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THE SYSTEMIC REDESIGN OF MANUFACTURING SYSTEMS IN SMALL TO MEDIUM SIZED ENTERPRISES

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- 2 -

By

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The Systemic Redesign of Manufacturing Systems within Small to Medium sized Enterprises

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Abstract

The research problem was to develop a new approach for redesigning manufacturing systems within Small to Medium sized Enterprises (SMEs). Field observation together with literature review showed that methodologies propounded in theory were not being applied in practice.

The research presents a new methodology for the systemic redesign of manufacturing systems within SMEs. The methodology consists of a four phase iterative design strategy consisting of Planning, Risk Assessment, Action and Evaluation leading to the next Planning phase. This is given a systemic basis through four perspectives: Structure; People; Process; and Technology; which frame and guide the Planning phase. Prior to this work there was no systemic approach for redesigning manufacturing systems within SMEs. These findings have been validated through the case study method and against criteria that have been identified and developed by the author.

The research adopts three complementary research approaches of participant observation, action research and case study research. These are consistent with the research philosophy developed within the research frame. Participant observation is used at the outset to establish the problem domain and application considerations. Action research is used to develop a methodology that functions independent of the researcher. The final validation is carried out using case study research to evaluate the application of the methodology.

LIST OF CONTENTS

LIST OF FIGURES AND TABLES

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AUTHOR'S DECLARATION

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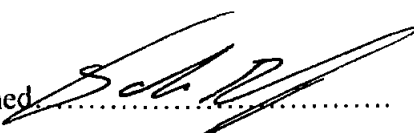
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- 12 -

1. Introduction

The research described in this thesis was carried out by the author. The research was conducted while the author was a Teaching Company Associate with Crydom Magnetics Ltd, a research student and later a research associate at the University of Plymouth. The research was supported by the Teaching Company Directorate (TCD), Engineering and Physical Sciences Research Council (EPSRC), European Union (EU) through research grant EU 26659, the Manufacturing and Business Systems Research Group (MABS) and the School of Computing at the University of Plymouth.

This chapter introduces and describes the evolution of the research project entitled 'The Redesign of Manufacturing Systems within Small to Medium sized Enterprises'. This will set the scene for the thesis by introducing the Research Question, subsequent objectives and the research domain. The research domain will be described by presenting the key concepts which underpin the research. The key concepts include the features that describe Small to Medium sized Enterprises (SMEs), background to design theories and systems thinking. The chapter concludes with a description of the thesis structure.

1.1 Background

Within the current British manufacturing environment Small to Medium sized Enterprises (companies with less than 250 employees) account for 99.8% of UK businesses, 55.4% of employment and 50.9% of total business turnover (DTI, 2000). For this reason alone they are vital to the fiscal health of the United Kingdom. Chapter 4 will develop a more detailed understanding of SMEs and Chapter 5 will relate current redesign methodologies back to that chapter to show why a new methodology is required.

Much of what has been written on manufacturing systems design has been written with reference to larger businesses (Bennett, 1986; Gallagher & Knight, 1986; Hill, 1984; O'Sullivan, 1994; Parish, 1990; Wu, 1994). These solutions have tended to focus on

technical solutions, as will be seen in Chapter 5. Joyce *et al* (1990) suggest that the investment required for such technical solutions is beyond most SMEs. The author contends, therefore, that work needs to be carried out to help SMEs redesign their manufacturing systems.

1.2 The Research Questions

In developing a new methodology for redesigning manufacturing systems within SMEs three areas presented themselves as being the focus of research. The areas were systems theory, design theory and understanding SMEs. Those areas provided questions which guided the foundational research:

- what is a manufacturing system?
- how do we carry out redesign?
- what are the requirements of SMEs?

With the understanding provided by those three questions the author was in a position to critically evaluate current redesign methodologies and develop a new methodology. In doing that three Research Questions were posited and answered:

1. Are current methodologies for redesigning manufacturing systems applicable in SMEs?
2. Are there alternative strategies to those in common use?
3. Can an alternative methodology be developed that is applicable for redesigning manufacturing systems within SMEs?

1.3 Contribution to knowledge

The thesis contributes to knowledge through answering the three questions from Section 1.2 above.

In answer to Question One from above, Chapter 7 demonstrates that current methodologies are not applicable for conducting manufacturing systems redesign within SMEs. This uses the knowledge of systems theory and SMEs developed from Chapters 3 and 4.

In answer to Question Two from above, Chapter 5 shows that there are many alternative strategies for conducting redesign activities. Chapter 8 builds on a strategy from Chapter 5, together with material from Chapters 3, 6 and 7 to produce a new methodology that is designed to provide a clear framework for systemically redesigning manufacturing systems within SMEs.

In answer to Question Three from above, Chapter 10 demonstrates that the new methodology presented in Chapter 8 is applicable to redesigning manufacturing systems within SMEs. This represents a new methodology that has not been previously demonstrated being used to redesign manufacturing systems within SMEs.

1.4 Thesis Structure

The thesis comprises 11 Chapters not including Appendices and References. This is the first chapter and deals with the introduction, research question and contribution to new knowledge.

Chapter 2 describes the philosophical foundation that underpins the research presented in the thesis. The chapter describes the fundamental ontological position of the author and cascades that through to the research methodologies that will be employed. In addition to literature reviews the research comprised of four phases of applied research. These are described and related to each other and the research philosophy in Chapter 2.

Chapter 3 introduces systems thinking and its development from Boulding (1956) and Bertalanffy (1968) to more recent concepts as described by Checkland & Scholes (1990) and Checkland & Haynes (1994). This is then applied to develop the concept of a manufacturing system. The concepts associated with social systems are introduced and a more expansive consideration of manufacturing systems presented. This consideration is further developed to provide a definition of a manufacturing system that may be used for redesign purposes.

Chapter 4 develops an understanding of SMEs and their particular features. This understanding will be used in later chapters to evaluate current redesign methodologies.

These features are summarised to provide a series of criteria that will be used to develop and evaluate the new methodology. The later case studies will be referred back to the theoretical understanding presented here to ensure that the assumptions made are valid in the light of empirical evidence.

Chapter 5 introduces design theory from the first distinction of design as separate from manufacture in the early 1700s to the emergence of a recognisable process of design in the mid 1950s. This later work is used as the basis from which modern redesign methodologies are shown to originate. The different strategies for conducting design are introduced. The preponderance of linear strategies is demonstrated and reasons for this are suggested. Alternative design strategies are also presented and their applicability for manufacturing systems is commented upon.

Chapter 6 describes the first phase of the applied research. This was a period of participant observation conducted with the assistance of Crydom Magnetics Ltd., the TCD and the University of Plymouth. This phase set out to develop an understanding of manufacturing systems redesign in an SME. No explicit attempt was made to influence the actions of the company and no suggestions were made on alternative approaches. The findings from this chapter support the theory described in Chapter 4.

Chapter 7 describes the second phase of applied research. This was a period of action research conducted with the assistance of Crydom Magnetics Ltd., the TCD and the University of Plymouth. During this phase the author actively undertook systems redesign within the company. In addition to making changes within the company, this phase was also used to determine the applicability of current redesign strategies identified in Chapter 5. The research also sought to identify the extent to which systems thinking as described in Chapter 3 was evident in the strategies adopted. A sample of the work conducted during this phase may be found at Appendix One. This contains notes, sample program printouts and additional notes.

Chapter 8 consolidated the findings of the previous five chapters. These findings are used to justify the need for a new methodology for redesigning manufacturing systems within SMEs. The findings are further used, together with Chapters 3, 4 and 5, to develop the new methodology.

Chapter 9 represents the fourth applied research phase where the proposed methodology is used with a number of SMEs. This phase was conducted with the assistance of the EPSRC, the MABS group and the University of Plymouth. Four local SMEs allowed the author access to their businesses so that manufacturing systems redesign could be undertaken. During this phase the methodology was applied with the support of the author. Comments and recommendations were gathered from the participating companies. These were related back to the findings from the earlier research phases and Chapters 3, 4 and 5 to produce the final version of the methodology. Meeting minutes and diagrams developed during this phase may be found at Appendix Two.

Chapter 10 represents the final research phase described in this document. This phase was conducted with the assistance of the EU, AGS Home Improvements Ltd., the MABS group and the University of Plymouth. It applies the methodology that resulted from Chapter 8 to assist in the redesign of the manufacturing system at AGS Home Improvements Ltd. The case study was conducted with minimal involvement from the author. The aim was to demonstrate that the methodology was applicable as an entity separate from the author. Meeting notes, diagrams and other supporting material may be found in Appendix Three.

Chapter 11 draws all the work in the preceding chapters to a close. The contribution to new knowledge is developed out of Chapters 6, 7, 9 and 10. The new methodology is related back to the requirements developed out of Chapters 3, 4 and 5. The final methodology is compared to the proposed methodology in Chapter 8 to determine the impact of the experimentation phase of Chapter 9. Potential areas for future research are also identified.

1.5 Summary

This introductory chapter has presented the background to the research together with the questions that the research aims to answer. The contribution to knowledge has been clearly identified. The structure of the thesis and a short description of each chapter has been presented to provide an overview of the research carried out. The following chapter will describe the research philosophy in detail and how that influenced the research approach.

2. Research Method

In this chapter the research method employed will be described. The aim of the research together with a brief description of the phenomenon under investigation will be stated. The philosophical basis for the research that will be presented is the foundation upon which the research approach and work plan are founded. The research was conducted in four phases: Realisation, Investigation, Experimentation, Validation. Each of these will be discussed in more detail later in the chapter and their relationship with established research methodologies will also be covered.

2.1 Research Aim

The aim of the research is to develop a new methodology for the redesign of manufacturing systems within SMEs. There are two distinct phenomena under investigation here: the concept of a manufacturing system and the manufacturing SME. Each of these phenomena has a corpus of literature that has been used to develop the understanding presented in Chapters 3 and 4 respectively. The particular unit of analysis here is the domain bounded by the intersection of these two phenomena.

The manufacturing SME is an instance of a business type that has been identified as having certain distinguishing features (Bridge *et al*, 1998; Ghobadian & Gallear, 1997; Scott & Bruce, 1987; Welsh & White, 1981). Prominent amongst these features are the number of employees (less than 250; DTI, 1997) and the concept of resource poverty (Scott *et al*, 1995; van der Wiele & Brown, 1998; Welsh & White, 1981).

The manufacturing system is a concept that arises out of a systems perspective (Checkland, 1981; Eisenhardt & Galunic, 2000; Scott, 1981) as applied to manufacturing companies (Mason-Jones *et al*, 1998, Meister, 1982; Parnaby, 1979, 1991; Smart *et al*, 1999). The systems perspective states that there will be multiple viewpoints for considering any system with many equally valid results. This is encapsulated by Parnaby (1979) when acknowledging that there is no single understanding of a manufacturing

system that encompasses the manufacturing system in its entirety. This perspective, more than the concept of an SME above, has profound implications for the research philosophy and this will now be dealt with.

2.2 Research Philosophy

There is a need to discuss philosophy since this will have a fundamental impact on the research conducted, the results derived and the solution thus developed. While this is not the place for a detailed philosophical debate, there are some points that should be made so that future decisions can be related back to an underlying method of thinking. Creswell (1994) identifies five levels of assumptions that are made regarding research in general. These assumptions relate to the ontological, epistemological, axiological, rhetorical and methodological positions that researchers adopt when considering their research domain and the research questions that they are seeking to solve. The most fundamental of these assumptions is the ontological one since this deals with seeking to define what is meant by 'reality' and the position of the researcher within that reality. For this reason it will be considered in some depth, the other assumptions follow on from this initial position and the purpose of the discussion here is to demonstrate an understanding of the issues raised and to ensure that a consistent philosophical thread runs through the research.

2.2.1 Ontology

Ontology relates to the branch of metaphysics concerned with the nature of being, that is the degree to which there is an absolute 'reality' that is distinguishable from the observer's perception (Creswell, 1994). At one end of the ontological spectrum there is the existential opinion that there is no absolute reality, that what we know as reality is merely a construct formed by our brains to interpret the signals received from the senses. There is no method for independently verifying those signals and so there is no method for independently verifying reality. In a similar manner, the causal relationships observed are generated by the brain to better interpret the signals received and may not reflect any

absolute laws. At the extreme, there can be no independent verification for the existence of others, leading to the solipsist stance that everything, including the existence of others, is a construct of the brain. This has profound implications for research since any knowledge will be rooted in the constructs of the researcher and there is no way of transferring those constructs to another, thus there is no way of transferring the knowledge gained.

The realist approach (Meredith *et al*, 1989) at the other end of the continuum suggests that there is an rational, independent reality and that we all experience this same reality (Sears *et al*, 1987). Since this reality is external to the observer, objectivity can be maintained in observing, recording and deducing results from those observations. Quantitative measures should be used to further remove the scope for interpretative distortion of reality. The fundamental limitation with research involving living systems for the realist is the lack of repeatability and lack of control over all the variables (Kirk & Millar, 1991). The highly complex nature of a human activity system implies that it is not possible to alter one variable and predict the full extent of the changes. While Newton's Three Laws of Dynamics (Newton 1687, in Chandrasekhar, 1995) may be demonstrated repeatedly with the same result (to the limits of conventional measurement systems), Maslow's hierarchy of needs (Maslow, 1954: in Armstrong & Dawson, 1989; Huczynski & Buchanan, 1991) is provided as a guide rather than a law that is borne out through experimentation.

Neither of these extremes is particularly useful in this programme of research since the solipsist stance precludes application of research by others and the realist precludes including perceptions as a valid source of research material. Mingers (1992) considers the only virtue in studying systems is to further our understanding of the relationships that exist within such systems. We can apply systems thinking to aid our understanding and further development of models that represent such social systems. Those within the system can, with external assistance where required, use those models to alter the system based on an increased understanding of what is happening.

This represents a position somewhere between the two extremes in the ontological debate described above. It makes the assumption that there is an external reality in which people and businesses operate. It is to this reality that understanding must be applied and thus it is from reality that observations and deductions should be made (Gorman *et al*, 1997). Checkland (1981) suggests that the systems under investigation (Human Activity Systems) only exist through the combined perceptions of those within them. Those perceptions define the system and direct the actions of those within the system. To this extent, axiomatic laws and logical relationships will not be applicable, nor are the 'normal' requirements for repeatability and validity. Qualitative measurement and validation will be required to support the work developed.

2.2.2   Epistemology

Following on from the ontology of the research we should consider the epistemology, that is the grounds of knowledge and the relationship between the researcher and the research domain (Creswell, 1994). To maintain philosophical integrity there should be a clear route from the ontological assumptions to epistemological ones. Adopting an existential ontology leads one towards a critical theory of knowledge generation (Meredith *et al*, 1989) along the lines of Jürgen Habermas (1979a, 1979b) where the researcher is an integral part of the research domain.

Quantitative or axiomatic research requires an objective researcher that maintains a distance from the research domain so as to maintain the 'purity' of the data gathered. There should be a clear distinction between the researcher and the research domain, the grounds upon which the knowledge is formulated.

2.2.3   Axiology

Axiology considers the role of values and the extent to which rules can be extrapolated from the knowledge gained about our reality (Creswell, 1994). It follows that if the researcher is objectively detached from the research domain, as with quantitative

research, it is assumed that data will be value-free and bias in raw data will be removed through careful experiment design. This allows logical rules to be deduced from the data and for that data to be represented using a logico-mathematic language type (Dery *et al*, 1993). Since the qualitative researcher is integrally a part of the research domain, values and biases are associated with all data gathered and there is no absolute view that can be adopted (Creswell, 1994). This means that while frames can be constructed and understanding can be advanced (Corbitt & Norman, 1991; Bartezzaghi, 1999) these do not represent axiomatic laws to which the phenomenon under investigation will adhere.

2.2.4 Rhetoric

The use of language within research changes as one moves along the ontological scale. Quantitative research tends to adopt a more formal and impersonal language, developing definitions and equations upon which value-free data can be related. (Creswell, 1994). The more qualitative research uses informal language and story-telling is frequently found to explain and develop arguments through which to relate value-laden data.

2.2.5 Methodology

Finally there is the methodology that is adopted for conducting research, which should reflect the assumptions concerning ontology, epistemology, axiology and rhetoric (Creswell, 1994; Meredith *et al*, 1989). Meredith (1993) identifies several possible methodologies that stem from fundamentally different ontologies. In keeping with the ontological assumptions made earlier that a position towards the mid-point of the imaginary continuum will be adopted, three applicable methodologies will be described here. Their choice has been based upon applicability and compliance with the philosophical position described above. While there are many methodologies that may have been applied, expediency required that a manageable suite was used.

Participative observation is a mode of field research (Johnson *et al*, 1999) where the researcher participates within the research domain without seeking to influence it. In

this respect it is significantly different from action research where the emphasis is on action and making changes to the research domain (Huxham & Eden, 1996; McNiff *et al* 1996). Participative observation is useful in establishing the environment and context for a research domain while providing a richer data source than might be obtained through an objective observer who seeks to distinguish himself from the research domain.

Action research is identified by Meredith et al (1989) as being suitable for deployment in the domain that they describe as operations research. Westbrook (1994) highlights action research as having particular relevance to operations research as it is well suited to unstructured or integrative research problems. Huxham & Eden (1996) and McNiff *et al* (1996) go on to build a structured frame upon which to reflect when conducting action research. This frame establishes change as the focus of research and the establishment of a mutually compatible framework ensuring theoretical validity and providing an ethical basis.

Yin (1994) describes the case study methodology as a general research tool, whereas Eisenhardt (1989) and Meredith (1998) concentrate on theory building. Case studies are summarised as being grounded in reality (Meredith *et al*, 1989), generating bottom-up and novel theories (Eisenhardt, 1989) and valuable for understanding the SME in its environment (Romano, 1989). Of principal concern is to establish the case study design and to consider whether it is a single or multiple phenomenon that is under investigation and whether a single or multiple case study will be most appropriate for the investigation (Yin, 1994).

In this instance the phenomenon is the redesign of a manufacturing system but for breadth to be added to the study a multiple case study will be carried out. In investigating decision making processes in SMEs, Chetty (1996) suggests a use of the case study approach that closely resembles the application in this research.

2.2.6 Conclusion

A philosophical position has been described whereby the researcher will make the ontological assumption that there is a concrete reality that can be discussed while accepting that each observer of that reality will have their personal construct of it. The primary epistemology for the research will be the establishing of such relationships as exist and the surfacing of the assumptions of those within the research domain, including those of the researcher. This will be carried out through three primary methodologies: participative observation, case studies and action research. This represents a philosophy that is aligned through the levels identified by Creswell (1994) and is consistent with the research domain being explored.

2.3 Research approach

In his 1988 paper, Reisman describes seven strategies that can be applied to research in management and social sciences. From those strategies the one that best encompasses this research would be 'technology transfer'. In this, a solution is taken from one domain and applied, with suitable modifications, to a different domain. In this manner the ideas for prototyping and organisational perspectives, taken from software engineering and managerial psychology respectively, will be transplanted into the domain of manufacturing systems redesign. Each has required some modification and the two have been unified into a single approach.

A four phase research plan may be used to describe the journey from initial conception to final exposition of theory. The research aim is to develop a methodology for redesigning manufacturing systems, however, the concept of a manufacturing system exists only in the perceptions of those observing and operating within such a system (Checkland, 1981). The methodology is thus really aiming to change the perceptions of those observing and operating within the perceived system and providing them with a structure such that they will make changes to their constructs. To achieve this the researcher will have to gain

an understanding of those constructs and the environment within which they operate. From this initial understanding further investigation will be required to determine the effect that current redesign methodologies have on those constructs and their external manifestations as represented by manufacturing systems. The next phase of research will be to determine theoretical structures that will assist those observing and those within manufacturing systems to realise their personal constructs of that system and to allow development of those constructs towards a mutually agreeable future state. This will establish the internal validity of the methodology in that it will ensure that all the structures proposed operate in concert towards the agreed goal of manufacturing systems redesign. Once those theoretical structures have been identified and assembled there will be a phase where the methodology will be applied to a separate manufacturing system to establish externally validity without the historical context of seeing the methodology grow and develop. These research phases may be summarised as: Realisation, Investigation, Experimentation, Validation.

2.3.1   Realisation

The first phase was one of Realisation that there was a research question to be asked and an answer sought. This phase was characterised by participative observation in an industrial setting. Several case studies were carried out, as described in Chapter 6, where the researcher was an integral part of the activity. There was a tremendous amount of contextual data gathered with considerable triangulation between cases to ensure that the phenomenon observed, the redesigning of manufacturing systems within SMEs, was neither unique or trivial.

A literature search revealed that the phenomenon, while described, was not tackled through practicable solutions. The literature adopted a highly realist philosophical position and proposed solutions that were highly separated from the contextual settings in which the problems resided. These solutions are more closely analysed in Chapter 5. To ensure that the phenomenon was not unique to the company in question, visits were made to companies that had dealings with the host business and to other companies in unrelated

areas. In all there was a common factor, that change was occurring but the solutions proposed were not being used.

2.3.2 Investigation

The second phase was to investigate why the identified situation existed. To establish why solutions from literature were not being implemented action research projects were initiated within the company. These are described in more detail in Chapter 7. The purpose of these projects was to establish why detailed and highly developed redesign methodologies from literature were not being more widely applied in the SME cases. The action research nature of these projects allowed for development of the methodologies during the course of each project.

The outcome from this phase was to be the genesis of the methodology that was to lead to the final outcome of the research. The final project abandoned the established approaches and adopted an approach that more closely reflected the manner in which businesses had been observed to solve problems. This approach, while of use, was still a long way from being a methodology for the redesign of manufacturing systems.

2.3.3 Experimentation

The third phase began with the kernel that was produced by the investigation phase. This kernel contained the basic idea, that of an iterative redesign approach but it required development and expansion to be capable of dealing with a manufacturing system. To this end experimentation was carried out with the consent of several manufacturing SMEs to hone the raw concept into an applicable methodology. The experimentation took the form of further literature search and action research.

The literature search was to uncover concepts and ideas that could be applied to the problem situation. This reflects the research strategy which was one of 'technology transfer'. It was this that led to the prototyping approach from Pressman (1992) and the organisational perspectives from Leavitt (1972), these proved to provide the two

foundations that would form the new methodology. Chapter 8 describes the considerable work conducted to marry these two disparate ideas into an applicable methodology.

The task of combining these ideas was realised through action research with local manufacturing SMEs. These companies understood that the work was experimental and they agreed to participate, knowing that the high level of researcher involvement would prevent disasters from being visited upon their manufacturing systems. The participating companies were closely involved in the development of the methodology since their feedback on the usefulness, or otherwise, resulted in the next version being deployed.

Although the methodology was developed in the light of the comments received from industry, there was an underlying concern for the maintenance of a sound theoretical basis. Thus considerable was care taken not to completely abandon the original ideas so that their theoretical basis would still prove valid. The theoretical basis for the completed methodology stemmed from the use in industry and the positive results gained not only from the implementation of successful changes but through the experience of those using the methodology.

The principal aim of the Investigation and Experimentation phases was to develop the ideas generated within the realisation phase and to create new theory for the redesign of manufacturing systems (Kemmis & McTaggart, 1982). This was to be carried out in concert with the participating companies that would be looking for tangible benefits. There was a strong ethical consideration in that all the businesses involved were engaged in a mutually agreed framework for extending current knowledge whilst working towards a better manufacturing system (Bassey, 1995).

2.3.4 Validation

Given that the methodology had been developed through action research, it is difficult to separate the methodology from the delivery mechanism, namely the researcher. To achieve this separation a validation phase was included to ensure that the methodology in its completed form could be used by companies that had not been participants in the

experimentation. For this purpose case studies were initiated where the host companies undertook a period of manufacturing systems redesign using the methodology.

