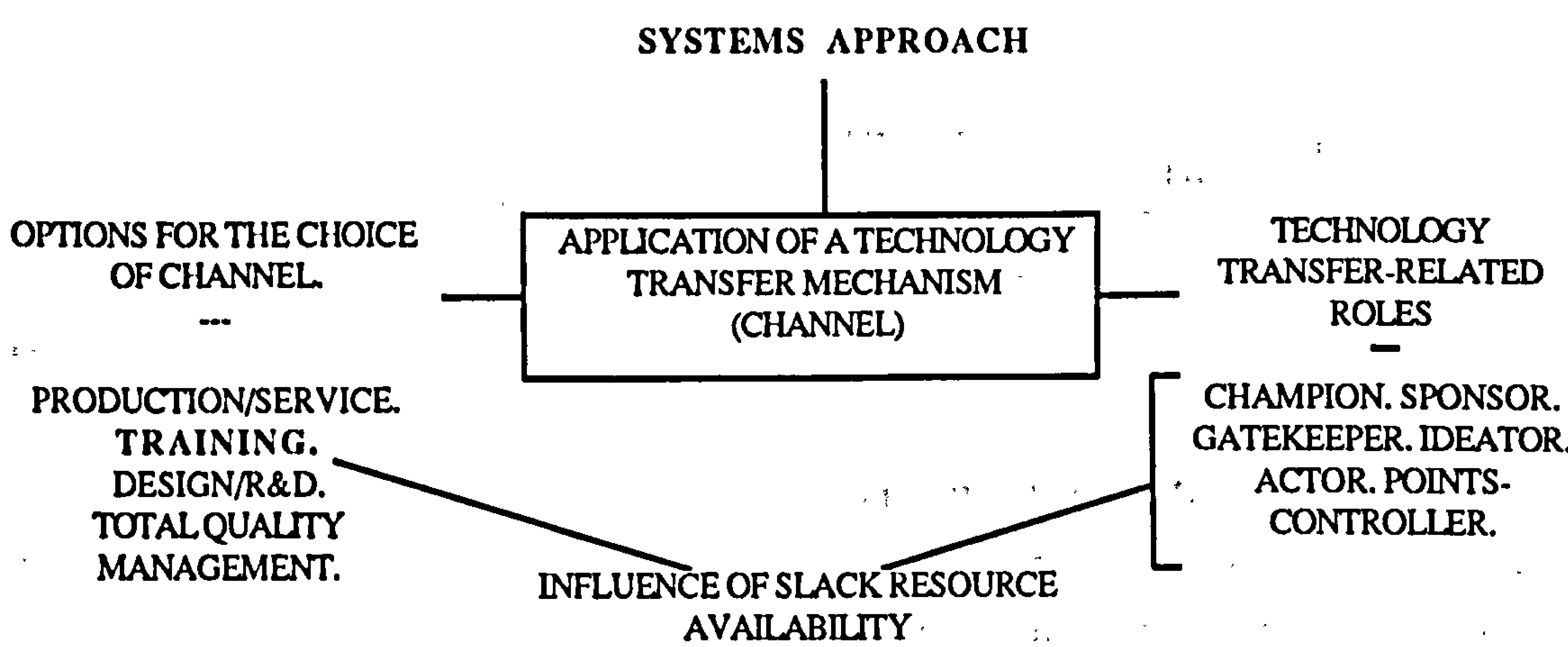


Diagram 11

The absence of 'slack' in terms of human resources was one of the most obvious inhibitors during transfer. As pointed out earlier in the thesis, the concept of slack resources (Galbraith, 1974) has been used here to illustrate a trend, particularly within small firms, towards rationalisation of staff numbers. One outcome of this trend is that people who have what has been described as the characteristics of the Technology Gatekeeper role, see Tables 4 and 5, have a reduction in their capacity to perform this role. In all cases in this project, where new technology has been adopted there has been an observed gap between its introduction and the use of knowledge and know-how necessary for full exploitation of the technology. In most cases there are people, mainly at Supervisory or Technician levels who could facilitate the necessary transfer, if given the necessary resources. The factor can also be said to partly account for the negative response to the research question about the suitability of training as a transfer channel, (Section 10.2).

* Factor B - Experienced-based learning.
The reliance upon experienced-based learning was a key factor in determining eventual response to the learning material and to a certain extent the response to adopting a wider approach embodied in systems thinking. The factor emerged from the stage of the project when the learning modules were being given pilot runs and during the transfer process.