The involvement of the researcher was significantly reduced in comparison to the action research phase to enable more a objective analysis of the methodology by the companies. Accepting that manufacturing systems redesign is highly complex and requires many skills and perspectives to achieve, support was provided to ensure full understanding of the methodology. Beyond the introduction and explanation, the actual implementation of the methodology was not interfered with.

2.4 Conclusion

This chapter has laid out the philosophical foundations upon which the research was conducted. These foundations are located between the extreme views of the existentialist and realist in that knowledge needs to be transferable, which implies some external reality that may be discussed, and an acknowledgement of the perceptions of others and the lack of axiomatic laws governing organisational change. This ontological stance then leads to an epistemological position that is akin to interpretism and a methodological approach that favours triangulation, qualitative data, researcher involvement, formulation of theories and the transfer of knowledge between parties. This philosophical grounding supports the four phases through which the research has progressed and the techniques adopted at each phase have been in keeping with the underlying philosophy of the research. Those techniques were the use of Participative Observation, Action Research and Case Study research methods. In a similar vein the resulting manufacturing systems redesign methodology reflects the philosophical basis from which it was derived.

3. An Understanding of Manufacturing Systems

In this chapter the concepts that form the basis of systems thinking will be explored, thus providing an understanding of manufacturing systems that is separate from the physical representation of any particular instance of a manufacturing system. This understanding will suggest the scope that a systemic methodology for the redesign of manufacturing systems should cover. It is not the aim here to provide a definition of a manufacturing system but rather to suggest issues that a redesign methodology should be capable of dealing with. It will be up to individual implementations of the methodology to consider the particular manufacturing system that is being redesigned.

3.1 Systems Complexity

Systems thinking grew out of a desire to consider increasingly complex groupings of elements (Bertalanffy 1968). These groupings display a hierarchical nature in complexity terms. This was noted by Boulding in 1956 when he proposed an Informal Survey of Levels in the Hierarchy of Systems (Table 3-1).

While this might not be a logical hierarchy, it is suggested that it is highly intuitive (Bertalanffy 1971). Examining the table one can see that, in general, systems of greater complexity (those nearer the bottom) are composed from those of lesser complexity. Examples of this would be systems that are comprised of clockwork mechanisms, animals of cells and socio-cultural systems of people. It should be noted, however, that the lower order systems are not pre-requisites for higher order ones. The hierarchy is useful here in that it provides a good illustration of the relative complexity of different systems. It also introduces the concept of hierarchy within systems and that a system may, in itself, be a collection of less complex sub-systems.

Level	Description and Examples	Theory and Models
Static structures	Atoms, molecules, crystals, biological structures from the electron microscope to the macroscopic level	Structural formulas of chemistry; crystallography; anatomical descriptions
Clock works	Clocks, conventional machines in general, solar systems	Conventional physics (Newton and Einstein)
Control systems	Thermostat, servo-mechanisms, homeostatic mechanism in organisms	Cybernetics; feedback and information theory
Open systems	Flame, cells and organisms in general	a) Expansion of physical theory to systems maintaining themselves in flow of matter (metabolism) b) Information storage in genetic code (DNA) Connection of (a) and (b) presently unclear
Lower organisms	'Plant-like' organisms: increasing differentiation of system (so-called division of labour); distinction of reproduction and functional individual (germ track and soma)	Theory and models almost lacking
Animals	Increasing importance of traffic in information (evolution of receptors, nervous systems); learning; beginnings of consciousness	Beginnings in automata theory (S-R relations), feedback (regulatory phenomenon), autonomous behaviour (relaxation oscillations), etc
Man	Symbolism; past and future, self and world awareness, etc., as consequences; communication by language	Incipient theory of symbolism
Socio-cultural systems	Populations of organisms (humans included); symbol-determined communities (cultures) in man only	Statistical and dynamic laws in population dynamics, sociology, economics, possibly history. Beginning of a theory of cultural systems
Symbolic systems	Language, logic, mathematics, sciences, arts, morals, etc.	Algorithms of systems (e.g. mathematics, grammar); 'rules of the game' such as in visual arts, music, etc.

Table 3-1 Boulding's Hierarchy of systems (1956)

3.2 Classification of systems

Since Boulding's hierarchy of systems work has continued in developing a classification of systems. The nine levels have been reduced to a set of five classes by Checkland (1981). These are respectively: natural, designed physical, designed abstract, human activity and social and cultural.

Natural systems range from plants and animals to the ecosystem of planet Earth to the motion of the planets and stars. They evolved over time without the express design

activity of mankind. Designed abstract systems are the collection of concepts that we use to achieve certain objectives; language and mathematics are designed abstract systems. Designed physical systems are things that have been designed and manufactured by mankind. Human activity systems (HASs) are groups of people acting in concert to achieve a common goal. Social and cultural systems are the wider manifestations of designed abstract systems. Of particular interest to the investigation of manufacturing systems are Designed Physical and Human Activity Systems.

Designed Physical systems are typically described using logical Designed Abstract systems such as mathematics. Their behaviours are governed through laws of physics and can be predicted given known initial conditions. While they may demonstrate complex behaviour, that behaviour can be predicted using sufficiently sophisticated models of the system. The HAS is a collection of people working together towards a common goal, such as the supply of goods for customers. As such their behaviour will not demonstrate the mechanistic cause-effect relationships found in Designed Physical systems. The HAS is described through language and is full of ambiguities. Checkland (1981) states that the HAS does not really exist at all except in the perceptions of those within the HAS. Both Human Activity Systems and Designed Physical Systems may be found in manufacturing systems but are present as sub-systems. To redesign the manufacturing system systemically requires both designed physical and human activity to be accounted for.

The design of machine tool routes, processing time for automated equipment, Bills of Material generation and such like are extensions of HASs and can be modelled and designed using traditional, largely mathematical, techniques (Burbidge 1971; Checkland 1981; Gallagher & Knight 1986; Wu 1994). This approach is well covered in the literature and there is continuing interest in developing these approaches further (for example; Gravel *et al*, 2000; Phillis et al, 2000; Santos *et al*, 2000).

Once human interactions are included in the manufacturing system (Brown *et al* 1996; Checkland & Scholes 1990; Hill 1984; New, 1998; Porter 1980; Schonberger, 1986;

Shingo, 1989) then the resulting human activity system cannot be analysed or re-designed using the same tools and techniques as the DPSs (Checkland 1981). There is also continuing interest in developing manufacturing systems as social systems (Lee *et al*, 2000) though work is less widely available. Until recently there have been few example of a truly systemic approach to manufacturing systems redesign (Childe *et al*, 1993; Childe *et al*, 1996; Maull *et al*, 2000; Smart *et al*, 1996).

3.3 *Systemic Thinking*

Bertalanffy (1971) has identified the concepts that are now generally thought of as systemic thinking in the philosophical writings of Leibniz (1646-1716). These concepts were developed out of a realisation that the reductionist approach to problem solving was incapable of coping with the increasingly complex machines being proposed. The field of biophysics suggested an approach that has developed into the concept that we now recognise as systems thinking (Bertalanffy, 1971, Checkland & Haynes 1994).

While parts of an organism might be considered to be in equilibrium, the organism cannot be considered such. The organism is not a closed system but has material transfer across its boundaries. Bertalanffy clearly identifies the requirement of systems to interact with their environment. Bertanlanffy builds his ideas up to describe a general open system upon which the history of systems thinking is based. Systemic thinking is then the consideration of the body as a whole, of the hierarchy of sub-systems that are contained within the boundary operating together to display some emergent properties that fulfil the system's objectives.

3.3.1 Boundary

A fundamental feature of all systems is the concept of a boundary that defines the elements that are part of the system as being separated from an environment that is outside the boundary. A designed physical system (Checkland, 1981) has an obvious boundary in the physical manifestation of the phenomenon. A vehicle has a physical 'outer limit' within

which are the components that constitute the system that we recognise as a vehicle: prime mover, drive chain, guidance mechanism, supporting chassis, load carrying area. Human Activity Systems (Checkland, 1981) have less obvious but no less real boundaries that serve to differentiate those within the human activity system from those outside or within the community at large.

A direct result of boundaries is the concept of the environment that the system operates within. If the boundary defines everything that is within the system then everything else is the environment. It is the interaction between the system and its environment that differentiates between closed and open systems (Bertalanffy, 1971). In this thesis we are only concerned with open systems, that is, those that interact with their environment.

3.3.2 Hierarchy

A system may be regarded as a collection of elements, within a conceptual boundary, that act together to achieve some purpose (Bertalanffy, 1971, Checkland, 1981). Within this system of co-operative elements it may be possible to identify groupings of elements that act in concert towards some part of the system's objective. These sub-groupings may be considered as systems in their own right, where their environment is the major system under investigation. This feature is central to understanding systems (ESPRIT 1993, IEE 1993). This allows us to consider sub-systems within the whole system without reducing the problem to component elements and losing a view of the emergent properties.

3.3.3 Emergent properties

The behaviour of the system is a function of the interaction of sub-systems, and elements, and cannot be deduced from the sub-systems, or elements, themselves (Bertalanffy, 1971, Checkland, 1981). This is a vital concept in the domain of systems analysis since it invalidates reductionism as an approach to understanding systems. The

system has to be considered as a whole, the objective of the system is separate from the objectives of the sub-systems and is achieved through the interactions of those sub-systems.

If you were to disassemble a piano into its component parts and consider each in turn you would not be able to deduce from a piece of piano wire that the designed physical system was a concert grand piano. Even knowing something of music and piano construction would not enable you to predict the sound produced when a particular key was pressed. The systems contention is that even with all the components available, it is not until they are correctly assembled that the final output, in this instance the clarity, timbre, tone and duration of the note, becomes apparent. If we add to this piano a pianist, string, brass, woodwind, percussion and conductor, how from the performance of the pianist in isolation can the atmosphere of the orchestral performance be determined?

There is a tension within systems analysis in that understanding whole systems is a highly complex task with interrelationships resulting in behaviour that is impossible to model using conventional mathematical models. It is far easier to reduce the system down to component parts and sub-systems, optimise those and then build the system back up but in doing so the danger is that the performance of the final system is extrapolated from the performance of a component, much like the piano and orchestra above. It is important to realise that the performance of a system relies on the interactions between all the component elements, whether sections of the orchestra or the elements of a manufacturing system.

3.4 Manufacturing systems

These three features; of components within a boundary, hierarchy and emergent properties, provide us with a definition of a system as: '...*a set of elements connected together which form a whole, this showing properties which are properties of the whole, rather than properties of its component parts*' (Checkland, 1981). We can adopt a view of a manufacturing system as consisting of integrated wholes with interacting sub-systems

that produce a transformation that defines the manufacturing system (Parnaby, 1979). Archer (1974) suggests that the design of such a phenomenon must be an embracive activity considering all the sub-systems and interactions rather than a reductive one considering the elements in isolation.

This manufacturing system will contain elements that are not manufacturing machines, there will be administrative elements to manage the information and people to ensure that the system operates as a whole (Parnaby, 1979). Checkland (1981) identifies this shift from a Designed Physical System (DPS) to a Human Activity System (HAS) by suggesting that the direct causal relationships that apply for DPSs do not apply for HASs. The DPS may be described using a logico-mathematical language which provides a predictive element whereas the HAS cannot be described thus (Dery *et al*, 1993; Wilson, 1992)

3.4.1 Boundary

The influence of systems thinking is becoming apparent in emerging definitions of the Manufacturing System. All investigations into manufacturing systems seem to utilise boundaries, either stated (Hill, 1983; O'Sullivan, 1994) or unstated (Bennett, 1986; Wu, 1992). Different authors adopt different criteria for laying out their boundaries.

Where the boundary is tightly focused on the mechanics of cutting metal, transporting parts and communicating production data the methodology becomes highly specific (for example; Gallagher & Knight, 1986; O'Sullivan, 1994; Parish, 1990; Singh & Rajamani, 1996; Wu, 1994). The use of computers to carry out the analysis and management of the system is heavily touted, as is the requirement for complementary data systems. This reflects the largely designed physical nature of the system under investigation.

As the boundary is relaxed to include HASs the methodology becomes less specific (Bennett, 1986; Burbidge, 1971). The wider boundary enables more aspects of the business to be encompassed, typically business reporting, strategy considerations and integrating

functions. While writers acknowledge the existence of humans within the manufacturing system, they still use 'hard' approaches.

Where the boundary is wide (Brown *et al* 1996; Checkland & Scholes 1990; Hill 1984; New, 1998; Porter 1980; Schonberger, 1986; Shingo, 1989), the methodology is understandably general. The aim here is to integrate the human activity system of manufacturing with other HASs throughout the business. The perceptions of those within the business (Checkland & Scholes 1990) are taken into account as being central to the issues that are being addressed at this level. Organisational issues are considered before technological issues (Duimering *et al*, 1993). While the Toyota Production System (Shingo, 1989) and World Class Manufacturing (Schonberger, 1986) are aimed at the production system and are frequently reported as being technological in approach, (Kozma, 1986; Lotenschtein, 1986), their implications are more wide reaching.

Setting the boundary wide and encompassing the whole value chain (Barker 1994) may have merit but this is not really considering the manufacturing system of an SME. Likewise, adopting a tight boundary definition will reduce the scope of the design problem but leaves open the argument that a truly systemic approach is not being followed. A boundary with medium scope will include factors that are beyond the purely mechanistic elements of the machine floor yet will not blossom uncontrollably into the design of a complete value chain.

3.4.2 Hierarchy

The manufacturing system operates within a hierarchy that contains other systems within a single business or value chain that bounds the environment that the manufacturing system interacts with. Just as there is no fixed boundary for the manufacturing system, nor is there a defined hierarchy. The individual business will have to determine its own manufacturing system and the extent to which it contains elements of the business. There will always be other systems operating within the business and there will be sub-systems

within the manufacturing system. These sub-system should be considered as such and analysed accordingly.

3.4.3 Emergent Properties

The emergent properties should be aligned to the business strategy and contribute towards the achievement of that strategy. The achievement will not be accomplished by the manufacturing system alone but through interaction with other systems within the business. In general the emergent properties of the manufacturing system will be the conversion of raw materials into products that can be sold to customers or the provision of services or similar. The exact objectives of the manufacturing system will depend upon the individual company but should be distinguishable from the business objectives while contributing to them.

3.5 Approaches for the Social element

While work has been carried out on the social elements within organisational systems (Armstrong & Dawson, 1989; Huczynski & Buchanan, 1991; Senge, 1990), this work has largely not been incorporated into manufacturing systems design or redesign methodologies. Modern research into social implications can be traced back to two fundamentally opposed approaches that emerged between 1870 and 1930, those of 'Scientific Management', championed by Fredrick Taylor (1911) and 'behaviourist' led by Elton Mayo (Armstrong & Dawson, 1989; Bennett 1986; Graham & Bennett, 1989; Huczynski & Buchman, 1991; Roethlisberger & Dickson, 1939).

One of the fundamental objectives of the Scientific method was to plan human variability out of the production process through the use of the manager's superior intellect (Taylor, 1911). The human element was treated as any other machine which would react in the same manner as all machines. One had only to programme it, maintain it and it would work at full capacity for the greater good. While the work carried out at the Hawthorne Works (Roethlisberger & Dickson, 1939) did not provide a frame for explaining or

predicting human behaviour, it did show that the logical approach of the Scientific method was also insufficient for predicting human performance in the workplace.

Stuart (1995) has conducted an expansive and detailed consideration of organisational change and how it has developed from the work of Mayo and Taylor. Stuart identifies a terrain map that describes the 'regions' that people travel through during a period of organisational change. Stuart does not present the map as a route for guiding people through change but as an aid to understanding the process of change so that the '...thoughts, feelings and behaviours' (Hodgkinson & Stewart 1991) might be rationalised in the wider context of organisational change. Stuart further describes the journey through his terrain map as being an unfolding process rather than a series of discrete events (Spencer & Adams, 1990). The steps on that journey are neither distinct or separate, thus phases and components emerge, unfurl, move into the foreground and recede into the background as the journey progresses (Parkes, 1986; Hodgkinson & Stewart 1991). It is even suggested that one person may simultaneously be at more than one point on their journey (Kubler-Ross, 1973) and may even be on more than one journey concurrently (Spencer & Adams, 1990).

What Stuart (1995) has made clear through his writing is that the process of change as experienced by people is far from linear or simple. The prospect of developing a plan to conduct even a single person through such a process is unrealistic (Stuart, 1995) much less a whole organisation of people. The durations that individuals will spend in the regions will be different (Parkes, 1986) as will their transitions between regions (Cotgrove *et al*, 1977). This ability for individuals to move around the terrain map suggests a requirement for a more flexible approach to considering organisational change.

3.6 Systemic consideration of manufacturing systems

Archer (1974) summarises good design as '...*wholistic design, in which all functional, cultural, social and economic interests of all those who are directly or indirectly touched by it are enriched as much, or impoverished as little as human ingenuity*

can contrive.' He goes on to emphasise that good design can only be '...*conceived as an element in human interaction, and it can only be assessed in mutual discourse.'* (Archer 1974). This description of good design touches on many aspects that are central to systemic thinking. Given that we have Designed Physical Systems and Human Activity Systems within the manufacturing system we need a frame with which to consider the manufacturing system systemically. Harold J Leavitt proposed in 1972 that there was more than one perspective that could be utilised to consider the phenomenon of an organisation. He identified those perspectives as structure, people, technology and task (Leavitt, 1972) and traced the development of those perspectives through the work of Taylor and the Scientific management school, industrial engineering, participative management and the *'brave new world of information management'*. The idea of different perspectives through which to consider an organisation has since gained much popularity.

Buchanan & Huczynski (1997) cite the Leavitt model as one of two principal concepts of classical organisational structural theory, the other being McGregor's Theory X and Y (1960). While McGregor's suggests that organisations adopt simplistic perspectives of their people as being either lazy with personal goals that run counter to those of the organisation (Theory X) or mature and self-motivated (Theory Y), the Leavitt work provides a more balanced and useful structure with which to consider organisations.

In considering organisational culture, Handy (1993) briefly describes the work of a McKinsey group that developed a 7-S's model of organisational culture based around a 'cold triangle' of Structure, Strategy, Systems, and a 'warm square' of Staff, Superordinate goals, Skills and Style. There is a close correlation between this model and Leavitt where Structure, Staff and Skills map directly onto Structure and People. Technology on the Leavitt model is dealt with through Systems while Tasks are covered through Superordinate Goals, though this is a less direct comparison. While Strategy is not directly dealt with through Leavitt's model, Child (1972) sub-divided organisational strategy into four components covering the scale of operations, technology, structure and 'Human

Resources'. Rollinson *et al* (1998) attribute the systems model of organisational change to Hellriegel *et al* (1989) whose model shows a clear lineage to Leavitt's but with the addition of strategy to the previous four elements.

3.6.1 Structure

Handy (1993) suggests that organisational culture has an intimate relationship with structure, although he points out that it is not a direct causal link. In considering the cultural phenomena that develop within organisations, Handy identifies four distinct types that he categorises as: Power, Role, Task and People. Each has its own particular strengths, weaknesses and associated features that reflect on authority, responsibility and decision making pathways.

3.6.2 People

In considering the people perspective the business is looking at the skills, competencies, morale and degree of job satisfaction experienced. Moving to a team based culture, developing inter-personal skills and trust within the work place would all be representative of a people focussed approach. Skills and competency matrices could be used to identify education and training opportunities. Developing a more open management style will help build trust.

3.6.3 Technology

Technology is frequently assumed to mean information technology and the control that it provides for the organisation. This can make a dramatic impact upon the workplace but so can new machinery. Included in the technology perspective are considerations of information and control over the organisation. These are increasingly linked to the information technology systems that are implemented and are thus included in the technology perspective.

3.6.4 Task

In considering a task perspective the business is looking at what activities it carries out, whether manually or through technology. This allows the business to identify those activities that are important and those that are no longer relevant. Activity modelling is frequently used to develop understanding within a business of their activities and how they link together to form a business process.

3.7 Conclusion

It has been shown that manufacturing systems are complex assemblies of Designed Physical and Human Activity sub-systems. The conflicting requirements of these different classes has led to redesign approaches that, while extensive and internally valid, only cater for one at a time. What is required is an approach that caters for both classes found within the manufacturing system and, moreover, helps the user to appreciate the existence of those different sub-systems.

In considering manufacturing systems, we are considering a system with Human Activity and Designed Physical sub-systems. This has important repercussions in determining the design methodology that is adopted. It will be shown elsewhere that there are many design strategies dependant on the design problem. It is proposed that a design strategy that is applicable for a system of certain complexity, say clockworks or control systems, might not be suitable for systems of higher complexity.

The four perspectives of Leavitt provide a frame for considering the manufacturing system without having to abstract the sub-systems and specify which class they belong to. The perspectives allow the same issue to be considered as part of either a Designed Physical or HAS without the user having to specify which. This reduces the analytical demands on users and enables them to concentrate on the problem of redesigning the system in front of them.

4. Understanding SMEs

This chapter will use literature references to establish an understanding of Small to Medium sized Enterprises (SMEs) and their distinguishing features when compared to larger organisations. From this will be drawn a series of requirements that a new methodology should seek to fulfil. It is not the aim here to develop a new and innovative appreciation of what it is to be an SME, rather a general understanding is sought so that a suitable methodology may be proposed. When current redesign methodologies are considered elsewhere in this thesis, reference will be made to the understanding developed here.

Within the current UK manufacturing environment, SMEs (companies with less than 250 employees) account for 99.8% of businesses, 56.5% of employment and 54.5% of total business turnover (DTI, 1997). This indicates that the applicable domain for work focusing on the SME community is both considerable and varied. It is contended here that, while varied, these SMEs have distinct characteristics that distinguish them from larger organisations and that these differences go beyond the simple consideration of employee head count. These distinguishing characteristics will have profound implications on attempts to conduct manufacturing systems redesign and are thus worthy of study in this document.

4.1 An introduction to the SME

Large and small firms have been identified as being fundamentally different by Penrose (1995). She uses the analogy that while caterpillars and butterflies are manifestations of the same creature they cannot be meaningfully compared with each other as the differences are too great. In considering the implementation of Total Quality Management (TQM), Ghobadian and Gallear (1997) conduct a comprehensive review of literature regarding the implications of organisational size. In particular they suggest that there are '...*significant structural differences between SMEs and large organizations,...*'

(Ghobadian & Gallear, 1997, pp127) and go on to identify six concepts from literature that may be related to organisations. The concepts relate to: structure, procedures, behaviour, processes, people and contact.

In considering the effect that size has on organisational structure Ghobadian and Gallear suggest that larger organisations will have many hierarchical management layers whereas the smaller firms will be flatter. It is suggested by Younger (1990) that this flatter structure results in a more flexible working environment, though the potential for increased interpersonal conflict is presented by Ghobadian and Gallear in counterpoint to this argument. Further consideration of the differences relating to organisational size highlights features such as management visibility and distance from point-of-delivery, the number of interest groups, cultural diversity and speed of response to the environment.

In total over 40 such characteristics are identified by Ghobadian and Gallear and are presented in a table describing how large organisations might differ from smaller ones. There is no attempt to suggest that, for example, being a large organisation imposes the requirement to display bureaucratic behaviours or that being small produces a unified culture. The table is distilled down to seven concerns that are likely to result in increased resistance to change in larger organisations:

1. the existence of a large number of different interest groups;
2. the prevalence of a strong departmental and functional mind-set;
3. the presence of a significant degree of cultural diversity and cultural inertia;
4. the existence of a high degree of standardization and formalisation;
5. the number of employees involved;
6. communication difficulties;
7. potentially high degree of unionization.