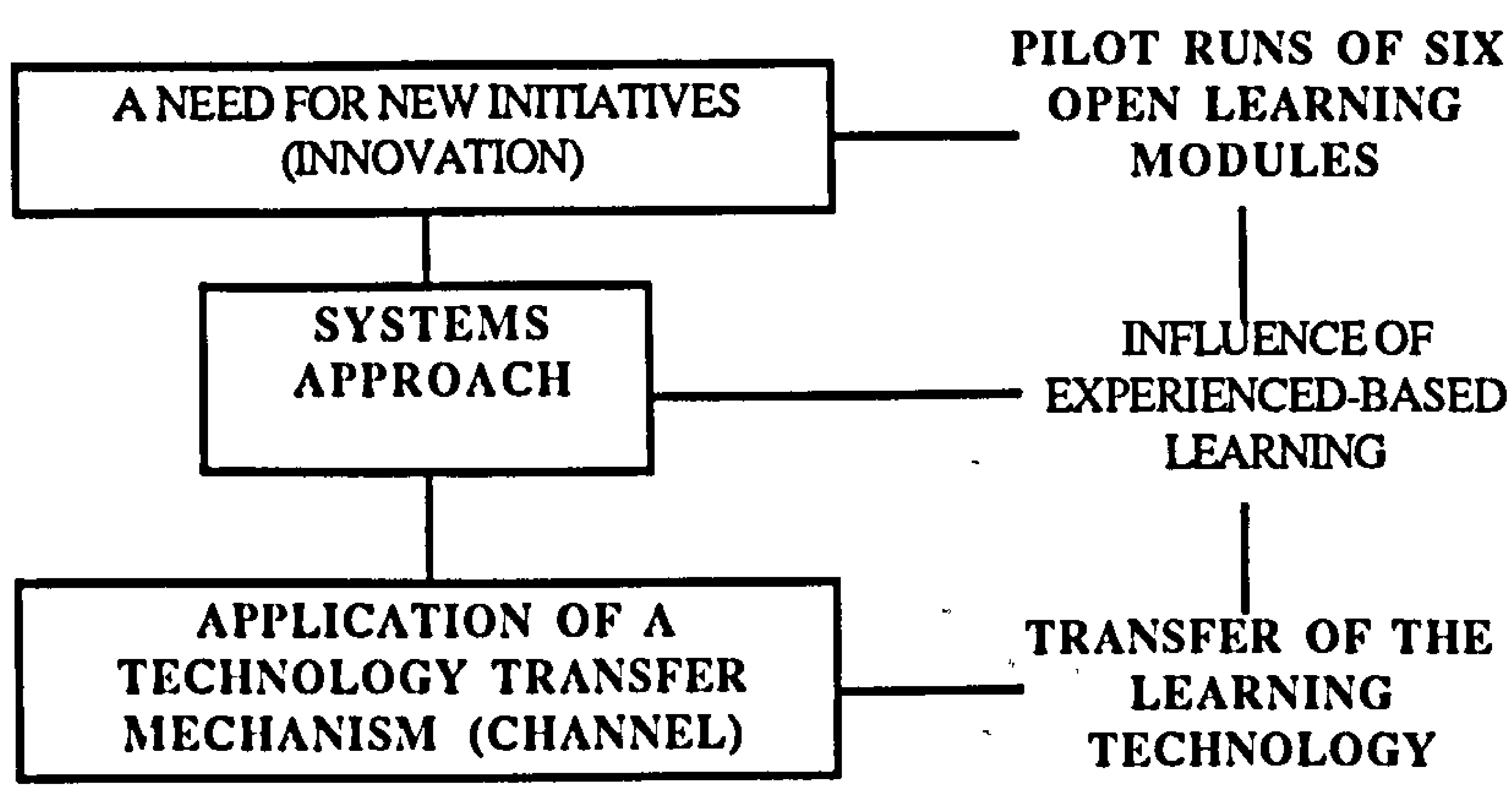


Diagram 12.

The reliance upon experience, which appears to be a continuation of learning practices which were more suitable for older technologies, needs to be recognised as a factor which now inhibits the transfer of technology. Implicit in experienced-based learning is that ample time will be available for the learning process; this can no longer be said to be true. Also implicit in this approach is that most of what needs to be learned is to be found in practical experience on-site, this can lead to what has been described as the 'not invented here syndrome' and a reluctance to transfer-in any new ideas. On the evidence from cases in this study there are three types of innovation that can be hindered in this way, new information about hardware and processes, new methods and approaches, and new means of learning from the development of training technologies. When relying upon experience, the first two types are most often picked up by trial and error, or by discovery learning. Throughout the cases there was a low level of awareness about training technologies, and it can be argued that reliance upon experience can partly account for this situation. Although the factors were expected to emerge from the project work, this particular factor was anticipated in the formulation of the research questions. During initial research for the project it was observed, mainly from anecdotal evidence, that Troubleshooters and Operators used the term 'experience' a good deal to describe how they learned fault finding and diagnosis. The evidence from all three research methods strongly support the idea that memory of past events accounts for a high proportion of diagnostic learning, and that this factor goes beyond diagnosis to influence aspects of technology transfer.

* Factor C - Use of Transfer Channels.

It appears, from emergence of this factor, that when a particular function is being used as a channel for the transfer of technology in the form of know-how and ideas, there is value in having one or two other functions to act as workable options in case for some reason there are sudden changes in the way that the chosen function operates, or is being phased out.