This would seem to suggest that implementing change, and TQM in particular, suffers significantly less resistance in SMEs than in larger organisations. Ghobadian and Gallear balanced this through the identification of 'resource paucity' as the most serious disadvantage faced by the SME considering implementation of TQM. The term 'resource' is used in its widest sense to cover not only financial resources but those of knowledge,

technical expertise and management time. This would suggest that an approach that would be successful with SMEs should have an explicit concern for resource sensitivity.

Two further points are made by Ghobadian and Gallear regarding the difficulties that SMEs encounter in implementation of TQM: the lack of formal review procedures (Bridge *et al*, 1998) and an unsystematic management style (Paper, 1998). Both these features may be explained through the resource paucity that SMEs find themselves suffering from (Bridge *et al*, 1998; Gibb, 1997; Welsh & White, 1981; Yusof, & Aspinwall, 2000). To reduce the level of committed resources, Gieskes *et al* (1999) identify that a focused approach to change is valuable in developing continuous improvement programs in SMEs.

In a further attempt to understand the differences between SMEs and larger organisations, we may consider the work carried out by Penrose (1959) and built upon by Wynarczyk *et al* (1993) where three central issues are developed in which small firms are different to large ones; innovation, uncertainty and firm evolution. These will each be considered in more detail and with reference to other literary examples of the same issues.

4.2 Innovation

Storey (1994) sees the role that innovation plays in small firms as stemming from their position in 'niche' markets where smaller firms are able to provide a marginally different product or service to that offered by larger businesses (Dodgson, 1985). Joyce *et al* (1990) identify a concept of 'niche hopping' whereby small businesses will take a moderate set of skills and apply them to different niche markets as they arise. This allows for rapid innovation without massive investment. Storey (1994) futher identifies a relative lack of basic research and development as being a feature of small businesses, however, small businesses are seen as being more likely to introduce fundamentally new innovations than large firms (Pavitt *et al*, 1987). This innovativeness may stem from the ease with which face-to-face communications throughout the organisation may be maintained as suggested by Lee *et al* (2000).

4.3 Uncertainty

Storey (1994) argues that small firms are subject to greater external uncertainty and greater internal consistency of motivation and action than large firms. The external uncertainty stems largely from the relatively large size of many customers of small firms, which gives the small firms little bargaining power with their customers. This in turn leads the SME to be more reactive to the business environment than their larger siblings (Siropolis, 1997) thus in a business environment that is more turbulent an SME will have to redesign itself more extensively and frequently than a larger business. Joyce *et al* (1990) suggest that one coping mechanism to deal with external uncertainty is the phenomenon of *'niche hopping'*. While each niche may only provide temporary respite, the ability to keep 'hopping' ensures the survival of the company.

The close relationship between the business and the owner is identified as being responsible for the greater internal consistency (Westhead & Storey, 1996; Wynarczyk *et al*, 1993). This has a resonance with the greater degree of cultural consistency and improved communications found by Ghobadian and Gallear above (1997) and is reflected in Bridge *et al*'s (1998) findings that SME's tend to be culturally uniform with that culture matching the personality of the owner-manager.

4.4 Firm evolution

The evolution of the small firm is usually seen in the context of it becoming a larger firm (Storey, 1994) and in this context there are many stage changes. These stage changes affect the role and style of management and the structure of the organisation (Scott & Bruce, 1987). Storey (1994) argues that the key point is that small businesses are more likely to be in a state of change than larger ones. Penrose (1995) suggests that this growth is usually both in turnover and employee levels and as such represents a greater rate of change than experienced by larger firms. Welsh and White (1981) assert that in addition to

an SME being more likely to be in a state of change through growth, that rate of growth is likely to be greater as a percentage of firm size than for a larger organisation.

4.5 Change Inhibitors

Several issues have been raised concerning the reluctance of SMEs to carry out change (Joyce *et al*, 1990; Ghobadian & Gallear, 1997; Scott *et al*, 1995). These highlight the fact that techniques suitable for large companies are not suitable for smaller companies (Ratcliff, 1997). Smart *et al* (1996) have used the categories established by Mount *et al* (1993) to divide their sample in to five groupings; Owner Operated, Transitional to Owner-Managed, Owner-Managed, Transition to Emergent-Functional and Functional. The common issue that Smart *et al* (1996) were able to establish across all categories was the '*...need for more resources, better skills and expertise, together with greater knowledge.*' The other issues that were raised were largely due to personalities within the businesses surveyed. In particular the reluctance of the MD to relinquish power over the business has been identified as an inhibitor to change (Ratcliff, 1997; Ghobadian & Gallear, 1997).

4.5.1 Internal Factors

Storey (1994) identifies the internal factors that affect a small business' ability to grow as being motivation, education and multiple business owners. Barber *et al* (1989) have suggested that these internal factors are the more fundamental considerations in an SME's ability to grow and evolve.

Ratcliff (1997) comments that the pressures that exist on SMEs to carry out the daily management of the manufacturing process do not leave sufficient resources for redesign activities. Ghobadian & Gallear (1997) relate this lack of redesign resource to the 'fire-fighting' approach typically adopted by many SMEs. The mindset of crisis management does not tend to encourage long term consideration of the system within which the manager is operating (Gunasekaran *et al*, 1996).

4.5.2 External Factors

The computerised techniques that some authors on the subject of manufacturing systems redesign espouse are beyond the capability of many SMEs to utilise (Gallagher & Knight, 1986; Parish, 1990; Wu, 1994). Financial constraints are widely reported as being external to the business's ability to influence and a significant constraint on redesign and growth in general (Bridge *et al*, 1998; Cambridge Small Business Research Centre, 1992; Ghobadian & Gallear, 1997; Scott *et al*, 1995; Welsh & White, 1981; Yusof & Aspinwall 2000).

4.6 Redesign Approach

From this understanding of SMEs some suggestions regarding a specification for a redesign methodology for manufacturing systems may be made. It is clear that one of the greatest constraints that SMEs face, financial resources, is an external one over which they have little influence. While a methodology cannot provide influence over external constraints, it should enable the SME to evaluate a proposed change against the available resources so that the business does not overextend itself. For this reason there should be some risk- or cost-benefit assessment to ensure that the resources of the business are equal to the proposed change. This applies for all resources available to the SME: managerial time, managerial skills, technical skills, manpower and money, (Bridge *et al*, 1998; Gunasekaran *et al*, 1996; Julien *et al*, 1997; Marsh *et al*, 1999; Symon & Clegg, 1991; Welsh & White, 1981; Wiele & Brown, 1998).

The twin issues of 'niche hopping' and firm evolution suggest that continuous redesign of the manufacturing system is likely to be a feature of SME existence (Bartezzaghi, 1999; Flynn *et al*, 1999; Grover & Malhotra, 1997; Gunasekaran et al, 2000; Savolainen, 1999). While continuous improvement (CI) is widely accepted in the academic literature, Gieskes *et al*, (1999) have identified that SMEs have difficulty implementing formal CI approaches.

Wiele & Brown (1998) identify the unease that SMEs have with current formal redesign methodologies. In looking at how SMEs adopt TQM, Wiele & Brown cite earlier work that suggests that SMEs are uncomfortable with formal methods (Banfield *et al*, 1996; Ghobadian & Gallear, 1996; Lee & Oakes, 1995; McTeer & Dale, 1994; also Gibb, 1997). Any methodology that is presented to SMEs should not, therefore, appear as a large and complex approach that will lack immediacy of applicability. The uncertainty that SMEs find themselves subjected to implies that a redesign methodology should be capable of rapid conversion of problem situations into solutions and the implementation of those solutions.

4.7 Conclusions

While the external constraints over which the SME has little or no influence cannot be encompassed, a redesign methodology for SMEs should assist the rapid and continuous change that enables SMEs to exist. In providing for this continuously changing environment there should be sufficient structure that the SME is able to manage the change and the associated risks without rejecting the methodology as being too formal or abstract. An ability to focus the change on a particular element of the problem domain will assist in limiting the resource consumption of the change programme and also reduce the loading on the, already over-stretched, management team.

This then provides a skeleton specification for a redesign methodology:

- it should allow focussing of change to minimise resource requirements;
- it should be risk aware to protect those resources;
- it should be iterative to allow quick translation of ideas into results and to react to changes in the business environment;
- it should appear simple yet provide sufficient structure to manage a conceptually complex change.

5. The development of a Redesign Approach

In this chapter an approach for redesigning will be arrived at from reference to literature. The history of design theory will be traced out to show the evolution of design methodologies. From this it will be shown that very similar approaches are adopted in highly disparate fields. This uniformity does not, however, preclude other methodologies from being effective.

There is also a fundamental issue to resolve in that the methodologies presented are largely concerned with design of new artefacts. This is different from redesign of operating manufacturing systems. This difference will be shown here and the requirements for redesign will be identified and the outline of a possible solution proposed.

5.1 What is Design?

Design activity has taken place for many millennia, however, design has only been considered a separable activity since the early 1700s (Archer, 1974; Armytage, 1961; Williams, 1958). Before this there was little distinction between design and manufacture. Indeed, even in the mid 1800's the process of design was often fully integrated with manufacture. The traditional craftsman had a corpus of knowledge built up through years of apprenticeship that allowed him to design and build products for clients.

Traditionally the design activity was intuitive and difficult to verbalise (Sturt, 1923). Design drawings (e.g. Third-rate Ship of 1670: Jones, 1992) were used on large projects for communications purposes but these were a visual expression of the result of the intuitive process required for smaller projects. While the drawings allowed many people to work on the project, there was no study carried out on the best way to produce the drawings.

While little research has investigated the design process in the craftsman tradition, there are two basic stages that can be deduced. The design process begins with an 'incubation' phase whereby the craftsman physically does very little (Broadbent, 1966: in

Jones, 1970). During this period the problem is being 'mulled over' and considered. Experience is used to bound the problem and to develop initial solutions. The second stage involves a 'leap of insight' that leads, very quickly, to the final solution (Broadbent, 1966: in Jones, 1970). This process is almost impossible to teach and develops over many years of trial and error by the craftsman.

5.2 Two schools of thought

The first attempt to teach design, as opposed to fine art, was made in 1823 with the foundation of the Mechanics' Institutes (Naylor, 1971). These concentrated on drawing skills as this was the extent to which design theory had been developed. The actual process of design was still in a craftsman mode of operation with the 'leap of insight' providing the designs that were then expressed through the taught drawing skills. The Institutes were attacked by Augustus Pugin (1812-1852) amongst others as being *'devices to poison the mind of the operatives with infidel and radical doctrines'* (Pugin, 1841: in Naylor, 1971). Pugin considered design, and architecture in particular, as an expression of faith rather than the considered creation of an artefact.

In 1836 and 1841 Pugin published two books that would begin a debate within design for over one hundred years. These were *Contrasts* (1836) and *True Principles of Christian Architecture* (1841). While Pugin can be thought of as the founding father of the Arts and Crafts movement, his was a largely theological battle against: *'the present decay of taste'* (Pugin, 1841: in Naylor, 1971). Pugin was in no way against mechanisation of production but he was vehemently against pagan design rather than the expression of Christian culture. His thoughts were widely read and led directly to the works of John Ruskin (1819-1900), William Morris (1834-1896) and the rest of the Arts and Crafts movement that was to dominate and sculpt design theory until the end of the Second World War (Sedding, 1893).

The South Kensington Circle was concerned with minimising ornament through selecting pure forms. After the Great Exhibition of 1851, in which endeavour Sir Henry

Cole (1808-1882) and his circle of friends were involved, there was much consternation that there was no unity within the designs exhibited. Over the following years the Kensington Circle aimed to educate the manufacturing and design fraternity in the distinction between good and bad design. Cole launched the *Journal of Design and Manufacture* in 1849 to educate manufacturers to distinguish between good and bad design. Cole took charge of reforming the Schools of Design between 1852 and 1873 and instigated a rigid regime of disciplined drawing rather than design (Naylor, 1971).

The Schools of Design were denounced as being misguided and materialist with the Arts and Crafts movement suggesting that: *'Drawing may be taught by tutors, but Design only by Heaven...'* (Cook & Wedderburn, 1912). Ruskin was developing a philosophy for design that extended Pugin's Christian beliefs into a doctrine that railed against mechanisation of any form. Ruskin and the Arts and Crafts movement in general believed that design was more than the exercise in utility of the South Kensington Circle; beauty was necessary to man's survival and well being. Their religious beliefs and desire for designs to be more inspiring led them to an anti-machine stance that identified many real issues prevalent both then and now. Theirs was a philosophy that idealised the craftsman and his intimate knowledge of the material at hand. It was this personal knowledge that allowed the designer to create (Ruskin, 1899: in Naylor, 1971).

Both the South Kensington Circle and the Arts and Crafts movement were concerned with design as an output or artefact. Neither school was considering the concept of design as a process that could be codified and studied in its own right. Indeed the Arts and Crafts movement was philosophically against such a study as the design activity was close to a religious affirmation for them.

5.3 Design as Process

It is only since the mid 1950's that the study of the design process has been undertaken with any academic rigour (Jones, 1992). Design activity may be described as the considered creation of man-made articles (Jones, 1970; Potter, 1989). This makes the

clear distinction between the process of design and the artefact that is produced. Early consideration of the design process was located in the fields of architecture, mechanical and electrical engineering. These fields were concerned with producing physical artefacts. As such they were working to produce tangible outputs which would be presented as completed wholes with no further work required.

5.4 Strategies for design

Without considering the activities that make up the design process we can consider the manner in which those activities are structured as the design strategy (Jones, 1970). Jones suggests that the design strategy may be presented as separate from the activities that constitute the design process, these are chosen at a separate, though unspecified, time. Jones suggests a logical classification of potential strategies into six families; linear, cyclic, branching, adaptive, incremental and random.

5.4.1 Linear Strategies

Linear strategies have clear starting and completion activities. The progression through the activities is sequential and the input for each activity is entirely dependent on the output of the preceding activity (Figure 5-1). The input for any activity is independent of the output of subsequent activities. There is no scope within a linear strategy for iteration or redoing of a previous activity in the light of subsequent activities, decisions or observations. Examples of this type may be found in many areas of design theory e.g. Borenstein et al (1999), Davenport & Short (1990), Rao & Gu (1997).
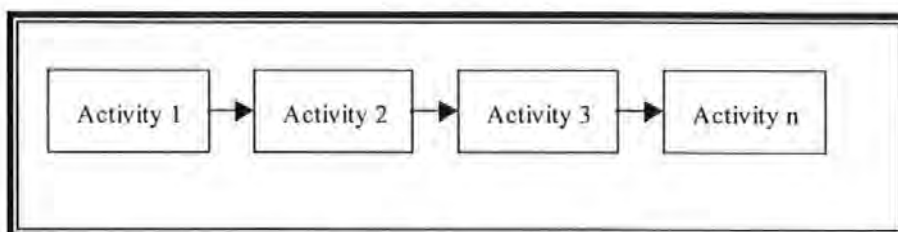
Figure 5-1 Linear Design Strategy

5.4.2 Cyclic Strategies

Cyclic strategies occur where an earlier stage has to be repeated after the output of a later stage becomes known (Figure 5-2). Jones acknowledged that there may be more than one feedback loop in such a design strategy. He also identifies a 'vicious circle' in which the designer gets caught in such a loop and cannot break out. Knowles et al (1969) saw design as essentially open loop with many iterations being required both within and of the design process to ensure that a suitable solution is found. A similar stance was taken by Ramirez (1996) in that the real world design process is not truncated but continues to be propagated by feedback from implementation and in-service use.
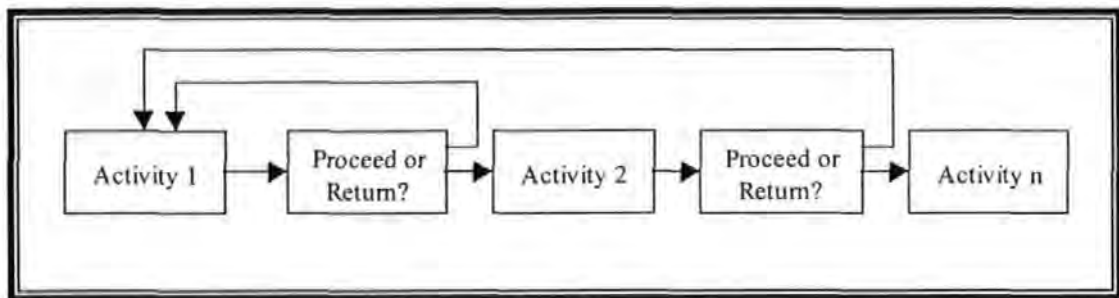
Figure 5-2 Cyclic Design Strategy

5.4.3 Branching Strategies

Where design actions can be carried out wholly independently of each other a branching strategy can be adopted (Figure 5-3). Where appropriate these independent actions might be carried out in parallel depending on resources available. There may be occasion to choose between two or more activities at a stage within the design process. That choice will lead to a branching strategy.
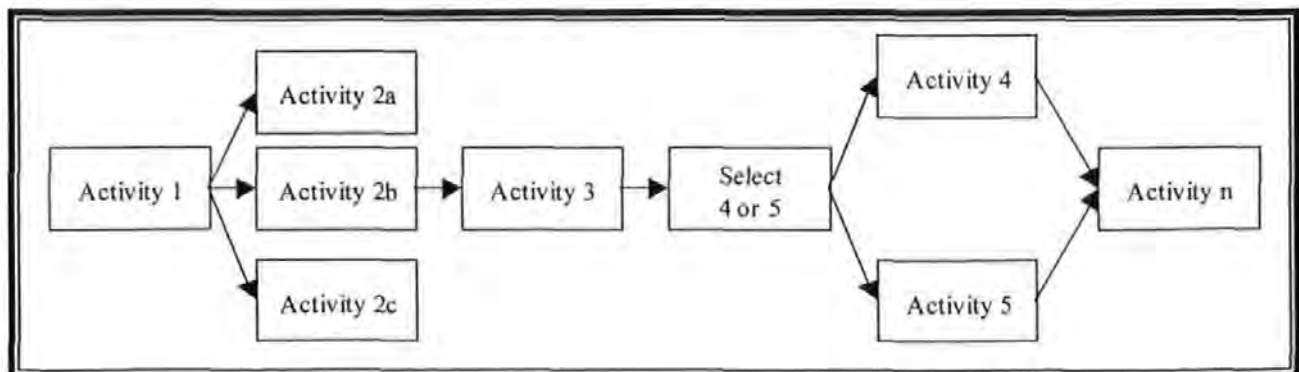
Figure 5-3 Branching Design Strategies

5.4.4 Adaptive Design Strategies

If the design actions are determined throughout the design process then an adaptive strategy has been adopted (Figure 5-4). The output of each activity determines what the next activity will be.
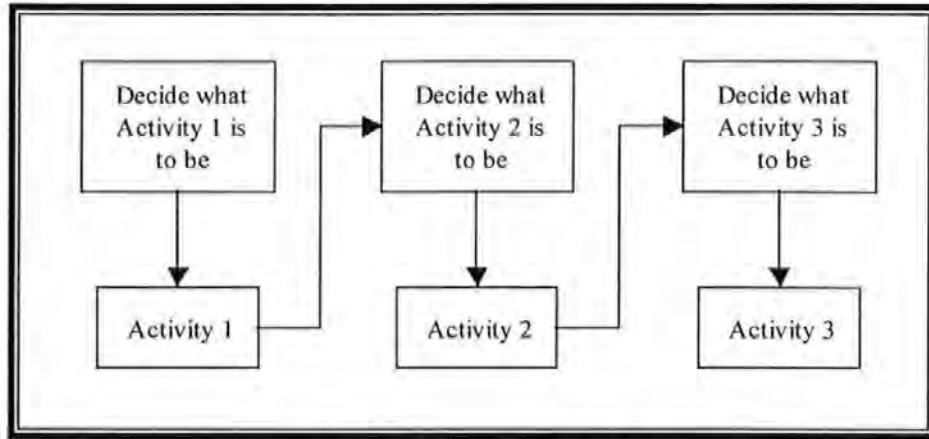
Figure 5-4 Adaptive Design Strategy

5.4.5 Incremental Design Strategies

More modest than adaptive design strategies are incremental strategies whereby a small element of an existing design is altered (Figure 5-5). Jones contends that this is the strategy adopted by most traditional, craft-based practitioners and also represents the procedures for automatic optimisation (Wilde, 1964).
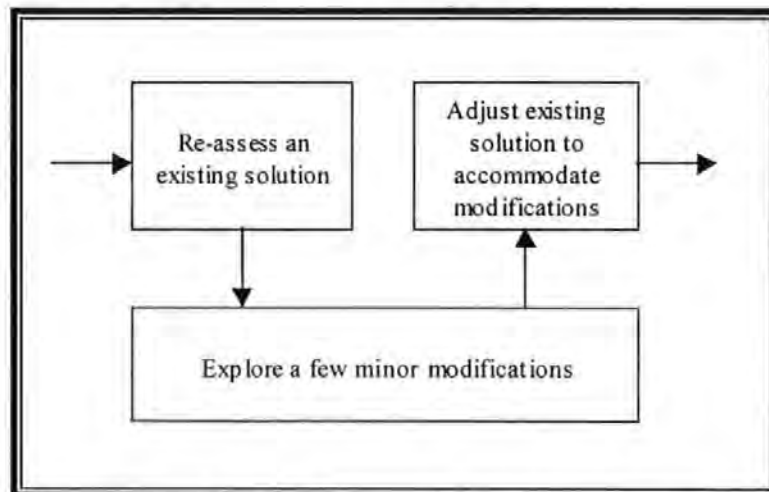
Figure 5-5 Incremental Design Strategy

5.4.6 Random Design Strategies

Jones also notes an approach he calls 'random' in which the designer picks a starting point at random and identifies a solution at that point before moving on to the next

random point (Figure 5-6). While this unplanned approach might seem without merit it can have application when many starting points to a design problem are required. It is closely aligned with brainstorming principles and seems to represent 'fire-fighting' within SMEs as described by Ghobadian & Gallear (1997).
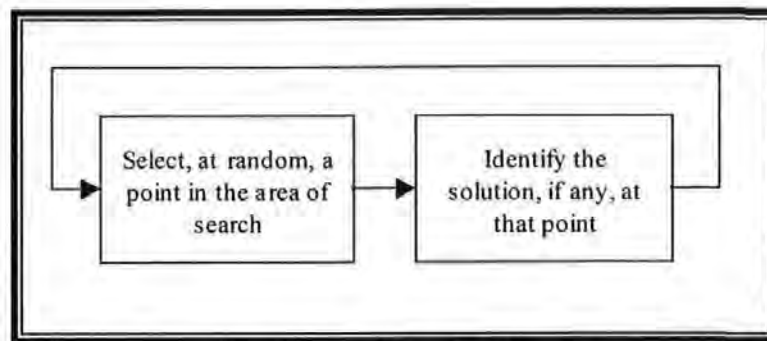
Figure 5-6 Random Design Strategy

5.4.7   Design methodologies

Jones goes on to state that: '*clearly a major objective in design methodology is to make designing less circular and more linear*' (Jones, 1970). This statement is based upon the supposition that circularity, or looping back to an earlier stage, implies that critical sub-processes are discovered too late and lead to revision of major decisions whereas linearity implies that all critical processes have been identified and effectively dealt with before proceeding to the next stage. The principal obstacles to linearity are identified as the unpredictability of the relationships between parts of the problem and the fact that these relationships are variable over time (Luckman, 1967: in Jones, 1970).