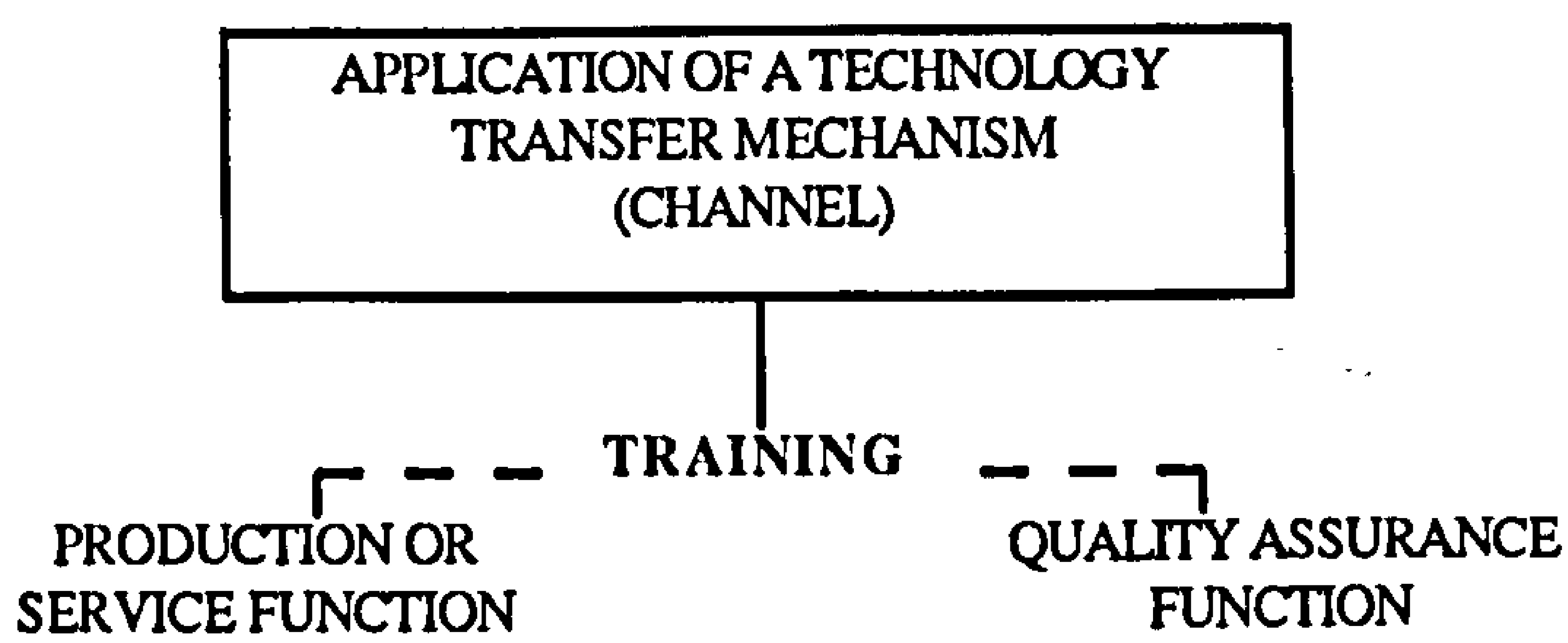


Diagram 13.

When training, the chosen channel for transfer, was found to be inadequate it was the production function that became automatically the means of transfer. To a certain extent this reflected a current trend in industry towards the phasing out of dedicated training departments and the introduction of production personnel who have assigned responsibility for training. When this approach is adopted it appears that little thought is given to who in production will access new ideas and new approaches to learning; previously this would be done in firms where an effective Training Manager was in post. When training has been integrated into the production function, as in two of the four large firms and five of the eight small firms, consideration needs to be given to how transfer takes place. The absence of a recognised channel, as described in Chapter 5, is a factor that can seriously hinder transfer of ideas and methods into a firm. Apart from asking the question, 'how does your firm learn ?' it is possible to be more specific by describing what is meant by 'transfer channel' and transfer-related roles, then asking how they are seen to function in practice.

* Factor D - Recognising the Gatekeeper Role.

Of the transfer-related roles, described in Chapter 6, it is the Technology Gatekeeper role that has proved to be the most critical in the transfer and dissemination of the innovation. The behaviours listed in Table 5, which have been drawn from the field work, help to summarise the function of this role. If the initial contact at the shop-floor level is unable to act as a sounding board for the ideas as they relate to the present context, any further progress becomes difficult.

TECHNOLOGY
TRANSFER-RELATED ROLES

GATEKEEPER
SPONSOR
CHAMPION
IDEATOR
ACTOR
POINTS-
CONTROLLER

WHO ?
TECHNICIAN.
SUPERVISOR.
MANAGER.
DIRECTOR.
OUTSIDE SALES
etc.

Diagram 14.

To perform this sounding board task well, the person must be receptive to the possibility of doing things differently, in other words being prepared to escape from the lessons of experience. In all cases where such a person was available, the initial transfer was achieved effectively. The other behaviours tended to follow on, though inevitably all effective Gatekeepers were mixed in how effectively they displayed all the behaviours listed. When it has been reported in this thesis that the Gatekeeper role was not to be found it means that the sounding board behaviour and many of the other behaviours were absent. The senior managers who performed the Champion and/or Sponsor role often displayed some of the Gatekeeper characteristics. However the finding from research in this area, (Allen, 1977) and (Rosenfeld and Servo, 1990) that people with these characteristics cease to apply them when promoted to beyond Supervisory or Middle-Manager level has been found to apply in this study. Upon reflection this appears to be unfortunate, especially in the case of small firms where such characteristics may not be widespread among the workforce. The absence of at least one Supervisor, Middle-Manager or Technician who can fulfil this role when required is recognised here as a factor that can hinder the transfer of knowledge and know-how into a firm.

* Factor E - Conceptualisation of Ideas.

The factor emerged primarily from application of the module (4) on fault recording, and in analyzing faults on the basis of general principles. Another area was in the use of systems thinking, module (3), and the use of concepts to help clarify what were complex situations.

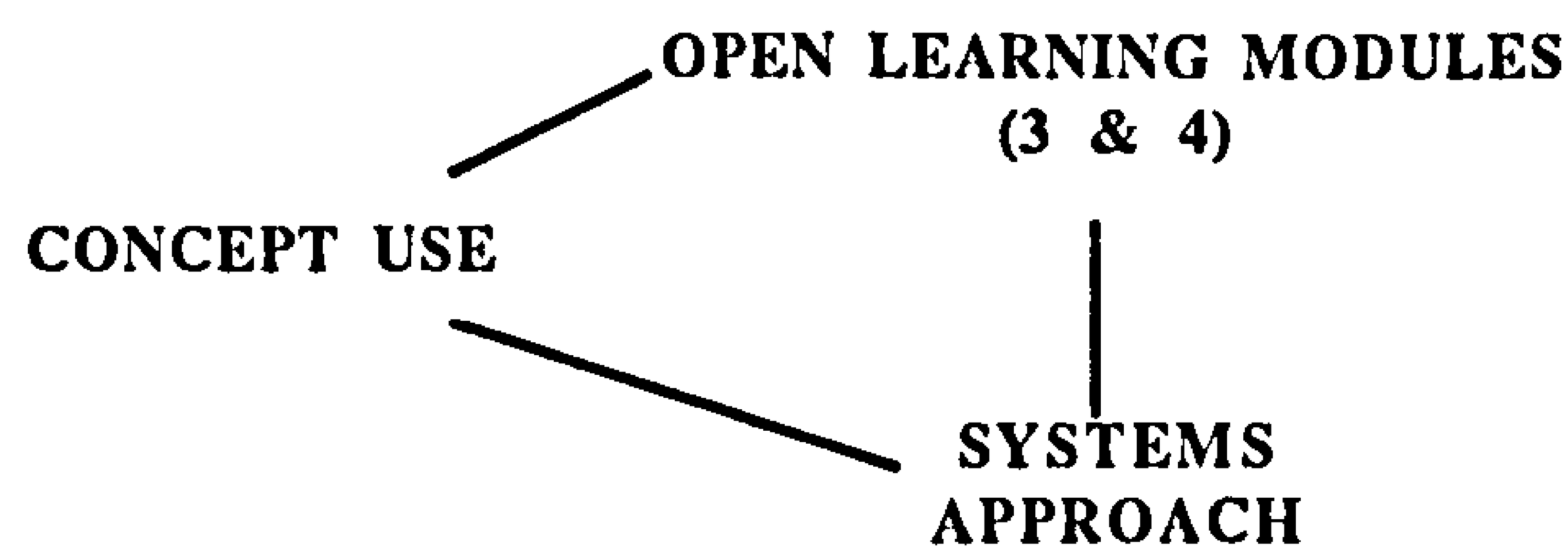


Diagram 15.

There were observed differences between Troubleshooters and Operators in how far they were prepared to recognise general principles that could apply across diverse situations. The main clue to identifying people who had difficulty in conceptualising came in two ways, one was to allocate uniqueness to a number of their tasks, and the other was to say that something different happened every day, and for this reason it was impossible to record all symptoms and causes because there were thousands. In these situations (and there were many) such people see each and every failure as a discrete event, there appears to be an inability to use concepts that can generalise fault events into groups that in principle are the same, for example faults that can be among others,temperature-related, adjustment-related or spares-related. Such conceptualisation of events can then lead to the adoption of relatively few diagnostic strategies, and each strategy can be related to an area that has been suitably conceptualised. In contrast, by suitable conceptualisation, a Troubleshooter who diagnoses hydraulic systems, can, in learning to diagnose digital electronic systems, transfer many principles from one to the other without having to learn from scratch.

The relating of so-called unique tasks can lead to a rejection of lessons from outside the firm, and in this situation all learning material must be generated from in-house experience before it can be accepted.

A systems approach to fault diagnosis emphasises, among other things, that fault events in complex systems are seldom discrete, and rely upon interaction with a number of diverse practices before a full understanding can be achieved. In these circumstances, it can be appreciated that the absence of conceptualisation can hinder the acceptance of a systems approach as well as the actual transfer of the ideas.

Relationships between factors.

It is possible to recognise relationships between the factors when they are mapped to the transfer model introduced in Chapter 1:

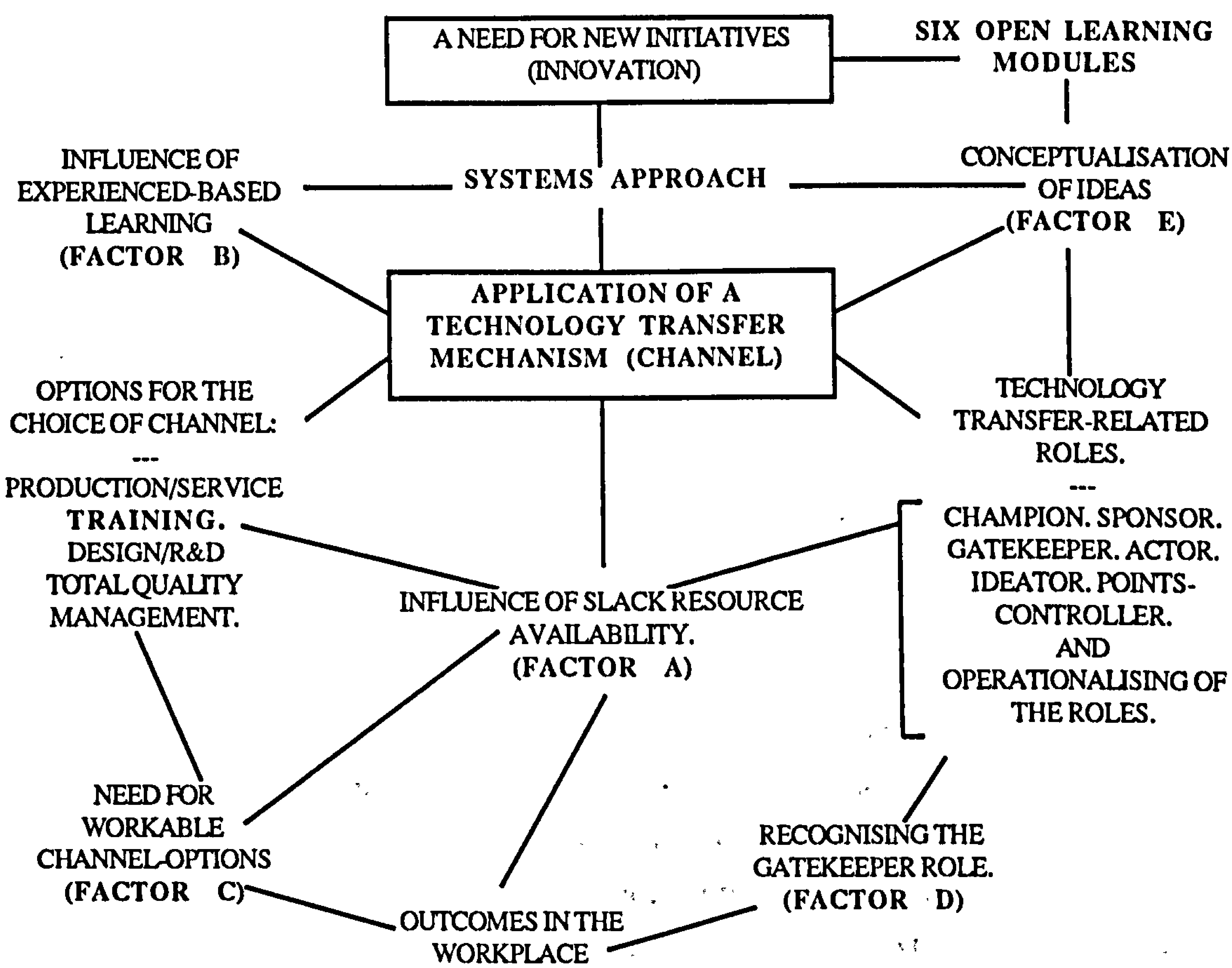


Diagram 16. Mapping the main factors.