Jones suggests that an adaptive strategy whereby research action is carried out before the design exercise to identify the possible sub-processes that might give rise to circularity may lead to a more linear though still adaptive approach. Jones acknowledges that these research actions will add to the expense and duration of the design process but claims that these extra expenses are recovered through less back-tracking and the generation of know-how that may be re-used in future designs. Ramirez (1996), however, contends that this circularity is a feature of the real world since the critical sub-processes cannot all be identified before design begins. In looking at groups as problem solving units,

Larson & Christensen (1993) consider the solution of poorly structured problems to require iterative or circular approaches.

The importance of these design strategies is that Jones is explicitly stating that there are different ways of structuring the design process. Different situations may be more amenable to certain strategies though there is an assumption that linearity is the preferred strategy. It should be noted that these strategies are independent of the activities of the design process.

5.5 Stages of design

Jones (1970) has suggested that a wholly logical methodology does not exist to solve design problems but that this does not prevent solution within the human brain. Jones builds upon the work of Asimow (1962) who identified four stages in design that cover feasibility, preliminary design, detailed design and planning (see Figure 5-7). Jones further describes the planning stage as evaluating and altering the design concept to suit the requirements of production, distribution, consumption and product retirement. It should be noted here that Jones only describes these stages as they relate to linear design strategies. The other strategies have been rejected through his statement in Section 3.4.7 above.
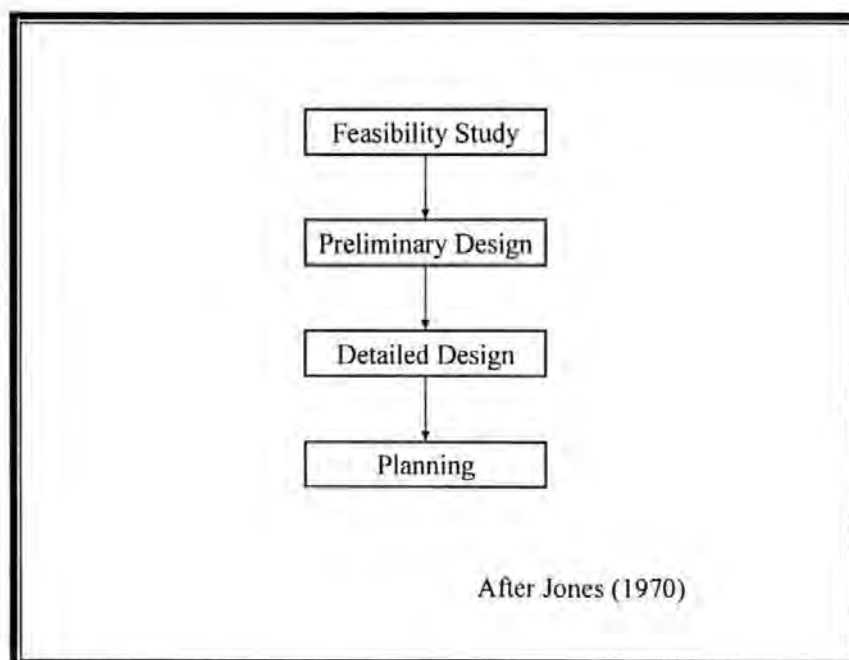
Figure 5-7 The Four Stages of Design

5.5.1 Feasibility

The first stage determines the feasibility of the project. Later authors, (Harrington, 1991; O'Sullivan, 1994; Ullman, 1997; Young, 1986), have further divided this stage in to *identification of need* and *specification of requirements*. It is this stage that determines the nature of the design activity, whether mechanical, electrical, architectural or control systems.

The specification of requirements is particularly important as it is against this that potential designs are compared to determine the 'best' design. A clear and complete specification of the requirements is fundamental to this linear design process. There is a philosophical issue to be raised here that while perceptions (Checkland, 1981) and mental models (Kim, 1993) may be discussed, they cannot be made explicit in a 'logico-mathematical' language (Dery *et al*, 1993). This is the primary reason for the circularity identified earlier. Without this unambiguous statement of requirements there is no way of anticipating potential areas of future conflict.

5.5.2 Preliminary design

During this stage conceptual ideas are drawn up, (Bradley *et al*, 1991; Young, 1986). These are not detailed and may not be practical. The object is to generate ideas from which a suitable solution might be found.

5.5.3 Detailed design

At this stage a design is constructed from those generated during preliminary design and the details are filled in. The specification of requirements is used to determine which designs, or parts of designs, are used. The detail will depend on the field of design activity but will generally extend to documents such as working drawings (Jones, 1970), circuit diagrams (Wobschall, 1987) or building plans (Broadbent, 1988).

5.5.4 Planning

In addition to the activities identified by Jones as planning, this stage often includes, or leads on to, the construction or building stage (Bradley *et al*, 1991; O'Sullivan, 1994; Wobschall, 1987; Young, 1986). It is not until this stage that the whole design is put together and tested.

Several authors (Bennett, 1986; O'Sullivan, 1994; Parish, 1990; Young, 1986), emphasise the requirement for feedback loops within the design process. These are usually shown as taking problems that have occurred in one stage and feeding them back in to earlier stages. While this is seen as a vital element in design, it is a modification to the basic, linear design process as presented by Jones (1970).

5.6 Influence in design

The four stages of Jones are to be found in mechanical (Ertas & Jones, 1993; Ullman, 1997), architectural (Broadbent, 1988; Young, 1986) and electronic design references (Wobschall 1987). It is assumed in these references that they are valid and effective strategies for the design of components and physical systems depending upon application. In this respect their applicability is not questioned within the scope of this thesis.

Theories for the design of manufacturing systems have largely taken the approach advocated for designed physical systems and modified them for the new requirements (Harrington, 1991; Hill, 1984; O'Sullivan, 1994; Wu, 1994). In building upon the work of Waston (1994), Mason-Jones *et al* (1998) suggest that the four stages should be: Understand, Document, Simplify, Optimise (UDSO).

While employing different stages to the model presented by Jones (1970), they are still using a four stage process. These can be related to the setting of requirements, conceptual design and detailed design. Mason-Jones *et al* are less concerned with

implementation though they do give examples of design arrived at using the UDSO process being implemented.

5.7 An alternative design process map

In considering the design problem Lawson (1997) largely looks at architectural design issues. He concedes that there might not be any generalisable design process for all design problems. Lawson arrives at this conclusion by examining the work of Matchett (1968) and Gregory (1966). Lawson tries to use their description of the design process as applied to disparate fields and concludes that there are subject-specific factors that invalidate the descriptions given. Lawson extends the work of Matchett and Gregory into the field of architectural design to discover any universal design process that might be applied to his specific field.
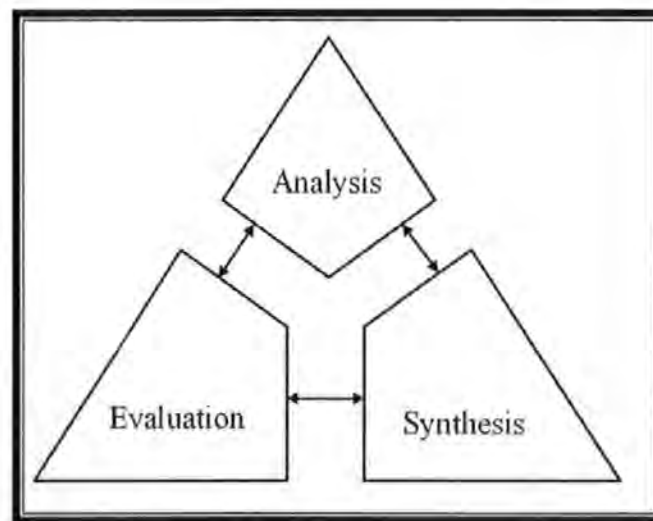
Figure 5-8 Universal Design Process (Lawson 1997)

The proposal is that the designer does not follow any path but simply: '...*put[s] it all together for [himself]*' (Lawson 1997, pp 38). In this manner the designer moves between analysis, evaluation and synthesis with no guiding route map (Figure 5-8). The designer somehow 'knows' when to move between these elements. While this might describe the actions of expert architects it is of little value in providing guidance for others.

In a further proposition on routes for the design process, Lawson (1997) describes what Darke (1978) calls the '*primary generator*'. In this instance the designers make an

assumption about the final design and then tailor the rest of the design process around this initial assumption. Rowe (1987) has also reported this phenomenon and the tenacity with which designers will continue to hold the initial assumption, even after it has been shown to be false. While this suggests that the entirely self governing approach identified by Lawson has a failing, it clearly demonstrates that non-linear design processes are both theoretically valid and applied in practice.

5.8 Design of socio-technical systems

Apart from the similarity that has been shown between manufacturing systems redesign methodologies, they also have a common missing element. There is often little or no consideration of the human factor. The methodologies recognise that social issues are important in the redesign of manufacturing systems but tend not to give those issues much consideration when presenting their design outline. This could be due to the technical genre from which these approaches evolved (Unesco, 1974).

Manufacturing systems have been viewed using a mechanistic model (Gharajedaghi & Ackoff, 1994) which presupposes that the system can be fully understood through analysis. This reductionist approach requires that all the elements in the system be decomposed and the relationships between those elements defined through cause and effect laws. The complexity of manufacturing systems is far greater than that of mechanical, electrical or architectural systems (Pondy & Mitroff, 1979). Meyerson & Martin (1994) propose that organisational change can be though of using three paradigms. These paradigms are characterised as; Integration (Schein, 1985), Differentiation and Ambiguity (March, 1981). Meyerson & Martin argue that any change among and between individuals within an organisation is cultural change. Only the integrative paradigm suggests that organisational change can be designed.

While these concerns stem from the practical issues that arise when attempting manufacturing systems redesign they reflect the desire for a systematic approach. In the field of architecture there is concern that the traditional design theories do not allow

sufficient '*freedom*' for the '*artistic*' nature of design (Young 1986), that the design process is too linear and mechanistic. While there is discussion about the social sciences and ergonomics, there is no suggested design process to replace the four stages presented by Jones in 1970.

Daft & Weick (1994) suggest that organisations should be viewed using a model that describes them as systems that interpret their environment and react accordingly. Daft & Weick go on to make the case that the environment within which organisations exist is not analysable. This means that there is no 'correct' answer to the question of organisational change. The answer will depend on the questions or actions of the organisation. This means that it is impossible, as most current methodologies propose, to plan the route from a current to a desired position because the situation will change *en-route*, a fully linear approach is rendered impractical (Daft & Weick, 1994).

5.9 Design as learning

Design is primarily concerned with creating something new. This means that the designer must begin with an end-state at some point in the future and determine those activities that will lead to such an end-state (Jones 1970). The greater the difference between the current-state and the end-state the greater the number of activities or scale of those activities required to navigate between the two. Since all this activity takes place in the future there can be no way of knowing that all the planned activities will proceed, or have outcomes that are exactly as planned.

To this extent the designer is continually learning about the system that is being designed. Constructivist learning suggests that a learner begins from a base of prior knowledge upon which further experience is integrated (Sticht 1976). This is carried out through a cyclic process such as the (1) Test, (2) Operate, (3) Test, (4) Exit learning model of Millar (1956). This cyclic approach has resonance with the (1) discovery, (2) invention, (3) production, (4) generalisation cycle of Argyis & Schon (1978), the (1) observation, (2) abstract conceptualisation, (3) test, (4) concrete experience cycle of Kolb (1984), the (1)

observation, (2) emotional reaction, (3) judgement, (4) intervention cycle of Schein (1987) and the (1) observe, (2) assess, (3) design, (4) implement cycle of Kofman used by Kim in his model of organisational double loop learning (1993).

Having established a knowledge base (Desforges & Lings, 1998) the new material can be integrated (Ausubel, 1963). The use of the cyclic methods above adds to the knowledge base at each iteration. This in turn leads to greater understanding of the phenomenon under investigation. If we think of the redesign as a voyage of exploration then the constructivist learning paradigm allows us to adopt a fundamentally different approach from that of conventional linear design.

The cyclic learning approach allows us to consider the manufacturing system as an ambiguous social organisation. We cannot know everything about the relationships between individuals but we can learn about their behaviours though experience. We can never consider this learning process complete as the individuals will be constantly developing and the culture of the organisation will develop with them.

It also allows us to consider the system as a differentiated organisation. The environment is fundamentally out of the scope of control of the designer. There is, however, scope for learning about the interactions between the organisation and the environment. A cyclical approach also allows for the modification of the system following changes in the environment. By adopting a design approach there is scope for a planned reaction to the environment. Given that the designer is learning about the environment there is also scope for influencing the environment in the organisation's favour.

5.10 Helical design

As early as 1939, Shewhart had described the need to move from the 'old' way of manufacturing with a linear progression through specification, production and inspection to the 'new' way with a cyclic process. By 1984 Deming had described the cyclic design methodology as being better than the linear model. Deming saw the linear model as having no direct feedback from consumers to the design effort. This is directly supported by

Ramirez (1996) and directly contradicts Jones (1970). In his cyclic, or helical, methodology, Deming describes a process of (1) design, (2) make/test, (3) market and (4) test in service. The results of the service test feed back in to the design process.

After Pressman (1992)
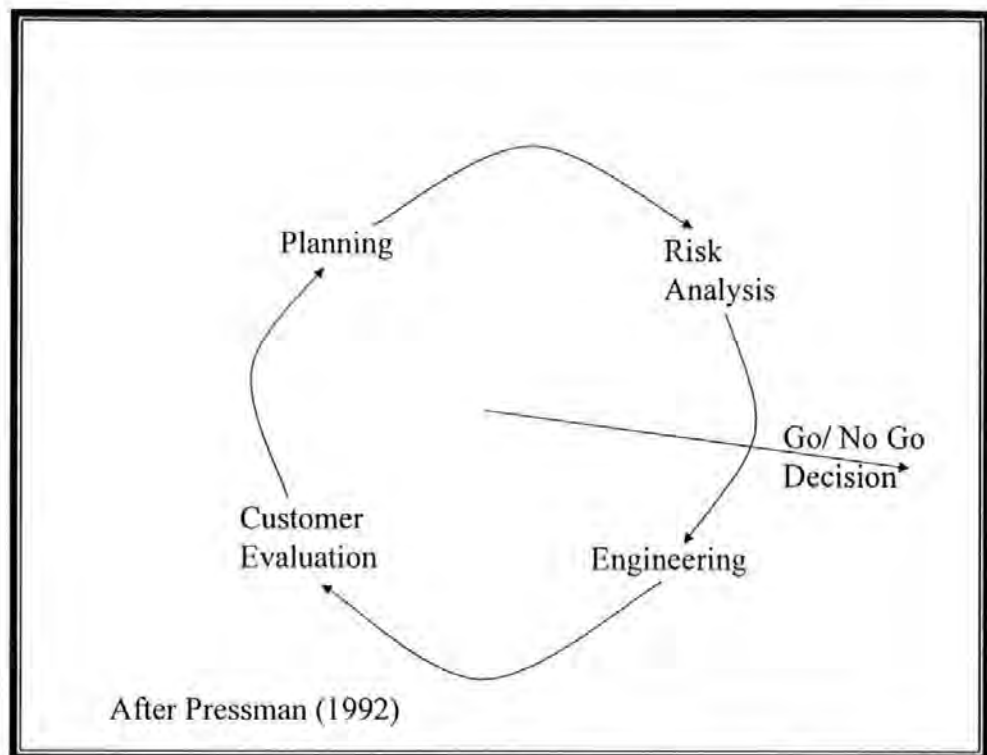
Figure 5-9 Software Prototyping model

Pressman (1992) develops an idea by Boehm (1988) for a spiral design model for software engineering (Fig. 5-9). In this model the stages are identified as being (1) planning, (2) risk analysis, (3) engineering and (4) customer evaluation. The customer evaluation feeds in to the next planning phase. At the risk analysis phase there is a go/no go decision based upon the analysis.

5.10.1 Planning

The Planning phase is to scope out what the subsequent iteration will aim to achieve. Marsh *et al* (1999) dispute the presumption that most production facility change is planned in a single 'big bang' approach, suggesting that an iterative planning approach is the more empirically founded one. Thompson et al (1998) identify the ability to autonomously develop a plan for change as the first indicator of high performance work teams. It is interesting to contrast the spiral approach which begins with planning the

change to the linear approach of Jones (1970) that ends with a plan for change. Boehm (1988) recognises that a perceived difficulty with the spiral model is that is can be hard to match it to existing contract and project planning software. Since each planning phase is primarily concerned with planning that iteration of the spiral, there is no 'whole project' plan. It should be borne in mind that this is an iterative approach and the consideration of 'how much is enough' (Boehm, 1988) will guide the planner in determining the scope of each iteration.

5.10.2 Risk Assessment

Any change carries some degree of risk or cost for the business (Yu *et al*, 2000; Koonce *et al*, 1996). The purpose of the Risk Assessment phase is to identify those risks and determine the probability that the benefits will out-weigh the risks. It should also be borne in mind that many risks will be capable of some reduction or minimisation activity (Boehm, 1988). In planning the change, consideration should be taken of the likely costs of: changing the organisation (Damodaran, 1996; Joyce *et al*, 1990); introducing training (Joyce *et al*, 1995; Sadler-Smith *et al*, 1998); new technology (Lefebvre *et al*, 1996; Marri *et al*, 1998); re-organising activities. These will be estimated costs but they should be sufficiently accurate for the business to be satisfied that they are not undertaking an unduly risky change. This level of perceived risk will be unique to individual businesses. It is this phase that prevents a primary generator from inhibiting the consideration of alternative designs or preventing termination of an unsuccessful change episode (Darke, 1978).

5.10.3 Action

The need for action is stressed in works on organisational development (Buchanan & Huczynski, 1997; Rollinson *et al*, 1998) and skills and training development (Berry, 1993; Douglas, 1999). More than just doing it, the actions and decisions made should be recorded so that they are available for evaluation (Buchanan & Huczynski, 1997; Gieskes et al, 1999; Knowles et al, 1969). Design is a learning activity and, therefore, each iteration

will be constructed upon the learning that occurs during previous action phases (Upton & Kim, 1998; Wemmerlov & Johnson, 2000).

5.10.4 Evaluation

Knowles *et al* (1969) identify the evaluation of results as being key to the closed loop nature of systems design. They go on to suggest that all evaluation consists of subjective consideration and that 'expert' consideration of subjective criteria can be just as valid as 'objective' measurements. Buchanan & Huczynski (1997) suggest that evaluation is so important that it should be carried out jointly between the client and the consultant. Meister (1982) carries out testing and evaluation in parallel with the detailed design stage of his linear approach.

5.10.5 Planning

Having carried out an iteration of the methodology, subsequent planning phases will have a slightly different composition. In addition to the strategic input there will be the results of the evaluation phase. These will lead the questioning on focus and aims for the iteration to come.

Where the evaluation may have identified a change episode that is beginning to lose momentum, it would be appropriate to investigate a different perspective to frame the following iteration. This is a valuable element as it prevents stagnation and self-limiting of the change process.

5.11 Conclusions

The concept of 'design' has come to mean many things since its separation from production at the turn of the 19th Century. The schism between the functional South Kensington Circle and the expressive Arts and Crafts Movement set up the boundaries for discussion about design that has lasted until today. With the advent of increasingly complex mechanical and control systems the desire has been to functionalise and control

the design process. Since the 1950's this has led to the development of linear design strategies to ensure that this degree of control was afforded.

During this developmental phase there has always been a nagging doubt that something was missing. Different writers suggested that the strategies were too prescriptive for designers, or that elements of the problem domain did not fit with the prescribed solution approach. This is reflected in the domain of organisational psychology where the ability to plan systemic changes runs counter to current understanding of the organisation and its relationship with both the environment and itself. This mitigates against a linear approach and suggests an adaptive or circular one. A circular or helical approach has resonance with the domain of constructivist learning theory in that we develop and grow not by planning out what needs to be learnt and then learning it but by adding to an existing knowledge base and using that knowledge base to integrate new experiences.

In a similar manner, redesign is building on an existing structure and integrating new elements into that structure, the relationships between the new and old cannot necessarily be forecast using 'logico-mathematical' languages. The helical method allows a rigorous approach to be allied with checks to prevent unsuccessful primary generators from subsuming a redesign activity. The real world nature of the problem domain further suggests that iterative approaches may be more suitable. Chapter 6 will consider how this approach may be applied to the redesign of manufacturing systems.

6. Initial Observation phase

This chapter sets out the first steps on the voyage of discovery that ended with a new methodology for the systemic redesign of manufacturing systems within SMEs. The chapter describes a period of participant observation within a manufacturing SME and the realisation that no formal redesign methodologies were being used in practice. The nature of this realisation phase was such that no formal plan existed, it was a more intuitive process whereby the current way of working became apparent. At this stage the Research Question was less clear and participant observation afforded an opportunity to observe a highly unstructured problem domain. The need for a research question arose from the observations during this phase of research and the actual question was formulated later during an Investigation phase.

The company provided a suitable environment within which the observations could be made. This chapter will describe the manufacturing system and to show that redesign of that system was being undertaken. The chapter will also show that no planned, systemic or systematic methodology was adopted in conducting the manufacturing systems redesign. (It is not the aim to assess the design or performance of the manufacturing system. No inferences should be drawn on the abilities of those within the system, this an observational study of a system reacting to external uncertainty and developing coping strategies.)

6.1 Company Background

The research began with a two year contract with a manufacturing business based in the South of England. This contract was arranged in partnership with the Teaching Company Directorate (TCD) which has the aim of introducing new graduates into industry. The contract was to redesign the manufacturing system through the development and implementation of automated production equipment. A period of strong growth was

predicted and this would have profound implications on the production facility such that a step change was required.

The programme contained three main projects that were to provide the increased volume to cope with the predicted business situation. In parallel to these flagship projects was the day-to-day running of the manufacturing system and work that was required to maintain and develop current production equipment. It was this general development of the manufacturing system that first drew investigative attention. While the product was relatively simple in concept, the assembly required considerable skill and the central component was of significant importance to product performance.

The company was a manufacturing SME that had been formed in the late 1960's as the electronics specialist within a larger organisation. Since then the business had been operated as a separate concern with no ties to the original company. The business developed new products and expanded into new markets. Considerable expertise had been transferred from the parent company through senior engineers who began to retire, taking their skills with them.

When this research began, the company was predicting a significant increase in product volume and had the desire to introduce new products. Several of the senior management team were experienced engineers but they were concerned with the management of the company and could not devote the time and energy required for such an undertaking. Several key personnel had departed taking key knowledge about the product and the physics governing product performance with them. This left a significant skills gap within the business regarding product design. The manufacturing system had never been formally designed. It had evolved over time as new equipment or business was purchased or acquired.

6.2 The Products

The products in question were reed relays with a reed switch surrounded by a wound coil for activation (see Appendix One). There were a range of switches to choose from and

formers to contain them and support the coil windings. The central reed switch was manufactured under clean conditions that could involve high vacuum and specialised materials in construction. Once manufactured the switch was a sealed unit requiring only leads and an activation coil. Customer demand had led to significant variety within the product range with normally open, normally closed, latching and change-over switches available. There were also different pin pitches and configurations depending on the application and market leading to over 350 possible product lines with up to 150 actively being sold at any one time.

Most of the products had moved very rapidly from conception to production with little time spent developing production versions of samples or the manufacturing techniques required. The whole manufacturing system had grown organically over the years with new products being added as customers requested them and old ones often not removed as customers could return with new orders for old products. The production planning and control system reflected this situation with spreadsheets being used to plan rough daily and weekly build profiles and capacity forecasting based on estimates of operatives required to meet the build profile. Planning was based as much on experience and intuition as upon scientific analysis of production records. Indeed, the detail was not really there for scientific analysis of production times and capacity.

In many respects the manufacturing system was no different to others found in SMEs, it had grown organically with no formal plan. Products had been transferred from development to production quickly to win orders but more thought could have been expended in designing them for manufacture which would have simplified the production process. The scheduling of production was based on a mixture of firm orders and forecasts but with little hard data to back the assumptions up, much was based upon experience and knowledge of the workforce. Furthermore, a constantly changing market demanded that the manufacturing system be improved, upgraded and generally redesigned.

6.3 The manufacturing system

The manufacturing system had evolved through the introduction of new machinery, products and personnel. While there was a general plan to increase volumes and reduce costs, no such plan had been made explicit or the subject of a concerted design effort (Appendix One). New products were conceived from customer enquiries rather than through planned product development or technical innovation. The products were then introduced to the shop floor without clear production plans or manufacturing strategies. As a result the production system for any product was a series of concepts that were at different stages of development. They worked because the operators were able to transfer knowledge between product groups to ensure that the final product met its design requirements.

6.3.1 A people perspective

Leadership of the manufacturing system was shared between two managers with one taking the position of General Manager and the other of Engineering Manager. Both came from engineering backgrounds but now dealt with different aspects of the manufacturing system. Daily production was controlled by a Production Controller who generated build plans and calculated labour requirements based upon production figures passed on by the General Manager. Issues concerning purchasing and future labour requirements were dealt with by the General Manager while more immediate concerns were passed to the Engineering Manager.

Within the shop floor there were several functional groups but few social boundaries between these groupings. The majority of operators could work in most areas of the factory. While the average educational level of the shop floor was modest the skill level required in production was high. The products were small with delicate parts that did not respond well to rough handling. Many production activities were carried out with tweezers and microscopes. While there was a high concentration of workers from temping

agencies on the shop floor, many of these had been at the factory for some time. There was little evidence of social barriers being placed between the permanent staff and the temporary workers.

The merging of other businesses did produce several parallel cultures on the shop floor. At one time there were, in effect, three companies housed within the same physical structure; the reed relay business, a liquid sensor business and a transformer winding business. The sensor business shared some switches with the relay business and the transformer business shared a limited amount of winding with the relay business. These three companies had their own personalities and their sudden mixing did not produce a homogeneous unit, which had an adverse affect on morale and the ability of the manufacturing system to cope with disturbances such as the introduction of new products.

6.3.2   A Structural perspective

The growth of the manufacturing system had resulted in a organisational structure that was relatively informally defined. Those within the organisation knew who to approach to resolve different problems but this information was not encoded in an organisational chart or formal procedures. There were few clear chains of command and the culture was very much that of a family business. Despite this, the business was described by the management team in terms that suggested a Role culture (Handy, 1993) with formal roles within the business being carried out by specific people.

In practice there was a combination of this formal Role culture with a more informal Task culture (Handy, 1993) with teams forming to solve problems and disbanding once an acceptable solution was found. The day-to-day control of the shop floor was delegated to the team leaders and retained at that level. The majority of problems were solved within the resources of the manufacturing system with few external calls for assistance or resources. There was a cultural suspicion of new technology since the technology within the product had been in existence for many years and had not been subject to significant development.

6.3.3 A Technology perspective

While computers were in evidence within the business, the extent of information technology within the manufacturing system was very limited. There was a Manufacturing Requirements Planning system that was only used for parts ordering and stock control and even these functions were treated with suspicion. Planning was carried out using spreadsheets and historical experience and intuition. The high degree of labour involvement in the production led to extreme variability in production rates which made accurate forecasting of capacity impossible.

Build instructions were largely memorised and recalled according to the build programme. Since there were relatively few models being produced at any one time this was within the capacity of the team leaders responsible. These team leaders also monitored capacity and production rates, feeding this information back to the Production Controller through informal discussions. This information feedback allowed for the updating of forecasts but prevented the systematic monitoring of production. Data was gathered on production rates, scrap and other metrics but nothing was done with this information.

6.3.4 A Task perspective

Each product followed the same basic route through the factory though each had variations that prevented a flow line being established. Batch production was the rule with large orders being broken down into batches that were then fed through the system. This allowed capacity to be switched around depending on labour and equipment availability. The majority of production activities were carried out manually with limited automation on a few stations. There was no automated handling between stations or loading of machines.

Toolshop		Store room	Planning Office	
Goods Inwards Inspection and storage	Final Assembly, test and packaging	Encapsul-ation	Clean Room	Sales offices
Finished goods store		Winding and General Assembly		
Plating and other rooms				
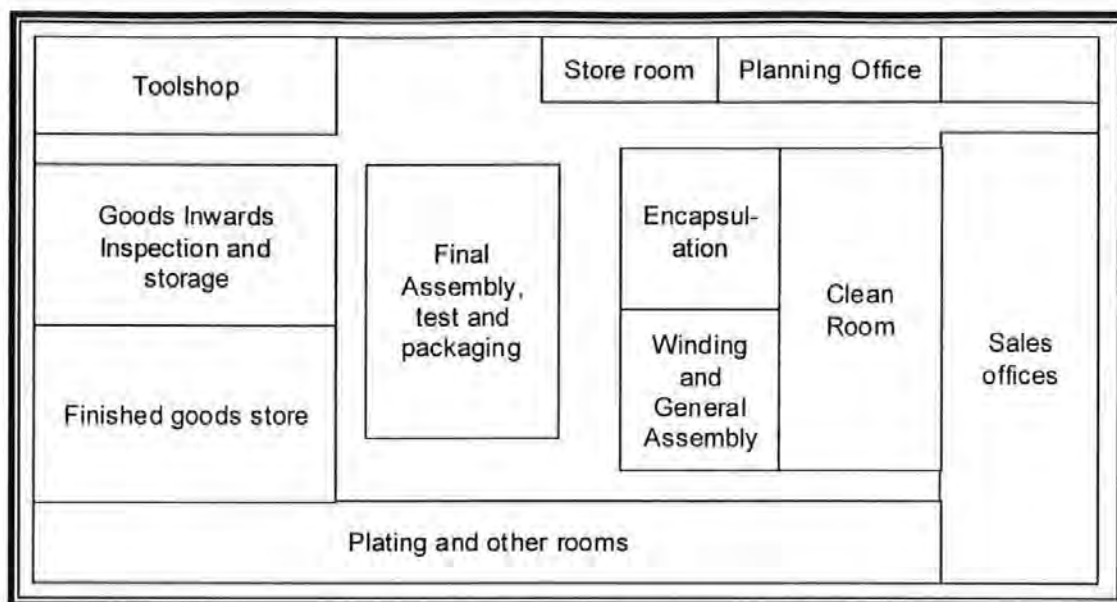
Figure 6-1 – General layout circa 1995

The shop floor was laid out along functional lines with winding machines grouped at one side of the factory (Figure 6-1). General assembly benches were located in front of the winding machines. To one side an area was seperated for encapsulation and a separate room was isolated for clean operations. A group of benches were allocated for testing and setting up of products and packaging ready for dispatch. A bonded area was reserved for materials storage and a workshop was available for tooling and jig production. There was no clear product flow from raw material storage to final dispatch. A second floor held further offices and engineering space. This engineering space was used to develop new products and to trouble shoot issues that arose on the shop floor.

6.4 An example of manufacturing systems redesign

The introduction of a new product family to the product portfolio necessitated a manufacturing systems redesign (FRD13000, Appendix One). Apart from the reed switch, the new product family shared no assemblies and no raw materials that were common to other product families. The new family was the result of a customer enquiry for a product that performed to a higher level than the existing range, particularly when in close proximity to other relays. The coils that are used to activate these switches are highly effective aerials for stray electro-magnetic fields. These fields could be sufficient to activate the switch without a control current being present. This was unacceptable and so

the solution was to screen the coil from unwanted radiation. This was achieved by placing the coil in an earthed shield that completely enveloped the coil except for two openings for the control wires (see Figure 6-2).
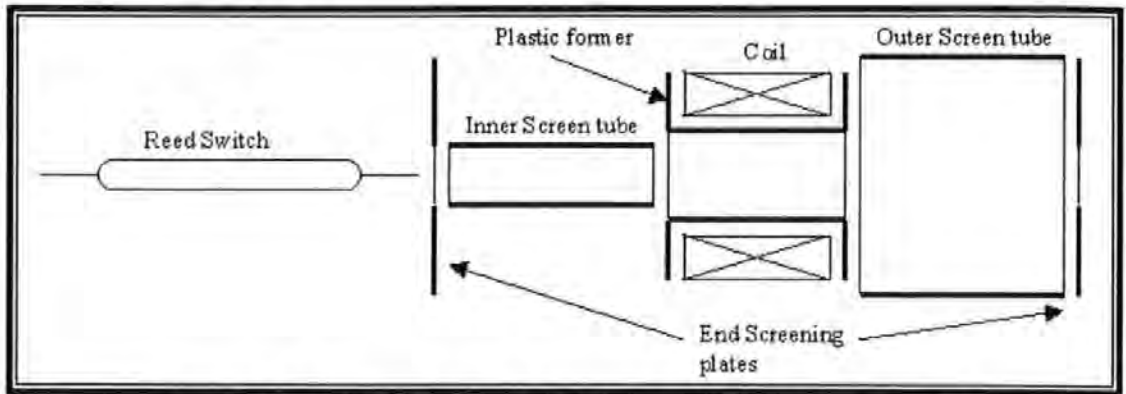
Figure 6-2 Fully Screened relay – Exploded view, control wires not shown

The effect that the new product family would have on the existing manufacturing system was not considered. The principal consideration was ensuring that the product met the customer's specifications and that the product performed as described. To this end the physical design of the product was afforded considerable attention to the detriment of the manufacturing system. None of the issues that were raised through the introduction of the fully screened relay was significantly detrimental alone but together they did cause problems for the manufacturing system and the staff running it.

6.4.1 People issues

There were several human factor implications for the manufacturing system generated by the new product family. The greatest issue was one of training. It was foreseen that some training would be required but the extent and true nature was not forecast. The initial lack of skills caused production problems and difficulty in schedule adherence. Lesser issues of morale, stress and anxiety were also encountered. These resulted from difficulties in winding, the requirement for training, lack of communication between the management and shop floor and cultural issues between the different parts of the factory involved in manufacturing this product.

New skills were required in three areas of assembly and production: winding, assembly and soldering. While fully screened multi-pole relays were manufactured in very

low volumes, this relay differed both in size, it was smaller, and in the materials used. The new former design required an ingenious new winding programme to be formulated on the automatic winding machines. The skill level of the operators was not sufficiently high to monitor and correct this programme which meant the design engineer had to spend considerable time on the shop floor winding parts rather than concentrating on product improvement or tooling design to alleviate the problem. Space limitations within the screened enclosure led to unusually fine winding wire being used, which was prone to breakages and re-threading the 4 spindle machine was an arduous and tiresome task which caused morale to suffer.

The new formers were produced from a different plastic to the rest of the product mix. This was cheaper and could support finer mouldings, critical given that space was at a premium within the screened enclosure. This plastic had a lower melting temperature than its higher performing cousin. This led to problems in terminating the winding wires and soldering the screening enclosure closed. If too long was spent heating the screening enclosure to facilitate solder flow the plastic former was liable to melt and fuse the winding wire. This destroyed the coil within and rendered the assembly useless.

6.4.2 Technology issues

Most of the technology issues related to the introduction of new materials and processes to the shop floor. The new product family highlighted several issues that were already known about the information management system that controlled scheduling and purchasing.

There was a significant learning curve involved in translating the design concept into the final product. In this respect the product was designed in a conventional manner in that there was minimal prototyping. The aim was to design out problems before they reached the shop floor. The high level of manual involvement in the production of the relay led to significant variations in both build quality and speed. The operators were able to make suggestions based upon their experience with other fully screened products that were

unknown to the designer. These developments only occurred once the product had been released to the shop floor for production.

A significant control issue arose during the initial production runs in that the estimates for assembly times were grossly inadequate and that the introduction of the product would have a detrimental effect on the system's ability to cope with the product mix. This led to a need to identify another method for the most time consuming portion of assembly, that of soldering the shielding into an electro-magnetically coherent unit. Carrying this out manually was highly skilled as it was both a complex shape and a large mass of metal to heat up. The shielding material was copper which acted as an excellent heat conductor, dissipating heat to the plastic and fine winding wire. Too much heat dissipation and the plastic would melt or the winding coil would break rendering the assembly scrap.

The solution was to use a wave soldering machine that was about to be scrapped. The business used to manufacture a small number of printed circuit boards and had a wave soldering machine for this purpose. That side of the business had fallen off and the machine was largely unused. The soldering of complex shapes such as the screened relay was new and trials were conducted to establish process parameters. The control variables included pre-heat, solder temperature, speed of the part through the solder wave, height of the solder wave and the profile of the wave. In parallel to these trials a jig was developed to hold the assembled parts while they were soldered. These jigs were initially formed from circuit board sheets held together with spacers, bolts, and springs. No designs were made as these were seen as trials to prove the concept of wave soldering. Once proven, the product was put into production with the temporary jigs. Further development work was required on the jigs and production process to enable the full volume to be passed through the wave solder process.

6.4.3 Structural issues

The final design utilised equipment from four different sections of the business: (1) winding, (2) assembly, (3) flow soldering and (4) final assembly and test. While there was a central co-ordinating supervisor for three of the four, flow soldering existed as nearly a separate entity within the business. There was very little consultation with the supervisor over the introduction of the product and this proved to be an oversight. Much could have been learned about the systemic implications had wider consultation been conducted, however, rapid introduction was seen as important.

The introduction of the new product had a knock-on effect on the scheduling of existing products that could not have been anticipated. The complexity of the winding programme led to frequent wire breakages that slowed production down. This delayed other products either through machine or operator unavailability.

6.4.4 Task issues

There was no area of the shop floor that could be dedicated to the new product. The new product would follow the same tortuous route that other products adopted. New jigs and trays were required to contain the unusual shaped formers and component parts. While instructions were developed to cover the assembly at each point, there was no process map covering the whole production process. Much of the development of the new production process was carried out in consultation with the Engineering Manager and General Manager. Without these two people the difficulty of generating a production route would have been greatly increased.

Some effort was made in the design and development stage to remove some of the operations that were involved in the existing product range. The rapid transition from prototype had led to products that were layered and complex to assemble. All the elements had justifications but these were sometimes spurious in the extreme. An example was the tape that was used to separate and protect the coils. This was dispensed with in the fully screened version since the coil would be protected by the shielding. A secondary reason

given for the tape was to provide insulation for the coils, this was proven to be unnecessary since the winding wire had a protective covering on it. Demonstration products without tape were produced with no reduction in performance. Existing products, however, were specified as containing tape and it was considered too expensive to retest and certify their performance without tape. Since this was an activity within the system that was not required, the new product was designed from the outset without tape.

6.5 Conclusions

The company had conducted production equipment development over many years where they were frequently working with the original equipment manufacturer to extend the capability of new equipment in handling small and delicate parts. This required careful design and the integration of different elements of production technology to produce the required parts to the requisite specification. This ability was not transferred to the development of the manufacturing system as a whole, nor was it enshrined in operating procedures.

There appeared to be an emergent approach that advanced incrementally, probing at problem situations until a technical solution presented itself. This solution would then be developed until the situation was resolved or a more pressing one arose. The frequent and verbalised solutions of choice were technical or process in nature. This focus on process and technology prevented alternative possibilities from the domains of human factors or organisational development being considered. Issues that arose during the redesign of this manufacturing system were easily categorised using Leavitt's four perspectives (1972). This suggests that the four perspectives may be applicable in the SME environment. It is contended that consideration of the perspectives would be useful in providing a more wholistic redesign to take place.

There was no planned development of ideas from conception to fruition, the redesign was entirely reactive and event driven. An issue would arise and a solution would be found, there was little evidence of evaluating changes to determine the degree of

improvement or real planning for change. The recalled perception of those projects was that they occurred in an almost random manner, with ideas being tried out until a suitable one was found that could be implemented. These initial ideas frequently found themselves on the shop floor without subsequent development.

One of the stated aims of the Teaching Company Scheme was to redesign the manufacturing system to cope with the forecast increased volume of production of new products being developed. To achieve this, a plan was instigated that would identify, design, develop and implement three system redesign projects. The projects were planned using conventional linear approaches and were forecast to provide the business with substantial productivity increases and cost savings. The following chapter will describe the execution of those projects and how they failed through a methodological mismatch between the problem situation and the problem solving strategy.

7. Investigation

The investigation phase considered four examples of manufacturing systems redesign within an SME. Three of the four examples were designed to follow a linear approach along the lines of Figure 5-7. The fourth example more closely represented the prototyping approach as shown in Figure 5-9. The purpose was to ascertain the degree to which the projects proceeded according to their chosen design strategy and to identify the reasons for deviations from that strategy. The involvement of the researcher made it possible for action research to be used to fully explore the interrelationships between the methodology, company and other factors.

7.1 Project outline

In the early part of the Investigation phase three projects were identified as being of particular significance to the business. These projects were significant in that they addressed fundamental technology features of the manufacturing system. There was minimal consideration of wider systemic considerations at the design stage. These would become clear during the development and implementation of the projects. Towards the end of these projects a fourth project was initiated that was to provide a comparison to the approach adopted for the original three.

7.2 Design approach

In setting up the first three projects a Gantt chart was constructed and planning was carried out to determine expected due dates for each project. The business did not have a formal project planning system that could be implemented, however, a linear methodology based upon that of Jones (1970; Figure 5-7) was adopted. This approach was chosen since it reflected conventional manufacturing systems design approaches in the literature (Bennett, 1986; Bradley *et al*, 1991; Brown *et al*, 1996; Hill, 1984; O'Sullivan, 1994; Parish, 1990; Singh & Rajamani, 1996; Wu, 1994). While the titles used may not have

been identical to those used by Jones in 1970, the project followed those guides and his headings (feasibility, preliminary design, detailed design, planning) will be used here to provide a frame within which to analyse the projects. The fourth project was tackled using a highly iterative, prototyping approach that was more akin to the methods seen within the business to that point in time.

7.3 Project One

The first project was to develop an automated encapsulation system for reed-relay products (Appendix Two). The marketing forecast was for rapid growth and the business perceived the encapsulation process to be a technical constraint. The product in question is assembled, largely by hand, and prior to testing and packing is subject to encapsulation (FRS12000 family, e.g. FRS12516, Appendix Two). This process increases the ability of the product to withstand high voltage potentials between internal components. The encapsulation compound also provides support for delicate parts within the assembly and this is perceived to be a factor when subjecting the product to shock and vibration testing as part of military specification requirements. The project was to fully automate the process from loaded jigs to cured products.

7.3.1 Feasibility

Project one was to be used on the main production family as this was hoped to be the volume range. In practice there was considerable internal reluctance to specify that other products would not be included. The overriding technical consideration was to make each piece of equipment as flexible as possible. With a product range in excess of 200 and around ten major product families this was a constraining functional requirement.

For products that required encapsulation this represented a significant portion of the product cost, much of this cost being expended on post-process cleaning of products. All this would be eliminated through the automated approach, significantly reducing the labour content and thus the manufacturing cost. Initial work carried out some years previously had

suggested that the encapsulant should flow easily around the product and that an automated process should not be difficult to arrange. All this led to a project that appeared both feasible and highly attractive for the business.

The major effort in the feasibility phase of the project was determining the cost and payback for the business. It was suggested that a payback period of no more than two years should be the target. In the event there were few meaningful figures to use in analysing the payback period. It was possible to show a payback of between 3 months and 3 years depending on how the figures were presented. The greatest unknown was the required capacity over the payback period. The machine was being designed for increased capacity over existing production levels, however, the sales department were unwilling to predict what the requirement would be in two years time. Eventually figures were agreed upon that showed a payback within an acceptable time frame (Appendix Two).

7.3.2 Preliminary design

Several initial designs were proposed to deal with the unique requirements presented by the encapsulation project. The greatest unknown was, at first, thought to be the volume that the process would have to cope with. To this end three designs were mooted that offered differing levels of automation and capacity, ranging from very minimal improvements over current practice to a fully automated, high capacity solution. The costs were correspondingly higher for the more advanced solutions. Uncertainties in the business environment caused a delay in deciding which solution to adopt, during which time it was proposed to re-visit the original work that suggested that the project would be viable.

This re-visiting of the earlier work showed that a fundamental assumption (that the encapsulation compound would flow around the parts easily) was flawed. While the compound did flow, the viscosity was such that the delay negated any capacity improvements gained through automation. This represented a departure from the linear design strategy and the adoption of prototyping to appease the concerns of the Engineering

Manager. It was recognised by the company that this was a departure but it was accepted that such unforeseen situations arise and that was all part of project management and systems design in the 'real world'.

At this stage other options were investigated, including pressure filling and multiple shot filling. Forcing the encapsulant in under pressure was rejected due to possibility for damaging internal components. The concept of multiple shots being used was attractive until the number of shots and degree of accuracy required became apparent. It is normal procedure in preliminary design to find multiple solutions and reject those that become unsatisfactory through further investigation.

It was then suggested that a different compound might be used and a period of materials testing ensued. This was again a period of prototyping to trial different materials and then evaluate their ability to withstand high voltage differentials, minimise attenuation to Radio Frequency (DC to 30MHz) signals and perform as a production material. This produced significant results for the business in terms of the product performance under different encapsulating materials but did not present a viable alternative.

The original material was retained and the preliminary design phase continued with proposals that would utilise this material and its mechanical properties. This resulted in three designs:

1. A fully automated multiple jig assembly line style system that would handle significantly increased volumes.
2. A fully automated single jig design that would have greater flexibility but limited capacity. The scope existed for multiple copies that would increase the capacity but require more operator involvement with jig loading and system management.
3. A manual system that would provide operator control over encapsulant dispensing, parity with current capacity but with savings on process time as post process activities would be removed.

7.3.3 Detailed Design

Detailed designs were drawn up of the three possible solutions and proposals placed to tender to establish the costs associated with each. The feedback from the

suppliers was that no single supplier was prepared to provide a complete solution. It would be possible to purchase a vacuum chamber with a fluid dispensing system but that it would need further modifications to fulfil the design requirements. It was also suggested that since single shot dispensing would be problematic due to material viscosity, multiple shots should be used to gradually encapsulate the reed-relay.

Further investigations showed that pre-programmed multiple shots were not a feasible solution due to compound errors in the shot dispensers (Appendix Two). The only solution provided was a closed loop feedback system that utilised optics to establish the level of the material in the product and release more material accordingly. The control system associated with such an approach would not be provided by any of the suppliers and the level of systems complexity was rapidly increasing together with the costs.

The move to multiple shots also reduced the capacity of the system significantly and thus the potential savings to the business. The project was now becoming too complex and only marginally cost-effective. After a further prolonged period of materials testing and consultation with suppliers it was decided that the project should not proceed. Parallel to this development a new business had been acquired which had a large vacuum chamber. Initial trials showed that encapsulation could be carried out in this chamber which allowed higher capacity than the existing approach resulting in adoption of this solution. The result was not automated, in fact the labour input was increased slightly but this was spread over more components and was felt to be justified.

There was no requirement for further work and so there was no definable planning phase. Work did continue on the system since the operators still required training on the new system. There were suggestions for modifying the equipment to make it more suitable for its new role. Responsibilities required clarifying over the new equipment since it was used for parts from many different product lines with very different and specialised encapsulating materials. Production scheduling now had to consider the requirements of

other business units in planning the work for that equipment. All this was carried out as part of normal operating duties and was not considered part of the design process.