The influence on transfer could be considered from a positive perspective by considering factors that can be said to facilitate rather than hinder. The factors listed above can also act as facilitators for transfer, however in doing this some qualifications need to be added. The lack of slack resources as a factor in inhibiting transfer of this kind cannot on this evidence be said to provide a facility for transfer when the reverse applies. All firms in the sample had experienced rationalisation of human resources, so there were no examples of the transfer being facilitated by these resources being in place.

With respect to experience-based learning, again this was so predominant, with few examples of formal organisational learning that draws upon a range of learning methods, that the alternatives to the emphasis upon experience could not be said, on this evidence, to positively facilitate transfer.

In the case of transfer channel use it can be said that in firms where either training or production provided the characteristics of a channel as described in Chapter 5 the transfer was significantly more effective than in firms where such characteristics were absent. The same can be said of the Gatekeeper transfer-related role. This was one of the most critical aspects of transfer effectiveness. In the firms where transfer was poor and acceptance was not achieved or was limited, there was a lack of at least one person with characteristics of the Gatekeeper role. In all other cases the role was in evidence.

The ability to conceptualise ideas has more effect at the individual level than in a broader transfer context. When the reverse of observations made above in respect of hindering transfer is applied, it can be recognised that most Troubleshooters and Operators who were able to respond to a systems approach also conceptualised in discussion, and made connections with events outside their immediate experience.

It was possible to speculate about other possible factors that could facilitate transfer. One in particular was relevant to the current recessionary conditions within industry in general, and this was that firms confident in their immediate future would be among those who could devote most time to this initiative and have more chance of transfer and acceptance. While being a plausible assumption it was not supported by the outcome. Three of the small firms where transfer and acceptance were positive experienced considerable uncertainty in their trading position because they were linked to larger firms in similar circumstances. None of the large firms experienced any real uncertainty so this factor could not be checked here.

Another possible factor to facilitate transfer could, it was felt, be found in particular characteristics of the training function. However, there were no examples of any proactive behaviour that could be described as innovative in this area. There was no evidence that any of the training functions in place could readily facilitate the transfer of new ideas into the firm.

11.3. Promoting further developments of the technology.

Currently there are four available means for the further development of the ideas and the approach. One comes from the British Polymer Training Association (BPTA) where it is recognised that firms in the plastics processing business can achieve significant cost reductions by adopting this approach. There have been discussions between their representative and the management of Cleveland Open Learning Unit who have taken on publication of the learning material. A general lack of such bodies as the BPTA for other sectors of industry is a possible hindering factor in the dissemination of ideas. A second means is offered by the services of bodies referred to as Training Enterprise Councils (TECs); each TEC has been circulated with details of this project by the Department of Employment, however at present any contact between TECs and industry is very limited, only two of the small firm's management in this sample had any knowledge of these bodies. Thirdly, plans are being discussed at the Cleveland Open Learning Unit for the promotion of a course in fault diagnosis based upon the open learning material. Fourthly, there is the possibility of adapting the material to fit a more general textbook on the subject of learning to diagnose.

11.4. Recommendations.

Two factors, more than any other, have emerged from this study, one is that current issues relevant to fault diagnosis, and consequently relevant to business performance, point to the need for a broader approach to this subject; the other is that the means of providing this approach have yet to be proven and accepted fully. The examples of acceptance and transfer have been due more to the response of certain individuals than through any corporate climate that is conducive to this approach. One recommendation is that one or two firms where the climate is already recognised as being responsive to a systems approach, where such an approach can operates at a corporate level, should apply the material in an in-depth way to allow for a thorough evaluation of the ideas and methods.
A further recommendation is that consideration be given to how the gap is bridged between the broader view commonly practised at senior manager level and those who supervise. For firms who need to adapt to rapidly changing technology it is important that people in

Supervisory roles can display Technology Gatekeeper characteristics, which means the adoption of a broader view previously thought of as exclusive to more senior managers. This gap was noticeable in the transfer of this innovation and it is reasonable to assume that it can effect other innovations too.

That the findings about access to technology information by the small firms, although a small sample, does reflect other reports of gaps in this respect. There does appear to be a need for some critical examination of this area. The report on the Faraday programme, reported in the summary below, may be a first step in this direction.

11.5. Thesis Summary.

Two key assumptions were made at the beginning of the thesis; that training support for people who must diagnose is poor in the United Kingdom, and that both research and shop-floor practice adopt a reductionist approach to the subject that is no longer appropriate for the complex interactive nature of the new technology being diagnosed. On the basis of the information gathered during the project there is no reason to challenge these two assumptions. Training in fault diagnosis is reported to be almost non-existent, and with the exception of only two firms in the sample, general training provision has been described as poor by management and shop-floor personnel. The spontaneous information provided by the case-study and critical incident approaches indicate that both manufacturing and service operations face increased complexity in the processes used, and increased interactions across more diverse groups of people. On the other hand, the information that has been provided about current practices in response to fault diagnosis issues reflects a strong tendency to adopt a reductionist approach. A similar observation has been made in a recent book on systems, (Senge, 1990), to quote, 'I have seen many situations where teams will say, " we are already thinking systemically", or espouse a systems view, then do nothing to put it into practice or simply hold stead-fastly to the view that, " There is nothing we can do except cope with the problem". Within the sample there were people who, by their behaviour served as exceptions to such observation but they were in the minority.

The observation made above relates to a proposition that there is a difference between receptivity to systems thinking depending upon whether the ideas have been presented descriptively or prescriptively. There is evidence from the information gathered here that such a difference does exist, and may be worthy of further research. During the project two aspects of the proposition emerged. First there was a willingness from senior managers to support the ideas as being relevant to the firm's needs, but less willingness from some people at shop-floor level who had the task of applying the ideas. Willingness could be said to follow systems description, and unwillingness to follow systems prescription. Second there was a difference between fault diagnostic issues, given by people on the shop floor, which were descriptive and reflected a broad systems-type view and their responses to these issues which were reductionist.

From technology transfer, the subject of the thesis, two critical factors emerged from the project. The first factor, and most important , was that on this evidence there were no examples of technology transfer mechanisms being in place within the small firms. It is worth noting at this point that a recent initiative has been set up by the Government to introduce elements of the Germany-based Frauhofer Institutes, (Brown, 1992), which it is reported are vital to small businesses in Germany. The Institutes manage a large part of the technology transfer process from source to points of application. However, according to Brown the British version called the Faraday programme, as planned, does not adequately replicate the original version. Although various Government bodies exist that ought to have the potential to act as part of a transfer mechanism, in practice there is little support for the dissemination of technology information to the small firm. For example, although each local Training Enterprise Council has knowledge of and access to the learning material developed during this project, there is little opportunity for dissemination through this channel. To disseminate the learning material further, it would be necessary to repeat the project again by starting at the beginning with Senior Managers in another sample of small firms.

The second factor is that given a valid and reliable technology transfer support system for the small firm, there is on this evidence the lack of a channel for the flow of technology information into the firm and then across department boundaries. Here the word 'channel' is being used as a metaphor for an aspect of organisational structure, and staffing, that allows for the free flow of information to the shop floor. It is not uncommon for department boundaries to be described as barriers, rather than as intended, 'organisational boundaries', (Liker and Hancock, 1986), and can hinder the transfer of technology within a firm. On the evidence presented here, such barriers can be as effective in the small firm as in the large firm where the phenomenon is more often discussed. However there were more effective means in the sample of large firms for accessing technology information. The links were to Universities, Colleges, Research Units, and Professional Institutes. In some of the small firms there were people who displayed the potential to act in the crucial role of Technology Gatekeeper, but the lack of a suitable transfer mechanism and specific channel, within the firms concerned, hindered any opportunity to exercise this role.

Where training provision was adequate, in two cases especially, it was possible to perceive this function as a transfer channel; given also that at least one person was available with the characteristics of a Gatekeeper. Where training provision was poor the function remained untested as a means of transferring the material. In these circumstances it was production, or the equivalent service activity, that absorbed what responsibility remained for training, and also had to act as the transfer channel.

Where the learning material has led to some demonstrable benefits, in the limited time of exposure, the gains have been achieved more through changes to procedure than through actual training activity. That is, in the way certain things are done, in particular by changing the method of transferring fault information between shifts, and by deeper analysis of fault events to indicate where in-house intervention could make savings on the use of outside contractors. The extent to which exposure to the material can influence diagnostic behaviour will take some time to emerge from the respective firms. At this stage it is only possible to gather levels of confidence from Operators and Troubleshooters about which benefits could, in their view, be achieved as a result of such learning. The willingness of Troubleshooters to accept fault diagnostic training is not reflected by training provision in this area. For example, in a recent report from the Engineering Training Authority, (EnTra, 1992), twelve units in the factory maintenance NVQ level 3 programme do not include fault diagnosis.

The use of the learning material to help establish competency statements, and to make a contribution to maintenance work assessment at NVQ level 3 raises an area of possible conflict between the approach adopted here and the current approach to occupational skill assessment. The systems approach to diagnosis stresses understanding, conceptualising and is strongly process orientated. In contrast, the current moves towards assessment are of the more simplistic can do type statements and while understanding is not entirely discounted it does have a low profile in terms of assessment. The approach can best be described as product orientated. The Manager and staff of the Cleveland Open Learning Unit, and their local Industrialists have expressed concern about the present trends towards simplification of occupational assessment, and recognise that deeper levels of understanding required for diagnosis and problem solving are being ignored. Evidence from the literature search described here and from the field work does indicate that skilled performance in this area is difficult to articulate and to learn; it is also difficult to assess, but this fact does not seem to provide a valid reason for avoiding the difficulties. There does appear to be a need to develop more effective means of learning and assessing these more difficult cognitive skills.

The receptivity of Troubleshooters to the idea of recording and analyzing fault records was poor, and this has supported earlier claims that technicians are reluctant to use the written word. The maintenance and analysis of records, as typically applied in the medical profession, are fundamental parts of the systems approach to diagnosis. Given the increased complexity of machines and equipment in use it is only through such analysis that modern plant can be adequately controlled. In systems terms most fault events are messes that are being treated by practitioners as well-bounded difficulties. The ideas presented in Chapter 6 on values beliefs and attitudes are relevant to this situation. There appears to be a strong belief that diagnostic information stored exclusively in personal memory provides a Troubleshooter with some security and status. This belief can be said to fuel the attitude represented by a reluctance to record and share fault event information. Only two firms made any attempt to record and analyze faults, which together with another firm, not in the sample, that performed this task in a near- perfect way, provided a contrast to what is the most common approach to this subject. Two quite different views are represented here; one view of management is that there is not time for fault recording and analysis, the other view from management is that they cannot afford to neglect fault analysis. The last one appears to be the minority view.

The main aim of this thesis was to identify factors that can be said to influence receptivity to fault diagnosis training as a result of applying a systems approach. It has been possible to list factors that on the one hand hinder receptivity and on the other facilitate receptivity.