7.3.4 Discussion

The initial project plan for redesigning the manufacturing system to incorporate automated encapsulation was based upon flawed internal research. The linear strategy was unable to cope this and could have proceeded to the commissioning of equipment before this error was discovered. There is no explicit error checking within the linear approaches since they assume that all the variables are known and can be factored into the design process. It was only the hunch of the Engineering Manager that prevented a costly mistake.

Once that hunch was acted upon the organisation reverted to an iterative approach to explore possible solutions and to develop a new design. With a new solution identified the linear plan was reinstated with suitable adjustments to allow for the time spent working iteratively. The linear plan was thrown into further confusion when the suppliers were unable to provide a complete solution and investigations were required by internal engineers to suggest a suitable control system.

The linear design strategy followed, really only dealt with the technical elements of the system. While there was a recognition that training would be required there was no planned analysis of the impact that the new equipment would have on the whole manufacturing system. As noted at the end of section 7.3.3 above, there were many activities carried out after the formal design process. These were vital to the operation of the equipment and its integration into the manufacturing system but were not part of the linear plan since the plan had a fixed end date rather than an acceptable end-state.

The two greatest failures of linear design strategies in this project were inability to cope with uncertainty, either internal or external and the lack of a truly systemic consideration. The business was keen to minimise risks throughout the project, given the early discoveries of errors in the underlying research, but there was nothing within the linear strategies that allowed for this. Since the assumption is that all variables are known

and can be factored for, there is no opportunity for continued risk minimisation or for coping with uncertainty.

7.4 Project Two

The second project was to automate the set-up and testing of a latching reed-relay product. The procedure was carried out under manual control using indirect measurements leading to highly variable capacity and quality. The set-up procedure was carried out using an oscilloscope to capture timing data from the product as it is operated. This timing data was interpreted by the operator and used to control the set-up equipment. The aim was to develop the automated equipment so that the feed-back loop provided by the operator could be removed.

7.4.1 Feasibility

Project two would only apply to a limited range of products but the uncertain marketing forecast made a prediction of volume very difficult. While the setting up process was fundamentally the same for all products that required it, the individual designs meant that the possibilities for cross-utilisation of jigs were minimal. Control voltages, pin layout, response timing, energy requirements were different for all models within the product range. This, coupled with the device size, ensured that a multi-functional test centre for all products would have been extremely complex. The labour hours attributed to the process represented a significant portion of product cost and this, together with the bottleneck that the process represented, was a prime driver for process development.

Initial technical analysis suggested that there should be a predictable relationship between the product performance and the set-up input. While this proved to be generally the case, there was too much variability experienced to provide a simple predictive solution and further investigation would be required. This would be outside the scope of a feasibility study and would be more akin to a research project in its own right.

Cost justification was also required to determine the feasibility of this project. This was even harder to determine since there was no model to suggest how long an automated test facility would take. Vendors had been contacted regarding similar machines but these did not carry out the tests that were required. For this reason no firm payback period was ever agreed.

7.4.2 Preliminary Design

Several initial designs were suggested to cope with the complexity of the product designs that were to be catered for. The greatest problems stemmed from the nature of the tests involved, some of which required high voltages to be maintained between pins in close proximity, others required measuring resistance, others capacitance and others timing data. All placed their own requirements on the connection design and this in turn reduced the possible range of solutions.

When the results of preliminary discussions with suppliers began to filter back it became clear that there was no simple technical solution. The manufacturers of test equipment were not used to developing equipment that would conduct the range of tests that were being requested. Several innovative solutions were proposed but none that met the business requirements.

Business developments, together with the lack of suitable solutions from suppliers, caused the preliminary design phase to drag on over many months. The continued inability to generate a clear payback that could be supported caused the project to eventually be shelved.

7.4.3 Discussion

This project fizzled out due mainly to a lack of demonstrable benefits for the company. The control software to manage the system would have required fundamental research into the physics of the products that was not required for normal operating uses.

The lag between feasibility and implementation meant that the management were focussed on the next business situation before results were likely to be realised.

Had the project been able to develop an understanding of the physics behind the products, this might have led to a truly innovative set-up system. Simple prototype tests would have revealed whether improvements could have been made with less sophisticated equipment. There were simply too many unknowns to be able to properly design and plan the solution.

7.5 Project Three

The third project was to develop an automated processing facility for the high voltage processing of reed switches, known as *'gettering'*. This was carried out under manual control using qualitative measurements to determine the extent of processing. There was no control over the amount of processing each part underwent. Each operator was left to carry out 'sufficient' processing to ensure that the part could pass a 'withstand' voltage test. After a minimum wait period of 72 hours, the parts were re-tested and any failures re-submitted for processing. The process suffered from highly variable capacity and quality control was subjective with switches being submitted for repeated processing before being discarded as scrap. The project was to develop a fully automated process from loading reed switches to the collection of switches sorted into 'pass' and 'fail' bins.

7.5.1 Feasibility

Project three dealt with parts at a much earlier stage in production and could, therefore, be used over a wider range of parts. The process was not required for all parts but the limited information from marketing led to the whole demand being scheduled for the process. The labour input to the process was significant, especially when the re-processing times were included. While the mechanics were not fully understood, the conditions for distinguishing a good switch from a bad switch were considered definable. The business had experience in handling high voltages since the product range was

specified to withstand in excess of 2000 volts DC. Thus this was seen to be a technically feasible project.

While the capacity would not be drastically increased it would be possible to remove the majority of labour input. This would be important when the cost forecasts were generated. In calculating the payback and benefit to the business, only the savings in labour were used. In this way a process that took a long time to complete was a prime candidate for automating, even if that automation did not increase capacity. The limiting factor with this production process was the equipment that generated the high voltages for switch conditioning. These units operated at a certain rate that was determined by their design and which was slower than the operators were capable of controlling. The deciding factor was the removal of operator input which brought the costs down.

7.5.2 Preliminary Design

This project had been considered previously and some ideas had already been generated. These ideas centred around two pieces of equipment that were already within the business, one being a vibratory bowl feeder, the other a customer designed test jig. While the original test jig had been designed for low voltage resistance measurements of the switches, the design lent itself to high voltage applications. These two elements formed the basis from which the rest of the design grew.

A small amount of testing was carried out to ensure that the bowl feeder would not damage the switches and that the test jig could cope with the high voltage application. Both these tests showed that the basic concept was viable. There were still significant design questions to be resolved, primarily around the control element. There was an in-house desire to use Programmable Logic Control (PLC) controllers as these were used elsewhere in the factory and there was some understanding of their functioning.

In determining the function that the equipment would be carrying out it became apparent at the early stages that PLC ladder logic was not suitable for the task in hand. There was also an expressed desire to record the performance of the switches to better

understand the process involved. This was not a simple task to achieve using PLC's. For this reason the final control system chosen was an industrial rack-mounted PC. This allowed the high voltage generator and other control circuitry to be securely mounted in the rack presenting a single unit for the shop floor.

7.5.3 Detailed Design

In developing the detailed designs of the gettering project several issues were raised by the Engineering Manager regarding risk and its management. The initial design was rapidly reduced to five elements that could be developed almost independently. These elements were: (1) component handling; (2) fixture; (3) high voltage management and delivery; (4) control; (5) interfacing. Of these five elements, three (component handling, the test fixture and the high voltage management and delivery) were already designed.

Component Handling

Component handling was provided by a vibratory rotary feeder unit. This was part of an old system that had since been removed, the feeder still worked and its use was part of the resource conservation that was a feature of the project. While highly effective at delivering a stream of single switches to a specific point, development was required to control the stream. Several mock ups were constructed from paper to prove the theory that a series of funnels and chutes would deliver a single switch to the test fixture. An arrangement of gates and baffles was used to isolate single switches and return others to the pool within the feeder unit.

Test Fixture

There was very little work required on the test fixtures. They were designed to carry out electrical resistance testing using a Wheatstone Bridge. This provided four contacts which could be used in pairs to maintain the high potential across the switch that was used in gettering. This provided a robust and reliable unit that was trusted and not subject to much development.

High Voltage

The generation, management and delivery of high voltages is a sophisticated science that was not within the company knowledge base. Designing the equipment to produce and manage high voltages was not within the scope of the project. Equipment was readily available for this purpose and had already been purchased with this project in mind. While this removed a significant design task it imposed certain constraints on the remaining design effort.

The equipment accepted control signals to allow voltage and trip currents to be set using external equipment. The rate at which the equipment could ramp the voltage to meet the requested voltage was not known. After a high voltage discharge there was a built in delay before the voltage could be reapplied, this was also unknown. The equipment was designed as test equipment and was not supposed to be subject to repeated high voltage discharges. Performance degradation was expected but, while human operators could factor such degradation easily, the control system would have to have some model for coping with any change in performance.

Control

The original idea to use PLC controllers was rejected when performance analysis was added to the design brief. This was not originally to be a feature but was added in later. To meet this requirement a computer control system based on an industrial Intel 386 chipset was chosen. This allowed a monitor to be used to provide live data on the work as it progressed, a keyboard to select different processing profiles and a 3 ½" disk drive so that stored data could be removed and analysed on more powerful machines. Internal data storage was provided by a memory card that retained data when the machine was turned off.

The programming of this computer was carried out in TurboPascal because there was an engineer with some experience in the language within the company. This experience proved insufficient for the handling of external inputs and the language had to

be learnt from scratch by the author with the trial and error that is involved. This development happened separately to the rest of the project development and resulted in 21 iterations before the final version was ready for operation. The final source file may be found in Appendix Three together with a version that was developed subsequent to the equipment being implemented.

Interfacing

Next to the development of the control system the interfacing was the most complex. The control system provided a series of outputs through an input/output board that was external to the control computer. These control signals were not sufficient to drive all the elements of the system. There were also concerns that noise from the high voltage discharges would be picked up by the control wires and fed back into the computer. This might lead to catastrophic failure of the computer.

The test fixture was powered by pneumatics and these were retained for their immunity to high voltages. The other physical control elements were also pneumatically powered. The computer could not sink sufficient current to operate the pneumatic valves, so these had to be buffered through the interface unit. Feedback was also provided through the use of various switches within the system to ensure that safety checks were in place before high voltage was applied.

The interface board was hard wired with certain safety checks to provide an override to the software and prevent unsafe operation. There was still the opportunity to manually override the safety switches but this required an understanding of the system and premeditation that ruled out casual action. This provided sufficient reduction of risk to the operator to be deemed safe for the shop floor.

7.5.4 Planning

Traditional project management techniques were employed to control costs and time. While the direct costs, bought in materials and suppliers' costs, were easy to monitor,

there were no structures in place to monitor indirect costs, engineering effort and stock materials. This was not a problem except that the true cost of the project will never be known. The only significant external requirement was the enclosure that would house the feeder unit and fixture. This was manufactured to specifications provided by the company and delivery was several weeks late. This caused some delay to the project but the time was taken up with testing and prototyping of software and control systems.

As indicated above, the planning phase consisted largely of assembling the elements that were developed during the detailed design phase. While it was the intention to separate design and fabrication, in practice this proved to be a fruitless exercise since it was quicker to produce a small prototype and evaluate that than to develop designs and mathematical models that would only be approximations.

The final equipment was released to the shop floor with a training manual that was developed to be as simple as possible. The amount of operator involvement was specified to be the bare minimum. In the end this was largely achieved, though variations in component profiles meant that jammed switches were to be an issue whatever the feeder design. Once this was identified further training was provided to ensure that safe operation was maintained.

There was no real resentment towards the new equipment since the department that it was released to was perceived to be a bottleneck for the factory. In actual fact this was not the case but it did reduce the workload on the remaining operators significantly. There was a misunderstanding that the equipment would eliminate all the scheduling issues around the gettering process. The new equipment was no faster than an average operator and was slower than a skilled one. The principal impetus was to increase capacity without increasing operating costs. This was achieved since in costing the project the running costs of equipment were included in overheads. The impact the project made on the business overheads was not considered as part of the project justification. Therefore, the capacity of

an operator was added to the factory with no increase in operating costs as determined by the company.

7.5.5 Discussion

There was no distinct transition between the preliminary design, detailed design and planning phases. Different parts of the project proceeded at different rates. The control system was easy to monitor through the phases but the material handling system was much harder to plan. Different ideas were proposed, designed tested, refined, discarded in favour of alternatives, revived and incorporated in the final design. The design was never finalised since the release of the equipment to the shop floor led to new developments being suggested through user evaluation.

The original linear design strategy proved completely incapable of handling such a complex, multi-speed development route. The final development was far more iterative and organic than originally planned for. This was due primarily to the desire to minimise costs and risks. Each element of the design was developed and evaluated before being incorporated into the design as released to the shop floor.

While the impact on the whole manufacturing system was moderately low, there were training and morale issues that were not adequately dealt with during the detailed design phase. Once the equipment was released to the shop floor several modifications were made in quick succession to tailor it to the perceived requirements. The modifications were largely cosmetic but they were important to the operators.

The equipment provided an opportunity to reassess the whole process of manufacturing switches since it could provide detailed and accurate data on individual switch performance. This was not fully appreciated until after the system had been developed. The opportunity to carry out monitoring on this scale was dismissed as not being of sufficient importance to the business. There was also such a time delay between manufacture and gettering that any data collected would have been of no use in improving the switch production process.

The main failing of the linear design strategy in this case was the speed and the different rates at which the project advanced. This made tracking using the original plan nearly impossible. The plan assumed that the rate of development for any element would remain constant over the development duration. This proved not to be the case leading to forecast finish dates that expanded and contracted as work sped ahead or was held up for some reason. It was not possible to adhere to a linear plan in such an uncertain environment. The actual development took place over a series of iterations.

7.6 Project Four

The fourth project was to develop an automated technique for producing one of the two blades that formed the small vacuum reed switch. This switch was technically the most sophisticated in the range with a superior switching profile and could isolate higher voltages than comparable products. The technique involved welding a tip element to a tube element, this welded component then formed one blade, the other being formed from a single piece of pressed wire. The two parts were placed inside a glass tube, the ends of which were melted so that it formed a hermetic seal around both blades, the hollow one being used to form the final vacuum within the switch. The current process involved manual loading of the weld equipment, control of the weld conditions and removal of the welded part. The project was to fully automate the process from loading of tubes and tips to collection of welded components.

7.6.1 Iterative approach

Since the other projects had tended towards iterative approaches despite the overtly linear intention it was decided to set out with an iterative model for the fourth project. No formal framework was adopted although the activities closely match the model in Figure 5-9. There was a conceptual requirement for the final system and its integration into the manufacturing system but there were no restrictions on the development of the solution. In this respect the development resembled most closely the mode of development observed

during the participant observation phase (Section 6.4), that is, a highly iterative, probing approach but without any formal methodology.

The first iteration analysed the current process and how it was carried out. This involved the researcher working several shifts on the existing machinery to fully appreciate the operating conditions. This provided a understanding of both the individual components of the existing system and the whole system as it was. A primary generator had been suggested that required an extensive redesign of both product and process.

Three fundamental unknowns were identified at the outset of the project:

- the ability of resistance welding to make a sufficiently good weld between different component shapes;
- the electrical performance of different component configurations;
- the performance of down-stream processes with different component configurations.

Only one of these performance requirements had detailed quantitative specifications attached, that of electrical performance.

Two of the unknowns were dealt with using physical experimentation, the third through mathematical modelling. The ability to resistance weld different component configurations was established using old equipment and modified components. This established that tube and blade designs other than those currently in use could be used to make mechanical joints. Switches were then constructed from those temporary assemblies and tested for electrical performance where they passed all the required tests with margins equal to existing assemblies.

The last element to evaluate was the time it took to pull a vacuum in the switch using the new designs. The fear was that to meet alignment requirements the tube through which air was extracted would be blocked by the new blade-tip design. Consideration of gases at high vacuum and modelling using a spreadsheet showed that the change in time taken to achieve the specified vacuum would not alter significantly and that there were far more significant factors that should have been taken into account.

Each element had been validated in isolation and their interactions considered in the light of known issues that applied across the design. At this stage contractors were called into evaluate the ability of their equipment to match the ideas being proposed. During these discussions the Teaching Company Scheme ended. Subsequent developments in the business environment caused the project to be shelved and so the involvement of the researcher ended.

7.6.2 Discussion

While the project appeared more chaotic, significant progress was made quickly and dead ends were eliminated from the design early. Confidence in the proposed design was high since the prototyping ensured that each element was evaluated before being incorporated into the design concept. There was no planned timeline for the project but progress was noticeably quicker than in earlier projects.

Most of the developments were technical in nature but in investigating the requirements time was taken to consider the people issues and how the new system would fit into the current system in the clean room. By trying out lots of ideas in a prototyping manner those within the system were very aware of the project and contributed suggestions regarding the final integration of the equipment into the manufacturing system. In particular the performance of the new parts as they progressed through the system was analysed. This was to ensure that no degradation in process or product performance would be introduced by the new equipment.

As the system developed and the specifications changed these were incorporated into the design whilst maintaining the original concept. This allowed the design process to adapt to uncertainties as they arose, rather than requiring a new design strategy to be formulated.

Even though the design strategy did not explicitly use the four perspectives of Leavitt (1972) to consider the manufacturing system, the prototyping method allowed a broader outlook to be maintained. When delays were experienced with a particular

iteration, another avenue could be opened up looking at training requirements, ergonomic considerations, the impact on the scheduling, etc. These allowed for a more systemic consideration to be carried out and issues that were only realised during the implementation of previous redesigns were tackled earlier.

7.7 Project Discussion

None of the three linear projects followed its design strategy. In each instance circumstances arose that required action outside the planned activities. When this happened the organisation reverted to an iterative mode of operating and this proved very effective at resolving the problem situations.

The ability to generate proposed solutions was not limited to one small phase of the design process. As the work progressed with all the projects, factors arose that could not have been envisaged in the initial design formulation sessions. Those factors called for a dynamic reassessment of the proposals. In the first project this led to the feasibility work being completely reassessed. In the other projects this resulted in fluctuations between preliminary design, detailed design and planning phases. While Jones (1970) describes a cyclic approach to design (Figure 5-2) the actual process was more like Pressman's prototyping approach (1992; Figure 5-9).

The linear stages were found to be sufficient when small elements of the projects were being considered since the scope for uncertainty was minimal. These sub-sections of the whole project were considered, ideas suggested, details sorted out and models developed and evaluated. Where the evaluation was favourable the sub-section was incorporated into the final design. This approach was explicitly followed in the fourth project and worked very well in developing a solution quickly and with the minimum resource consumption.

The linear approach derived from the literature did not explicitly call for a systemic consideration of the manufacturing system or the situation being investigated. This was a significant failing in the first project where a solution was eventually found but work was

required to integrate the solution into the manufacturing system. While the iterative approach did not explicitly set out to develop a more systemic understanding of the situation, as the project developed this understanding emerged from the work being carried out. At different moments within the project, issues relating to people, organisational structure, technology and control and the process were dealt with. This was not planned but occurred as a natural part of the development of the project.

7.7.1 Risk minimisation

While not a part of the amalgamated design approach adopted for the first three projects, it was considered prudent within the business, given the knowledge gaps mentioned in Section 7.3.2, to carry out engineering trials to ensure technical feasibility. Technical feasibility should have been clarified before the project was initiated but without knowing the preliminary designs the technical feasibility could not be fully assessed.

Risk minimisation could not be identified with any single phase of the redesign activity, it was employed at all points to ensure that the perceived risk to the business was kept to a minimum. At no point, however, was a specific value placed upon this perceived risk, it was more to provide a degree of comfort and support that undue risks were not being taken to the extent that, should the project fail, the financial outlay would not be too great.

7.8 Conclusions

When the design approach was explicitly iterative the problems with containing the development to the planned strategy evaporated. The project advanced with new ideas replacing those that had been shown to be inadequate. The greatest problem with the iterative method used was that there was insufficient structure to ensure that all aspects of the new system were considered. While the scope of the iterative approach was wider than the linear approach, there was still a tendency to focus on the technical elements of the problem to be solved.

The iterative approach was much easier than the linear approach for managing and ensuring that the project was progressing. It suffered from a lack of formal control or review procedures to evaluate proposed action ideas, the evaluation being carried out informally between the researcher and the Manufacturing Manager. There was no explicit structure to allow different perspectives to be incorporated into the design and there was no requirement to consider human issues or how the development would fit within the existing manufacturing system.

8. Proposed Methodology

The previous chapters have identified SME specific requirements for manufacturing systems redesign methodologies (Chapter 4), suggested how a systemic approach might be adopted (Chapter 3), evaluated current and alternative redesign strategies (Chapter 5), shown that current practice does not reflect current theory (Chapter 6) and that even when explicitly adopted, current redesign strategies do not fulfil the needs of SMEs (Chapter 7; also Bradford & Childe, 1999). This chapter will review these previous chapters to make the case for a new methodology. The important discoveries will be highlighted together with the supporting case evidence. The chapter will go on to describe such a methodology and relate its components to the requirements identified.

8.1 Manufacturing systems redesign critique

The high level of uncertainty found during the action research was the most significant finding of Chapter 7. This uncertainty was identified in Section 4.3 while considering the features of SMEs. Ghobadian & Gallear (1997) describe the activity of 'fire-fighting' as being a coping strategy of SMEs for dealing with uncertainties and the lack of internal resources to cope. Section 6.4 found frequent evidence of issues being dealt with as they arose rather that as a result of careful planning. Further case evidence for the inability to cope with uncertainty is most obvious in Section 7.3 where discoveries made during a well planned project led to short periods of highly iterative activity to solve a design issue. In none of the action research conducted in Chapter 7 did the redesign proceed as planned. The plans were developed according to current linear theories as described in Sections 5.5 and 5.6. The only time things went according to plan was in Section 7.6 where there was no plan as such and the redesign adopted a highly iterative strategy.

In considering the needs of SMEs in Chapter 4, the feature of resource poverty was widely reported as inhibiting structured change. Evidence of this was found relating to

formal learning (Gibb, 1997), implementation of TQM (Ghobadian & Gallear, 1997; Yusof & Aspinwall, 2000) and even the day to day existence of the SME (Bridge *et al*, 1998). This lack of resources was further evidenced in Chapter 6 where the skills of new product development were not transferable to the redesign of the manufacturing system. This may be considered a form of resource paucity as defined Ghobadian & Gallear (1997), Marri et al (1998) and Scott *et al* (1995). While the redesign methodologies reported in the previous chapter (Sections 7.3 to 7.5) demonstrated a degree of susceptibility to resource poverty, the inability to cope was not the most significant failing of the strategies chosen.

Systems thinking was considered extensively in Chapter 3 and its application to manufacturing systems in Section 3.6 in particular. Section 3.2 described the development of ideas that has led to the recognition of socio-technical systems and Sections 3.4 and 3.6 demonstrated how these ideas are applicable to manufacturing systems in general. What is notably missing from the case evidence from Section 6.4 and Sections 7.3 through 7.5 is evidence of wider systemic consideration being supported by the design methodology. While evidence of systemic consideration is not provided by the iterative redesign strategy in Section 7.6 it does emerge from the case activities (as discussed in Section 7.6.2).

While Jones (1970) claims (Section 5.4) that: *'clearly a major objective in design methodology is to make designing less circular and more linear'*, he is countered by Ramirez (1996) and Larson & Christensen (1993) who suggest that the solution of real world problems requires circular or iterative strategies. These suggestions are supported in Section 5.9 where the work of cognitive learning theoreticians is discussed. Further support for iterative strategies is derived from the organisational development domain where, in considering a linear intervention plan, Buchanan & Huczynski (1997) conclude that change is *'rarely so straightforward'*. Iterative redesign strategies are introduced in Section 5.10 and related to work by Shewhart (1939), Deming (1984) and Pressman (1992).