Factors that facilitate:

* The existence of at least one person in the firm with the characteristics of a Technology Gatekeeper. (As defined in Tables 4 and 5 in Chapter 6).
* The development and maintenance of a mechanism (channel) for the free flow of technology information into the firm and throughout the firm.
* A blame-free organisational climate in which people can be encouraged to do things differently as opposed to simply doing them better.
* The existence of a designated person with responsibility for training within the firm.
* The existence of weak department boundaries.
* A recognisable training structure in place, either as part of the production process or as a specific training function.
* A willingness, among the workforce, to share fault diagnostic information.

Factors that hinder:

* A reliance upon experience as a means of learning.
* A reluctance, among the workforce, to make use of the written word as a means of learning.
* A reluctance, among the workforce, to write about fault events.
* The existence of the not invented here syndrome that means general principlesof diagnosis cannot be generalised across many firms where they are equally applicable.
* The difficulty some practitioners have in conceptualising fault events in terms of general principles, which helps in recognising important relationships between events, leading to difficulty in accepting systems ideas.
* The absence of anyone in the Technology Gatekeeper role.
* The absence of a transfer channel.
* The absence of slack in terms of human resources, to allow training to take place.

This concludes the thesis, I trust that it has made enjoyable and informative reading.

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APPENDIX A

TRAINING
IN
FAULT DIAGNOSIS

A QUESTIONNAIRE

Thank you for agreeing to complete this questionnaire. The results will be used to guide the development of training in fault diagnosis. The responses you give are confidential, there will be no reference made to named persons or named companies. The giving of your name is optional.

You may find that it is not possible to answer some questions, if this is the case please put a line through to show that you have considered the question.

Please return this questionnaire personally, or through your department in the envelope provided.

Malcolm Craig

Training in Fault Diagnosis
Questionnaire

Practical Fault Diagnosis

Please tick **one, or more than one,** box to show the type of fault diagnosis work that you do.

a)	Mechanical.	☐	a
b)	Hydraulic and/or Pneumatic.	☐	b
c)	Electronic (Digital).	☐	c
d)	Electronic (Analogue).	☐	d
e)	As a Process/Machine Operator.	☐	e
f)	Instrumentation and Control.	☐	f
g)	As a Production/Process Engineer.	☐	g
h)	Other...........................	☐	h
	....		

Learning.

Please tick **one, or more than one,** box to show how you have learned to Diagnose.

a)	By experience alone.	☐	a
b)	Experience, plus some instruction on the job.	☐	b
c)	'Sitting next to Nellie' ...	☐	c
d)	Further Education College Courses in Fault Diagnosis.	☐	d
e)	Off-the-Job Fault Diagnosis Course(s).	☐	e
f)	Planned On-the-Job Training in Fault Diagnosis.	☐	f
g)	Computer-Based Training in Fault Diagnosis	☐	g
h)	Open Learning Programme in Fault Diagnosis.	☐	h
i)	Distance Learning Programme in Fault Diagnosis.	☐	i
j)	Other	☐	j

Skills.

First, read down the list of skills given and then add others you can think of. When you have done this, put **1** in a box for the skill you consider to be most important when fault diagnosing. Then a **2** for the next in importance, and so on until you have completed all the boxes.

a)	Reading Drawings and Diagrams.	☐	a
b)	Interpreting Manuals.	☐	b
c)	Recognising Correct Symptoms.	☐	c
d)	Using Fault Diagnosis Techniques.	☐	d
e)	Gathering Fault Information.	☐	e
f)	Reasoning Logically.	☐	f
g)	Recording Fault Information.	☐	g
h)	Listening to, and questioning, other people.	☐	h
i)	Other......................................	☐	i
j)	Other......................................	☐	j

Issues.

Thinking about the Fault Diagnostic work that you do, please write down below the main issues at the present time. For example, one could be that spare parts bought by the company are not sufficiently reliable.

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Relevance of Training in Fault Diagnosis.

Please tick a box to show what you feel about Training in Fault Diagnosis.

a) I could benefit from training in Fault Diagnosis. ☐ a

b) I see no need for training in Fault Diagnosis. ☐ b

c) I am prepared to consider the need for such training. ☐ c

Type of Training.

If you ticked either **a** or **c** above, please tick **one, or more than one,** box to show how you would prefer this Training to be delivered.

a) Working through Training Modules on your own. ☐ a

b) Working through Training Modules with a Tutor in support. ☐ b

c) Formal, Off-the-Job Training Course. ☐ c

d) Computer-Based Training. ☐ d

e) Interactive Video. ☐ e

f) On-the-Job Formal Instruction. ☐ f

g) Informal, next to Nellie, Instruction. ☐ g

h) Other.. ☐ h

....

Training in General.

Keeping in mind the previous question, describe briefly the ways that you receive training **of any kind** in your organisation.

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Planned Training.

Six Training Modules in Open Learning format have been produced. The skills covered are listed below, please write down what you think is missing.

1) Listening and Questioning for fault information.

2) How to use Fault Diagnosis Techniques.

3) How to think of machines/processes as systems (Systems Thinking).

4) How to record and maintain Fault Information.

5) How to be aware of costs involved in Fault Diagnosis.

6) Managing Fault Diagnosis Training.

What, if anything, is missing?..

....

....

Use of the Modules.

If you have worked through these six Training Modules, or are familiar with them, please tick the boxes below to show what value you give to each one.

	VALUABLE	SOME VALUE	NO VALUE	
Module 1	☐	☐	☐	1
Module 2	☐	☐	☐	2
Module 3	☐	☐	☐	3
Module 4	☐	☐	☐	4
Module 5	☐	☐	☐	5
Module 6	☐	☐	☐	6

General Comments on Modules:

....

....

Benefits Section

Instructions.

Please begin by ticking **one, or more than one,** box to show which benefits can, in your opinion, be achieved by use of training in fault diagnosis.

Next, write a number between **one and four alongside each box that you have ticked,** to show how confident you are that these measures could in fact be made in your company.

A guide for giving your level of confidence, and the list of questions begins below.

Guide to your level of confidence.

1. = Absolutely Confident.
2. = Confident.
3. = Doubtful.
4. = Not Confident.

Use this guide for answering in the second column of boxes.

Benefits to be gained in TIME.	**Tick**	**Write 1to 4**
a) Improvement in time taken to respond to a reported fault.	☐	☐
b) Improvement in time taken to diagnose a fault.	☐	☐
c) Improvement in downtime, caused by faults.	☐	☐
d) Improvement in the time between **Same Faults, ie Repetitive Faults.**	☐	☐
e) Improvement in the time taken to raise spare parts.	☐	☐
f) Improvement in the time taken to report faults.	☐	☐
g) Other .... (Please add your own)	☐	☐

Benefits from cost saving.	**Tick**	**Write 1 to 4**
a) A reduction in the cost of spare parts held in stock.	☐	☐
b) A reduction in the cost of unnecessary call-outs	☐	☐
c) An improvement in equipment/ machine pay-back time on capital, as a result of less downtime.	☐	☐
d) A reduction in quality costs, as a result of greater equipment/ machine reliability.	☐	☐
e) A reduction in maintenance costs.	☐	☐
f) A reduction in cost of outside Contractor's service.	☐	☐
g) Other............................	☐	☐

....
(Please add your own)

Other Benefits.

The next three lists of questions ask about benefits that are difficult to measure by using numbers. These are measures that are gathered by getting indications of improvement from your own observations, and from the opinions of those around you.

Benefits from improved Customer Relations

Here, The word 'Customer' can mean any user of equipment or a machine. For example, a person working as a Process Operator is a Customer to the Engineer who diagnoses and repairs faults.

	Tick	Write 1 to 4
a) Increased Customer confidence in machine/equipment reliability.	☐	☐
b) Greater Customer's satisfaction with service on equipment or a machine.	☐	☐
c) Greater Customer involvement in fault diagnosis.	☐	☐
d) Improvements in Customer satisfaction with fault diagnosis feedback.	☐	☐
e) Other................................ .... (Please add your own)	☐	☐

Benefits from better fault information recording.

	Tick	Write 1 to 4
a) Improvements in the amount, and the quality, of information shared between those who diagnose.	☐	☐
b) Improved design features as a result of giving better feedback about design-related faults to design personnel.	☐	☐
c) Greater prediction of faults as a result of improved fault recording.	☐	☐

d) An improved flow of fault information between departments.	☐	☐
e) Improvements in stores control as a result of analysing improved fault records.	☐	☐
f) Improvements in fault information from customers.	☐	☐
g) Other..................................	☐	☐

(Please add your own)

Benefits shown by changes in general attitude.

	Tick	Write 1 to 4
a) More listening, questioning and analysis, and less `diving in'shown by those who diagnose.	☐	☐
b) Fault recording is now recognised as a vital part of diagnosis.	☐	☐
c) Signs that Maintenance Personnel now work **with** rather than **for** production.	☐	☐
d) Greater `ownership' of equipment/ machines is indictated from Operators being more involved in fault diagnosis.	☐	☐
e) Technicians and Operators now recognise fault diagnosis as a set of skills that can be improved through training.	☐	☐
f) Other..	☐	☐

End of this Questionnaire.

Many thanks for your time and your cooperation in answering these questions.

Please return this questionnaire either yourself or through your department in the stamped addressed envelope provided.

Please complete this section before posting:

Name................................(Optional)

Date...................................

Company Name...

Tel No......................

Department...

Your Job Title/Position..................................

Years in Job/Position............

APPENDIX B.

Critical Incident Procedures.

There are three recognised methods for conducting critical incident research, one, and the most common method, is by face-to-face interview, second is through small group discussion, and third is by questionnaire. The face-to-face method was used during this project because the Researcher had developed the necessary skills for use of this approach and had less practice in using the other two methods.

Up to one hour was allowed for each formal critical incident interview to take place. The respondents were asked to think specifically of the fault diagnostic work that they did, and asked what they considered to be most critical to this work in terms of incidents. In each case it was explained that 'critical' means those events and behaviours that can make a significant difference to the outcome. It was further explained that tasks that we do in any job contain what can be called 'padding'. that is events and behaviour that do not greatly influence the effectiveness of the outcome.

From this point onwards the respondent dictated the interview rather than the Researcher. The Researcher's only intervention was to ask for more incidents, and to follow-up on stated generalities. For example, if the respondent said "I needed to use my initiative at this stage", the key word 'initiative' would be picked up by saying, "you said initiative, will you tell me what you did that makes you say this was initiative? As with many words of this kind, unless there is an example of an incident the comment made above is really meaningless. Another example where follow-ups were used, was when statements were made that are relative and need some kind of standard such as " downtime is too high here" or "most dive into fault too quickly" The aim in taking this approach is to capture spontaneous views about what practitioners consider to be critical and intervene only when more clarity is required. It was important that no further intervention was made by the Researcher otherwise respondents are side-tracked to incidents that are critical to the Researcher and not to them personally.

Among the homogeneous groups of Troubleshooters and Operators seen it was seldom that the fifth person to be interviewed added any new incidents. In this case it is the use of interpersonal skills by the Researcher that makes the fourth and fifth respondent feel that all incidents are being heard for the first time; in this way the flow of incidents is maintained until the final person has been seen.

Finally, it is possible to recognise some contradiction between research that aims to take a holistic approach and a methodology that encourages respondents to adopt a an approach that is focused upon specific incidents. However the outcome is that the incidents produced spontaneously did range across a wide area and beyond what has been described as the machine-centred view.