Section 5.8 considered the field of organisational development and found a noticeable shortage of design methodologies. Stuart (1995) has tackled the organisational

element of the redesign problem through the development of terrain maps. However, these are not provided for planning purposes but to understand the process of change. Other texts on the subject of organisational behaviour and change identify cultures (Handy, 1993) within the organisation and how these may affect the reaction of the organisation to change. They still do not provide a guide on what to consider or how to go about it. New (1998) raises a caution about blind adherence to technical solutions, while the majority of solutions propounded (for example: Gong & McGinnis, 1996; Koonce *et al*, 1996; Mason-Jones *et al*, 1998; Rao & Gu, 1997; Shewchuk & Moodie, 2000; Wu, 1994) adopt and propose technical solutions for manufacturing systems design.

Thus we can summarise that a systemic methodology for manufacturing systems redesign within SMEs should:

1. allow rapid translation of design concept into implementation;
2. allow for learning about the system under consideration;
3. react to changes in the business environment;
4. explicitly show different perspectives relating to systemic considerations of manufacturing systems;
5. manage resource poverty;
6. be resource sensitive through risk awareness;
7. appear simple yet provide sufficient structure to manage a conceptually complex change.

8.2 Proposed Approach

From the investigation into design approaches (Chapter 5) we can see that manufacturing systems redesign tends to adopt one of two positions. The 'soft' approach (Sections 5.8 & 5.9) seeks to understand the social and organisational interactions that occur within a manufacturing system, (Checkland & Scholes, 1990; Huczynski & Buchanan, 1991; Neave 1995). Section 5.8 further deals with texts that consider general management issues but without addressing the practical aspects of altering manufacturing systems.

The 'hard' approach (Section 5.4 to 5.6) deals with the practical aspects of changing the manufacturing system but tends to address technical issues such as routing, part numbering, machine layout etc., (Burbidge, 1971; Hill, 1983; O'Sullivan 1994; Parish, 1990; Wu, 1992). These texts only briefly mention the socio-technical aspects, however, all acknowledge the requirement for human factors to be considered.

The proposed approach provides a solid frame upon which to structure the redesign activity. It is based upon the prototyping model described by Pressman (1992) and also subscribes to the concept of differing perceptions through the four views provided through Leavitt (1972). Neither is sufficient in itself to act as a frame for manufacturing systems redesign, nor is a simple conglomeration appropriate (Bradford & Childe, 1999). The role of each must be considered together with its contribution towards the goal of systems redesign.

8.3   Practitioner framework

The methodology takes as its basis the assumption that strategic intent exists within the company. It is not the purpose of this methodology to review, evaluate or form strategic intent. It is thus proposed that the company will have a desired end-state for their manufacturing system. It is also recognised that this end-state is not fixed but moving in response to the external uncertainties, as described in Section 4.3. It is also beyond the scope of the methodology to validate the chosen end-state. It is sufficient that the methodology is useful in achieving the desired transformations of the manufacturing system.

While this is a cyclic methodology it will be described in abstract terms here to demonstrate the phases that exist and the progression between phases and iterations. Once the process has been initiated, subsequent iterations will take the same form as previous ones, the only change being in the focus and detail. There is no evidence to suggest that the first iteration should take any particular perspective nor is there any evidence regarding the weighting of perspectives (Leavitt & Baharmi, 1988). Where the perspectives are

described, they are in no particular order and the order they appear should not be taken as indicating that any preference should be shown. The proposed methodology consists of Planning, Risk Assessment, Action and Evaluation phases.
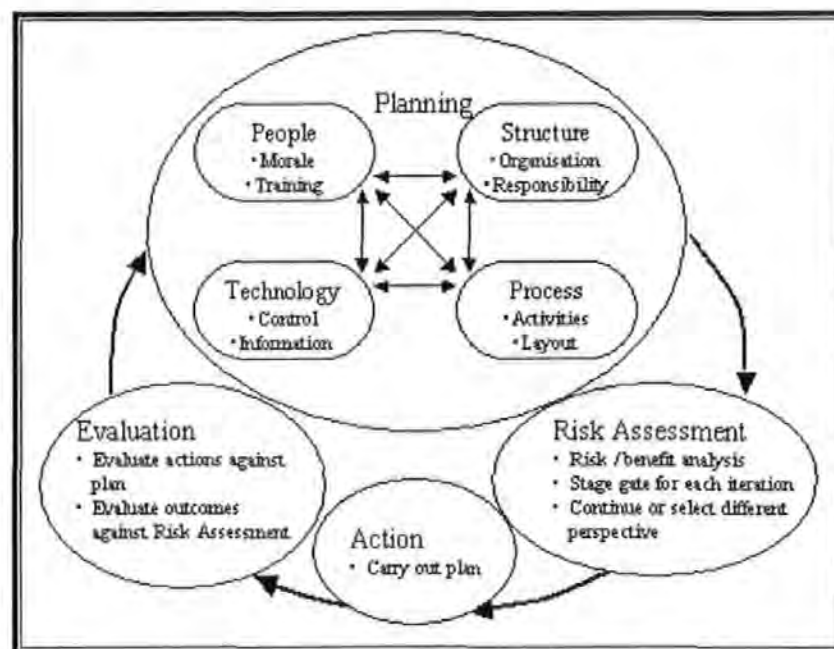
Figure 8-1 Proposed approach

8.4 Planning

Since this methodology is concerned with the redesign of manufacturing system, it assumes a strategic intent within the business. The methodology is not concerned with business or manufacturing strategy formulation, it seeks to reflect strategy through iterative redesign of the manufacturing system. Consideration of strategy is used within the planning phase to gauge progress towards wider business goals. In this manner the current iteration will neither negate previous work nor advance counter to business strategy.

Within the planning phase of Figure 8-1 are the four perspectives (Structure, People, Process, Technology) that have been developed from the work of Leavitt & Baharmi (1988). The company will have a view on where their problems lies with respect to these four perspectives. This is likely to be expressed as a conceptual solution or primary generator (Darke, 1978). There is nothing within the methodology to directly challenge this initial view, except to make explicit the existence of other perspectives. Care

should be taken to ensure that, while multiple perspectives are not excluded, appropriate focus is maintained relative to availability of resources.

Having determined the focus of the change programme a change team should be assigned to carry out the changes and to run the iteration. This is no different to conventional systems change methodologies; a change champion, owner and team should be named in the planning phase (see methodologies described in Section 5.6). Any budget that is available should also be specified together with any constraints that the change has. It is vital that a time frame is specified as it is easy with any approach to let actions slip, especially when business situations can change quickly and resources are committed elsewhere.

As will be described, the fourth phase is an evaluation one. To be able to carry out that evaluation some form of metrics are required, which must be specified at the planning phase so that they can be deployed in the action phase and reflected upon in the Evaluation phase. There is no theoretical requirement to specify qualitative over quantitative metrics providing that all are happy with the measurements chosen.

8.4.1 People

In adopting a people perspective the change programme is looking at the skills, competencies, morale and degree of job satisfaction experienced. While it is important to know the activities that are being carried out by the process, it is the ability of the people to carry out that process that is assessed with the people perspective. There may be informal teams or social groups within the business that enable information to be transmitted more effectively than the formal reporting structure, in a similar manner, peer group pressure may be more powerful than the formal disciplinary structure.

The literature discussed in Sections 3.5 and 5.8 contains numerous tools for analysing the people and their issues within an organisation. The important feature of note is that there is an explicit requirement for the people perspective to be considered at the

planning phase and for it to be taken into account when determining the perspective to continue the redesign activity.

8.4.2 Process

In Leavitt & Baharmi's work (1988) this perspective is labelled 'Task'. They see this as the external focus of managing change, of matching the tasks of the business to market requirements. However, current methodologies focus almost exclusively on the internal activities and technology within the system (see the discussion at Section 5.6). There is a demonstrated requirement from the field work to understand the internal activities and processes within the system (see Sections 6.4.4, 7.3.4 and 7.5.5).

In considering the manufacturing system in Chapter 3 it is argued that a systemic consideration should adopt a holistic focus. This leads to the consideration of the manufacturing system as a series of connected wholes or processes (see Section 3.4). These processes contain the activities which enable the tasks of the system to be undertaken. Thus, in considering the tasks of the business from a systemic viewpoint suggests a process perspective. For these reasons the Process perspective is concerned with the business processes and activities that the business undertakes internally.

8.4.3 Technology

The technology perspective considers the control and information elements of the system and how technology facilitates their implementation. The information element of this perspective is concerned with the flow of information around a business and how that information is used to control the processes of that business. It is primarily concerned with control of the process and the information and technology that is used to administer that control. There is an associated requirement to consider all the technological facets of the system. Since this is a manufacturing system, there will be manufacturing machinery that will form a significant technology base within the business.

This manufacturing technology will have a profound impact on the ability of the system to react to market needs and the perceptions of customers regarding the processes that should be undertaken, the time scales that the business should operate on and the costs involved. There will also be people issues arising from a technological perspective that sees a requirement to introduce new technology and information management systems. The introduction of new information management technology may also have a profound impact on the organisational structure of the business as communication patterns alter. There may be further impacts on the organisational structure as decision making moves between people and the traditional authority and accountability structures no longer reflect the practice of the business.

The redesign of information systems and the technology of manufacturing systems is well developed within the literature as described in earlier chapters (see Sections 5.5 & 5.6). The important feature to note here, as with the previous two perspectives, is that this is but one perspective that should be considered in concert with the others. Whichever is chosen as the focus for any particular iteration should not be chosen to the exclusion of the others.

8.4.4 Organisation

In considering an organisational perspective the change programme is looking at the areas of responsibility, location of authority and the route of decision making. This is the organisational structure of the business and how it provides the support structures for the processes, people and technology. This may not be formally expressed in smaller businesses but there will still be reporting channels, lines of authority and responsibility. Where these are informal or have been superseded over time, the organisational approach will help the business to gain clarity over these issues and to determine the exact structure required. Larger businesses may find that they have changed significantly while their organisational structure has not kept pace. This can lead to excessive managerial structures, unclear job roles, confused authority remits and informal power structures being formed.

Organisational change is a well established discipline that specialises in the analysis of business organisations, their strengths, their weaknesses and the optimal method for getting from one state to the other. This methodology will not evaluate the different approaches to organisational change except to point out that they should be used with the iterative approach described here. That will ensure that the redesign is systemic and not entirely focussed on one perspective to the detriment of the others.

8.5 Risk Assessment

The principal purpose of this phase is to reach a Go / No-go decision for the proposed change identified in the planning phase. The risk assessment should be appropriate for the perspective being adopted and in line with company norms in managing risk. Some companies will accept higher levels of risk in anticipation of greater payoffs if successful, others will adopt a more conservative approach preferring to minimise their risk exposure.

Any change carries some degree of risk or cost for the business. The purpose of the Risk Assessment phase is to identify those risks and determine the probability that the benefits will out-weigh the costs. In planning the change, consideration should be taken of the likely costs of changing the organisation, introducing training, new technology or re-organising activities. These will be estimated costs but they should be sufficiently accurate for the business to be satisfied that they are not undertaking an unduly risky venture. This level of perceived risk will be unique to individual businesses as will the acceptable level of perceived risk beyond which actions are considered too risky to undertake.

Where a particular primary generator for ideas is proving to be unfruitful then this phase is there to catch that and suggest that a different perspective be adopted. Where previous work has been carried out (through previous iterations) the benefits should be weighed against the costs involved incurred. Pareto (1897) analysis may be used to judge when the 80% benefit level has been reached and the remaining 20% can be left for

another day (Hammer & Champy, 1993; Hammer & Stanton, 1995). Future iterations with a different focus may realise this remaining benefit as part of their change.

8.6 Action

It is important to carry out those actions proposed in the planning phase and justified in the risk assessment phase. The actions carried out should be recorded so that they are available for evaluation and the continual improvement of the redesign process. The planning phase will have specified a time plan and metrics against which the action phase can be measured. It may, at this point, be worth employing a linear project planning aid to ensure that the tasks identified in the action plan are carried out according to the plan. This may prevent slippage and ensure that the action phase does not cause the project to grind to a halt because no action has been taken.

8.7 Evaluation

Having carried out some actions in accordance with the plan, there is a requirement to evaluate the outcome of those actions. This is where the metrics become important. If the measurement system is not accurately thought out then the changes will be evaluated against incorrect criteria. It is important that the evaluation is carried out while the project is still fresh so that objectivity can be used. Too long a delay may result in people taking an overly optimistic or pessimistic stance in analysing the change.

Redesign is a learning activity and, therefore, each iteration will be constructed upon the learning that occurs during previous action phases. The evaluation phase is an opportunity to reflect on the actions that have gone before and the perspectives adopted to determine what can be learnt for the next planning phase. As the company gains in experience, the knowledge base upon which choices about the appropriate perspective will be made will grow. While this may not lead to more accurate forecasting of the appropriate perspective, it will lead to greater understanding regarding the importance of the different perspectives, their interrelationships and the implications for the manufacturing system.

8.8 Planning

Having carried out an iteration of the methodology, subsequent planning phases will have a slightly different composition. In addition to the strategic input there will be the results of the evaluation phase. These will lead the discussion on focus and aims for the iteration to come.

Where the evaluation may have identified a change episode that is beginning to lose momentum, it would be appropriate to investigate a different perspective to frame the following iteration. This is a valuable element as it prevents stagnation and self-limiting of the change process.

8.9 The methodology in action (see Figure 8-1)

Each initial iteration begins with a primary generator (Darke, 1978) which contains a problem situation and potential solution strategy. During the first planning activity the company considers the primary generator from each of the four perspectives. This allows alternative solutions to be considered. Once an appropriate plan had been developed and aligned with the perspectives the company would progress to the Risk Assessment phase.

The Risk Assessment phase acts as a stage gate to ensure that the company is aware of the risks inherent in the plan. It also allows the company to establish when a particular change stream has run its course and it is time to change perspectives. In this instance the company returns to the Planning Phase to either consider the original primary generator from a different perspective or to locate a new primary generator which would be considered from all four perspectives.

Once the plan as been assessed the Action phase carries out the plan. Any further project management activities that may have been specified in the plan are also conducted. When the Action has been completed the company Evaluates the outcomes against the plan. This will provide historical data for both future Planning and Risk Assessment

phases. The Evaluation phase may also suggest a change in perspective for the subsequent Planning phase.

8.10 Conclusion

A series of criteria have been developed from literature, participative observation and action research. These criteria represent an advance in understanding the phenomenon of manufacturing systems redesign within SMEs. The new understanding relates redesign requirements to an SME environment that is characterised by uncertainty, high rates of change, resource poverty and the need for simple applicable approaches. It can be summarised that a systemic methodology for manufacturing systems redesign within SMEs should:

1. allow rapid translation of design concept into implementation;
2. allow for learning about the system under consideration;
3. react to changes in the business environment;
4. explicitly show different perspectives relating to systemic consideration of manufacturing systems;
5. manage resource poverty;
6. be resource sensitive through risk awareness;
7. appear simple yet provide sufficient structure to manage a conceptually complex change.

From these criteria a methodology has been proposed that will allow the new understanding to be validated through field research. The methodology espouses a systemic consideration of a manufacturing system through the use of four complementary perspectives. From this systemic starting point an iterative redesign approach is adopted to develop the new system, manage risk and resource allocation and to check the efficacy of the process while maintaining a systemic overview. Each of the two concepts that gave rise to this methodology has been modified to better suit their new application and to complement each other in the desired task of providing a structure for manufacturing systems redesign. The result is a methodology that allows SMEs to proceed at their own

pace but ensures that they are not overwhelmed by the scale of the task ahead, nor are they allowed to focus solely on one aspect of the business.

While there is no directive in the methodology to consider each perspective in a set order, or to change perspectives after a certain number of iterations, this is not seen as a weakness. Each business will have its own prime generator which will, in turn, suggest an initial perspective. The decision to change that perspective may occur after only one iteration or after many. No methodology can predict how many iterations is the 'right' number. This methodology does require the business to consider different perspectives and how else the problem situation might be considered in the planning phase. It is ultimately up to the business to make their decisions since they are the ones who are responsible for the success or otherwise of that business. This methodology provides a framework for developing their manufacturing system in a resource sensitive, risk aware and systemic fashion.

The following chapters will take the proposed methodology described above and conduct a series of experiments. These experiments will apply the methodology in different companies to determine its applicability and usefulness with operating SMEs. This will be carried out through a series of action research episodes with each company. The results of the action research will be fed back into the methodology. Any changes that are suggested by the companies or the evidence will be used to modify the methodology. Once that phase has been completed the methodology will be validated in a further company to ensure that it is usable without extensive researcher involvement. Dery et al (1993) make the argument that research with a social dimension, as this has been through the inclusion of the structure and people perspectives, cannot be scientifically validated. The aim is to ensure that sufficient confidence can be ascribed to the methodology that the validating company would recommend its use to another company.

9. Experimentation

Chapters 6 and 7 established that manufacturing systems design was not being carried out systemically within SMEs and that those methodologies available were largely inadequate. In Chapters 3 and 5 two complementary domains were investigated. Chapter 8 developed the proposed methodology from the work conducted in Chapters 3 and 5 and with reference to the SME specific issues identified in Chapter 4. At this stage the methodology was in a proposed format and had not been tested in its entirety in an operating manufacturing system. The translation of approaches from one domain to another raises questions regarding applicability and the possible requirement to tailor the material to suit the new application. For this reason the experimentation phase aimed to take the proposed methodology and apply it in manufacturing SMEs and observe and incorporate their responses and thus develop the methodology. Once suggestions for improvements began to cease and the methodology was operating to the satisfaction of those using it, the experimentation phase would be complete.

This phase took place with four manufacturing SMEs in the UK. These businesses were self selecting in that they had identified that there were issues arising in their businesses that required external assistance. To this extent they had arranged with the University of Plymouth to manage Teaching Company Schemes (TCS) to conduct specific 2 year projects connected with those business issues identified. None of the TCS programmes was explicitly dealing with the redesign of the manufacturing system, they were concerned with information systems, strategy, materials development and new product development. The companies were approached and the purpose of the intervention was explained together with the expected outcomes for both the researcher and the business. All the companies were concerned with systems wide redesign activities rather than improvements to a particular machine or element of the manufacturing system. There

was an explicit concern for developing the manufacturing system with regard to all four of the perspectives.

Care was taken to ensure that the action research did not interfere with the schemes so that the results from each could be distinguishable from the other. While the principal contact point was the graduate employed on the TCS in two of the four cases, this was managed so that their time was not subsumed entirely to the research, the work was scheduled around their other activities and, where possible, at such a time as the two could operate in concert to the mutual benefit of both parties. In the other cases the principal contact point was the Works Director and Manufacturing Director, neither of whom was directly involved in the TCS being run at the time.

9.1 Research Format

In each experimentation instance both the research and researcher were introduced to the company. This was essential to ensure that a mutually agreed framework for working was established between the parties and to prevent the company from expecting something that was not on offer. The introduction activity typically consisted of a one hour informal discussion. During this time the research was introduced through early versions of the diagram shown in Figure 8-1. These were sketched out using a notepad while the general engineering and manufacturing situation at the case company was discussed. This provided for an environment in which both parties could set out their desired outcomes from the field study.

It was made clear that the research would not cost the business over and above the cost of implementing the designs agreed upon, nor was the research considered payable consulting. This was important to gain the trust of the companies that they were not committing to something that would lead to unplanned expenditure in the future. This also established the credibility of the researcher as an industrially grounded engineer who had moved into the field of manufacturing systems redesign. This also helped to build a rapport and working relationship between the researcher and the business.

The general structure of the methodology was felt to be one that would produce the results that were being sought by the business. It was also felt that the opportunity to consider the manufacturing system from different perspectives would provide greater scope for identifying solutions to the business problem situations that were being experienced. To this extent the methodology was agreed by the companies to be a valid approach to manufacturing systems redesign. The experimentation was to determine the development required to translate this basic concept into a methodology that would be applied in the real business world.

The investigation was carried out through a series of informal interviews and working sessions with the industrial contacts. This phase of the research was conducted in line with Action Research as described by Huxham & Eden (1996). To this extent there was significant involvement of the researcher in the development of the methodology as well as the development of solutions for the individual businesses. Since the phenomenon under investigation, the improvement of the proposed methodology, was an unstructured situation, formal interviews and questionnaires were not used. The research question was used to guide the work and notes were kept of the meetings. Visits to the companies frequently involved sessions spent with operators and managers within the business as specific solutions were developed using the methodology. These sessions provided a wider appreciation of the individual manufacturing systems and the particular application of the methodology.

9.2 Company A

Company A manufacture speciality furniture for children with severe disabilities. The business has grown steadily over recent years with products being introduced as its owner encountered new situations that the current range did not cater for. The low technology materials involved in the production of the products led to relatively unskilled personnel manning simple machines to produce moderately low volumes from a large

range of products. As the company grew and the product range grew with it, stock levels became a significant cause for concern.

A TCS graduate was developing a database to manage the control of design changes and part numbers but there was a significant problem on the shop floor with control of job cards and routings being less that adequate. On average 5 job cards were going missing each week, with an average of 12 parts per job card, this represented nearly sixty parts (21%) each week that went missing from the control system (Appendix Four). The family nature of the business had led to quite a nurturing culture and it was seen as not acceptable to lay staff off in search of more skilled or more highly qualified replacements. There was a real need to develop the manufacturing system to reduce the Work in Progress (WIP) stocks to free capital for investment in technology to help with the design process and to introduce training for the staff.

9.2.1 Planning, Iteration 1

Issue: Process

A significant amount of work had already taken place at Company A in developing their information systems through the introduction of consistent part numbering and Bill of Material (BOM) construction. This 'back office' work now required extension on to the shop floor where the staff were having to cope with increased orders and the new needs of the information system. A simple and effective version of Kan-Ban had been introduced to ensure that orders were only produced once and that the correct parts were made. The issuing of Kan-Ban tickets was strictly controlled, however, there were circumstances where a new ticket was issued. This happened more frequently than required with the result that there could be more than one ticket on the shop floor for the same part. This led to excess stock being carried, negating one of the prime reasons for introducing the Kan-Ban system. The loss of tickets was a social issue as the tickets themselves are large, wooden, red plaques that are easily visible (from many metres).

The change took a Process perspective initially to analyse the process to determine where the Kan-Ban tickets were going missing and to then determine a cause and develop

some actions to rectify the situation. Modelling of the process was suggested using both formal IDEF0 and informal sketches of activities using Post-It™ notes. These were to identify the areas where the tickets were going missing and suggest a solution to rectify the situation.

9.2.2 Risk Analysis

Issue: Process A quick analysis of existing data within the system provided a base line from which improvements could be predicted. This was used to justify the minimal interference with the system that the redesign activity would involve. The primary consideration was the savings that would be accrued since there were no capacity constraints apart from the increased stock held as WIP due to the problems with the Kan-Ban tickets.

9.2.3 Action

Issue: Process The modelling was carried out over several sessions at the factory. The early analysis suggested that there were four potential points in the manufacturing system where the tickets could go missing. Subsequent analysis focussed on these points and how the tickets were handled.

While it was possible that the tickets could be lost on the shop floor, this was not considered to be a significant risk. The tickets were substantial (4"x6") wooden plaques which were painted red with the part code in black. They were highly visible and the shop floor was relatively small. While there was undoubtedly some loss from the shop floor, it was decided to tackle that problem through training at a later date.

Further investigation of the system revealed that once the parts left the shop floor they were subject to a dipping operation that delivered a non-toxic protective varnish to the parts. Parts entering the dipping area were recorded and this was where the data indicating ticket loss was captured. Once the parts were recorded the tickets were returned to the Area Controller via a Blue Box. At this point the parts were effectively lost from the system

until they were returned to stores as finished goods. There were no figures to refer to since tracking had been lost but analysis of the whole process showed that significant delays were experienced in post-processing (i.e. consolidating production and stock records). Considerable stock was also being held. This was partially due to the break in the control line but also to the accumulation of stock that had been lost from the Kan-Ban tickets.

This discovery suggested that there was a larger problem than the missing tickets in the Work In Progress (WIP) held between dipping and stores. It was quickly decided that this was a more pressing issue to be dealt with than the duplication of Kan-Ban tickets. The modelling was invaluable since without that action, the larger problem would not have been identified.

9.2.4 Evaluation

Issue: Process   The initial action had highlighted a problem that was not part of the original systems redesign remit. This required a refocusing of effort from the process/social issue of Kan-Ban control to establishing the technology and tasks to maintain the link between the tickets and the parts throughout the production process.

9.2.5 Planning, Iteration 2

Issue: Technology   The plan to maintain the link between the tickets and their associated parts was relatively simple. It involved drilling a hole in the wooden ticket so that it could be attached to the dipping rack together with the parts it represented. While the tickets would slowly build up layers of varnish, they were cheap and simple to replace as required.

To minimise the disruption to production it was decided to carry out the changes on a rolling basis. The operator on the dipping station was given a power drill with the correct bit and left to drill a suitable hole in any non-drilled tickets. This also allowed the system to check for duplicate tickets and remove them when they arrived at the dipping station.

9.2.6 Risk Analysis

| Issue: Technology | While there would be some production time lost due to the

drilling activities, this would be minimal. The activity was relatively labour intensive since

the jigs for varnishing required loading. The additional workload associated with drilling a

single hole and loading that ticket on the varnishing rig was deemed acceptable. The delay

to production was also offset by the improved quality of data on stock levels and the

projected reduction in duplicate Kan-Ban tickets in circulation.

9.2.7 Action

| Issue: Technology | At the dipping station all the parts were loaded on a rig and

dipped, batches were mixed and split to keep the rig full at all times. Originally the tickets

would have been separated from their batch and returned to the production controller. Now

when a ticket arrived at the dipping station, it could be checked and drilled out (if required)

and hung on the dipping rig with the other parts. When the rig was emptied the tickets

could be kept with their corresponding parts.

9.2.8 Evaluation

| Issue: Technology | Following the redesign of the tickets to allow them to remain

with the parts through dipping, the general stock situation improved with visible stock

levels reducing significantly and throughput times beginning to fall. The next phase was to

return to the original problem of lost Kan-Ban tickets within the production process.

The change over of the Kan-Ban tickets progressed smoothly with few problems.

This has led to an improvement in part control visibility and reduced the number of

missing batches. It also provided the management team with accurate data regarding the

true capacity and stock within the system. Previously the loss of the tickets meant that

monitoring ceased at the dipping station.

While this increase in control was not part of the planned change, it demonstrates

the inter-linked benefits that accrue from systemic changes. Since the redesign began with

a technology and control focus, a non-systemic approach might have introduced a checking procedure for ensuring that new tickets were not issued. The database of tickets and orders might have been developed to identify those parts with duplicate tickets and the problem solved that way. While these may have worked, and developments of the database are planned, the ability to consider the wider possibilities allowed a much simpler and quicker solution to be identified.

The systemic approach had implications for the operators that were quickly identified through the four perspective concept. Part of the change was to enforce the authority and responsibility of the dipping process operator to reject part batches or batches that did not have a valid Kan-Ban ticket. This highlighted the need for a more Structural change that dealt with the culture on the shop floor. This future iteration will be required in parallel with People changes to ensure that the workforce has the skills and abilities to match their new job role.

9.2.9   Planning, Iteration 3

Issue: Structure   There were few changes that could be made to the actual production processes so the emphasis shifted to a Structural perspective to try and ensure that the operators stuck to the procedures that had been introduced. The person receiving parts for dipping was given the responsibility and authority not to accept parts without a ticket. An education programme was also instigated with the Kan-Ban system being explained again together with the reasons for introducing it.

The person running the dipping station was given the express authority not to accept incomplete batches or parts that did not have a ticket. The other workers in the system were gathered and the new regime explained. Coupled with the Structural focus of this perspective was a recognition that a People centred change was required to develop the culture of the manufacturing system. The aim was not to change the culture explicitly but to improve the ability of the people within the system to operate the system as designed.

9.2.10 Discussion

The iterative framework was particularly successful in both reacting to changing focus and maintaining momentum through instigating action on the shop floor. There was a concern that too much modelling or analysis would not lead to any changes. This was explained by suggesting that the manufacturing system was very simple, the materials were very traditional and there was little experience within the company of higher education. The perception was that methodologies from academia and literature were aimed at more 'advanced' companies and would be too complex for such a 'simple' company.

In fact the methodology worked with minimal guidance from the researcher. All the suggestions for improvements were developed by the management team of Company A. The initial investigation revealed an area of concern that was not readily apparent without the knowledge gained from the modelling. This led to another redesign iteration where the Kan-Ban tickets were modified to maintain the link with their associated parts. This had a double benefit in filtering out redundant tickets as they reached the dipping process and providing real data on the stocks held between dipping and stores.

The four perspectives were not described by the company in sufficient detail to be certain which focus was being adopted. While this did not prove to be an issue, because it was not possible to be certain which perspective was in force, it was not possible to suggest other perspectives from which to consider the situation.

Retrospectively it may be suggested that the original perspective was a process one. The focus was on identifying the flow of activities and where, within those activities, tickets were going missing. The second iteration was more concerned with technology and control. This was ensuring that the information on the shop floor was being captured (the exact state of tickets) and putting the technology in place to do that (the drilling of the holes). This does not represent advanced technology but it falls into the technology category none the less.

9.3 Company B

Company B are a traditional manufacturer of engineering machinery and equipment, the basic design of which has not changed since the original designs over 30 years ago. The company had been trading for over 50 years with most of the current employees being there for over ten years. In the last few years the company had been through an extended period of contraction, the result of newer models from the Far East and the rise of Numerically Controlled (NC) and Computer Numerically Controlled (CNC) machines that offered superior performance to their own products. This has led to understaffing and problems with a manufacturing system that was designed for a much larger operation using manual techniques.

The company wanted to determine what their manufacturing system should be actually doing, how they should be doing it and what new technology was available to assist them in achieving this change. To that extent they were concerned with redesigning their manufacturing system to provide them with a base from which to grow. A new graduate employee was developing a new product that would lead to a planned period of growth. It was perceived that this growth would be stifled under the present manufacturing system.

9.3.1 Planning

Issue: Process   The steady decline seen at Company B over the last decade had led to a manufacturing system that was operating at reduced throughput but with a legacy manufacturing planning and control structure. The original system was well designed to ensure that control and accountability were maintained throughout the manufacturing operation and that orders were met in a timely and sustainable manner. The reduction in throughput had led to a corresponding reduction in staffing levels but not in the planning and control system. Staff members were required to fulfil several roles within the planning and control system. The situation was such that the planning and control system was

beginning to disintegrate with staff circumventing it to maintain operational effectiveness on the shop floor. The initial focus at Company B was to analyse their processes from an external perspective to determine exactly what they were required to do for the customer.

Having discussed the situation with the Works Director it became clear that the people within the company were skilled at their jobs, had considerable loyalty to the business and would be reasonably open to change. The only morale issues that existed were linked to the steady decline that the business had endured. There were significant issues around the information and control systems and the Works Director considered that improvements to the processes within the company should precede changes to the information system. The company was a family owned concern with a very flat management structure that was not available for change in the early stages of the programme.

The first iterations were to adopt a Process perspective, investigating the activities, processes and information exchanges within the manufacturing system. Having conducted this process analysis it was clear that several activities had become too complex due to historical reasons and the gradual shrinkage of the manufacturing system. There was still a good case to be made for re-organising some activities, removing some redundant activities and generally streamlining the manufacturing system to make it more in tune with the current business environment. To this extent, a work plan was drafted to develop the 'fulfil order' process (Smart *et al*, 1996) and to redesign the control and planning system in parallel.

9.3.2   Risk Analysis

Issue: Process   There were initial concerns about financial outlay but these were connected with the involvement of the researcher, once these were clarified the decision to go ahead was made based upon the lack of information currently within the system. The expenditure was minimal since the researcher was to assist with the modelling activity and there was general agreement within the business that some action was required urgently.

No budget was set aside for redesign activity, it was to be justified on an individual case basis.

9.3.3 Action

Issue: Process The initial action was to develop a diagrammatic model of the manufacturing system and the fulfil order process in particular. This was carried out using the IDEF$_0$ activity modelling method. The models were constructed from interviews with the Works Director and associated members of the shop floor. The organisation had no skills in activity modelling and so this was provided. The Works Director had already begun to attempt some modelling of the shop floor but had neither the time nor skills to carry this out.

The greatest limitation on the modelling was gaining access to the Works Director to capture his extensive knowledge of the system. He was the only one within the company who had a holistic vision of the manufacturing system. The detail was filled in by those who worked in the different areas of the system. This provided illustrations of the formal system often being bypassed through lack of time or personnel to operate it.

9.3.4 Evaluation

Issue: Process Having established some of the background to the manufacturing systems redesign, some issues became apparent. The largest issue that the Production Director was concerned with was the perceived requirement for ISO9001 and CE mark approval. The business had attempted to attain ISO9001 accreditation previous to the research period. This had been with the assistance of an external consultant. The business, however, did not feel that the business benefits gained could justify the consultant's fees. The problem was felt to be too complex for the business to tackle on its own.

The business was not seeing strong growth and this was making it cautious in spending money. Ultimately the business could not convince itself that changing the

manufacturing system would lead to significant benefits. The future of the company was aligned with the new product development and its success in the marketplace.

9.3.5   Discussion

The structure of the methodology was well liked and was favourably compared to the 'fire-fighting' mode that predominated. The structure was seen to be sufficient to ensure that considered redesign occurred but with the flexibility that was vital within the business.

The four perspectives were also found to be useful. The long gestation period of the business situation had provided plenty of time for reflection. When the perspectives were presented, the Works Director quickly identified issues and previously proposed solutions for each perspective. The drawback to this was that the problem situation was now so large that tackling it all in one redesign, as suggested by conventional methodologies, was beyond the resources of the business. The iterative methodology provided an approach that could deal with the situation in manageable units without losing the global perspective.

Initial modelling had suggested areas of manufacturing activity that could be improved upon. Elements of the control system that were sub-optimal were also identified through the modelling activity. This information has been retained by the company for when they decide to re-initiate their manufacturing systems redesign.

9.4   Company C

Company C manufacture super-yachts to the designs of specialist yacht designers working with individual clients. The vessels are manufactured from exotic laminate technology to ensure the maximum strength-to-weight ratio, thus providing superior performance for a luxury sailing vessel. Every yacht is unique with each hull mould being scrapped after the lay-up and most of the interior fittings being designed according to a design theme determined by either the naval architect or fitting out designers. The use of

exotic laminates often requires reference to manufacturers to ensure that the proposed mix of materials will perform in the planned manner.

While the materials used in manufacturing are often highly specialised, the process of manufacturing is relatively simple and some aspects are not dissimilar to surfboard construction. The greatest differences are the scale, the need for accuracy and the cost of failure. The majority of the work force were from the surfboard industry or had worked building their own surfboards (Appendix Six). This has led to two distinct cultures within the business, those who have contact with the super-rich clientele and the surfers that form the workforce. While the process of building a vessel is well understood there is no real manual that could be used to train new workers when they arrived. There was also a concern about the lack of process development and the high cost of production. It was considered that redesigning the manufacturing system would enable the business to reduce costs while increasing quality, morale and the skill level of the workforce.

Company C were experiencing a period of growth in their market together with increased competition from global competitors. The nature of the market that Company C operated in was such that customers and clients operated in a global marketplace as a matter of course. The order winners were widely agreed to be performance and quality. Company C had an enviable reputation for excellence in building quality and this resulted in steady work for the company. It was perceived that maintaining this level of customer satisfaction involved an ongoing battle to maintain those quality levels. Developments by some competitors were causing a rethink of the position at Company C about whether changes could be made to further improve quality while reducing build times.

9.4.1 Planning, Iteration 1

| Issue: Technology | The iteration adopted a Technology focus since the initial perception was that better information and control procedures were required. While this depended upon a knowledge of the activities and processes in the manufacturing system the change focus was on information and control. The activities were to involve modelling

the manufacturing process and identifying the information and control that were involved in managing that system.

There was little perceived benefit to be gained from reorganising the process. A recent business development had been to import a new quality systems manual and the idea was to blend the new manual and the existing system to ensure that the manufacturing system at Company C was under control. This desire stemmed from the perception that the system was not fully under control.

9.4.2   Risk Analysis

| Issue: Technology |

Financial considerations were not a high priority since the actions were not likely to accrue significant costs. The greatest consideration was disruption to work and this was minimised through the use of the researcher and a new graduate employee who was working on materials development. This arrangement meant that the work could be carried out without disrupting the work patterns of the staff. This risk evaluation applied to all the changes developed using the methodology and was generally carried out by the management team to reflect their approach to making changes to the manufacturing system.

9.4.3   Action

| Issue: Technology |

The action phase involved analysing the manufacturing system's activities and processes to determine the information and control features that were required in the procedural manuals. This involved interviews with the Manufacturing Manager to build up a picture of the manufacturing system. This allowed the procedures manual to be evaluated against the processes within the system. This evaluation produced a clear set of activity maps that could be compared with the procedures manual to show how the procedures mapped to the reported activities (Appendix Six).

9.4.4 Evaluation

Issue: Technology

The action phase provided evidence that the perceived problem was not a control one. While the mapping of the activities had not established any improvements in the manufacturing system it extended the company's understanding of their manufacturing system. It also provided them with a simple, graphical map of the activities required to produce a complex product. This was not previously available, as the procedures manual did not show a schematic of the process being described. This desire for increased understanding and an ability to better identify issues that affected the manufacturing system provided the impetus for the subsequent iterations.

The procedures that were in place were sufficiently rigorous and closely matched to the actual process that there was likely to be little benefit from introducing more. There was little scope for making the current procedures manual more detailed since each boat was largely a new project. This meant that there were small variations that were part of the build orders for each order.

Since the procedures were found to be sufficient for managing the manufacturing process there remained the issue that quality was perceived to be at risk of deterioration. This was supported by business developments. The issue was then to consider the other perspectives to identify how else quality might be tackled. At this point the people perspective suggested an answer.

The majority of the workforce were from the surfing community with minimal comprehension of production concepts. They were not used to working as a large team on a complex and technically advanced project. Most of the workforce were relatively new to the technology but frequently had considerable experience working with composite materials. This led to re-invention of solutions for common manufacturing problems.

9.4.5 Planning, Iteration 2

Issue: People

The subsequent iteration shifted to a people perspective to try to encourage the staff to follow the procedures laid out and to report problems earlier in the manufacturing process so that they could be analysed and solutions found. There were many solutions that had been developed by the staff that were not captured in the documentation and these also needed to be formalised (Appendix Seven).

The high staff turnover was cited as the principal reason why organisational learning about the manufacturing process was so slow. Just as the staff began to understand the system, they left. It was suggested that a notice board should be used to collect ideas. This would allow ideas to be collected, peer reviewed, selected and finally enshrined in new operating procedures. The supposition was that by taking practice from the shop floor and converting it to procedures, (providing traceability and quality were maintained), those procedures would be followed by the operators that had suggested them.

9.4.6 Risk Analysis

Issue: People

The potential costs of installing a notice board were minimal, as were the ongoing costs of maintaining such a board. There was a risk that the impact would be rapidly lost if the information was not maintained and old messages not removed. To overcome this a particular person would be allocated responsibility for maintaining the board. The potential lack of credibility of notices would be addressed though a mediating foreman who would prevent patronising or 'pointless' notices.

9.4.7 Action

Issue: People

The action phase was indefinitely postponed due to external disruptions to the production system. The plan was to introduce a notice board based upon a dry wipe board that would allow messages to be recorded and modified as they arose. These could then be filtered over time to distil out those that should be enshrined in the written procedures.

New procedures had recently been introduced and it was considered that they were theoretically sufficient to ensure that the manufacturing system performed as required. The system had not been developed with the assistance of the shop floor and it was thought that they had not bought in to the system. This transfer of knowledge from the shop floor into the procedures manual would produce operating procedures that accurately reflected the practice on the shop floor and acted to maintain the required quality levels.

9.4.8 Discussion

The business had the clear perception that they required better procedures to facilitate maintenance of quality levels. This was evident from the early meetings held with the company managers. The new quality system that was purchased during the contact period was further evidence that the use of procedures was seen as the primary design requirement for the manufacturing system (Appendix Seven). The work with the methodology showed the company that there were different perspectives to the problem.

The first iteration developed the process models that were used to evaluate the control system. This perspective did not produce any options for developing the system further to improve quality. There simply was nothing that could reasonably be done to improve on the procedures manual to ensure that the build quality was maintained. The other perspectives produced a near instantaneous identification of another solution model.

While it was recognised that initial adoption of the people perspective would have produced a solution more quickly, the business considered the process models valuable in their own right as supporting documentation for the quality procedures system. These models were integrated into the quality system and used to supply an overview and to provide the context for the rest of the system. To this extent the initial iterations were considered to have been valuable learning periods which had delivered business benefits, albeit of a non-tangible nature.

9.5 Company D

Company D produce control panels for pumps that are used in utility industries. These control panels have to handle high currents and complex switching arrangements to control the supply of utilities between geographical areas. Each unit is unique in design and requirements and is constructed as a project against a specific order. These orders represent significant capital expenditure plans for the customers and tend not to occur that frequently, a single installation could take over 9 months with gaps between orders of 4 months not uncommon. A significant part of the lead time is spent conducting the design work on the switching requirements and control equipment and purchasing high value parts such as pumps.

A primary concern of the business was to introduce ISO 9001 to qualify them to bid for contracts since this was increasingly a requirement of the industry. This change would require alteration to every element of the business. While an employee was concerned with documentation and information management, there was a significant design exercise required on the manufacturing system that was to be carried out in parallel to the ISO work to ensure that the final system was not only ISO compliant but also suitable for Company D.

9.5.1 Planning, Iteration 1

| Issue: Process | The issues that existed with the manufacturing system were perceived to be concerned with the processes and activities. The first iteration thus adopted a Process perspective and focussed on modelling the processes and activities involved in fulfilling the orders that Company D had contracted for.

9.5.2 Risk Analysis

| Issue: Process | The principal concern was to evaluate the production process and to

determine the new technology that would be beneficial to the business. The introduction of the technology would be justified on the basis of cost savings against current lead times in developing solutions for customer enquiries.

9.5.3 Action

Issue: Process The first iteration was to develop a process map from which improvements to the production and assembly activities could be identified. The mapping was carried out with the assistance of the new graduate and the personnel on the shop floor. During the mapping it became clear that the issues that were most pertinent to the business situation at Company D stemmed from information control issues surrounding the product development process. This led to early termination of the mapping task.

9.5.4 Evaluation

Issue: Process Company D found that the information required to produce costing for financial reporting was not reliable. This was coupled with a general lack of project management within the business that made it hard to plan production and to effectively allocate limited resources. There were also situations whereby the manufacturing facility was being operated as a separate entity within the larger business. This led to a requirement for the formal exchange of information which might otherwise have taken place informally. Where this exchange did not occur satisfactorily, errors or delays in production occurred. There was a perception shift from Process analysis to Technology (Appendix Eight). The redesign was to focus more on the information generated by the product development process and the communication between the product development process and the fulfil order process.

As the product is manufactured using project management principles it is difficult for the business to introduce organisational changes incrementally. The feeling within the business was that it would be better to introduce a 'Year Zero' from which point all jobs would be progressed using the new system. This has implications in that the change is seen

to be radical and extensive with considerable importance being placed upon ISO 9001 compliance.

9.5.5 Planning, Iteration 2

Issue: Technology The second iteration adopted a more Technology based perspective and considered the upgrading of the information technology involved in producing quotations and designs. The issue that arose next was a resource based problem whereby there were insufficient resources to develop and implement a new technology led solution.

9.5.6 Risk Analysis

Issue: Technology The project nature and market sector of the business produced substantial delays between projects and extended contract negotiation phases that produced extreme uncertainty within the business. The project was postponed until more managerial time and financial capital would be available. To date the project has not be reinstated.

9.5.7 Discussion

While this project did not advance as planned, it did demonstrate the risk assessment phase in preventing more resource commitment on the change than was available. The perspectives worked very well in differentiating between the original process focus and the later technology and control focus. There was an associated structural issue surrounding the business organisation. This was recognised and it was decided that changing this was too large a project to be undertaken, given the moves towards ISO accreditation and the existing business environment.

9.6 Field Study Discussion

In general the methodology has been a success with little need for further development. In all the cases, at least something was achieved. Each of the four instances of the methodology in action has led to a different outcome for the companies involved.

Each instance also shows particular strengths of the methodology and where weaknesses were identified, these have been worked on and improved for future implementation.

Lack of resources, whether financial (as with Company D and Company C), managerial time (as with Company B) or managerial expertise (as with Company A) was a significant feature of all the companies. This reflects the general findings of Chapter 4 regarding the redesign needs of SMEs. Where the redesign effort failed it was always for financial reasons, despite the best efforts to develop solutions for minimal cost and to impose minimum loading on the employees helping with the redesign. This reflects the findings of Section 4.5.2 where financial constraints are identified as the most significant inhibitor of change. It has been found that while not invulnerable to resource constraints, the iterative methodology is highly resilient at continuing redesign effort despite the constraints imposed by the companies visited.

9.6.1   Planning

The initial planning phase in all the companies, involved determining the perspective that would be most useful to their understanding of the problem and the subsequent search for design solutions. In most cases this proved to be a process perspective as they were unsure of the actual activities that constituted the process being considered. The process perspective was also the most appropriate for moving towards a business-process focus. While this transition is not explicit within the methodology it was expressed as desirable by all the companies taking part in the research. The process perspective proved to be valuable in providing a boundary for the manufacturing system, within which the redesign activity could take place.

Once the different perspectives were described, all the companies involved were certain that they understood where the problem lay, in that they knew which perspective would be appropriate. This probably relates to the prime generator concept discussed in Section 5.7 and it is interesting that all four companies began by regarding their problem as being task or process focussed in nature. One of the significant experimental results is that

three of the four companies consciously changed their perspective at some point within their redesign activity.

In Section 5.7 the prime generator was identified as the conceptual design assumptions that are used to begin the design process. These are frequently adhered to even after they have been proved to be detrimental to the design. A significant failing of non-linear, self-governing design strategies was identified as an inability to reject non-advantageous prime generators. The iterative methodology used in the experiments above is clearly not suffering from this phenomenon since the participants were all able to reject their initial preconceptions of suitable solutions once alternative perspectives were presented.

The planning phase is also required to generate realistic time frames for the iteration and these tended to be measured in weeks or a month at the outside. This led to budgets that reflected the short time scales and were easy to justify in that the knowledge gained or saving made were scaled against a minimal outlay. This ability to translate planning into action supports the contention in the concluding section of Chapter 4 that SMEs require such approaches to cope with rapidly changing business environments.

9.6.2 Risk Analysis

One of the principal aims of the iterative approach is to reduce risk exposure for the business and this was achieved in all cases. The principal risk analysis approach adopted was a financial cost benefit style analysis where the expenditure involved was compared with the expected return in savings to the business. In every case this was either sufficiently significant to justify the proposed change or there were other factors that weighed more heavily, such as the need to understand the problem before proper analysis could be carried out. In all the cases, the changes were approved on cost grounds since any proposed change could be converted and argued from a cost basis.

When a change in focus was decided it was not because the risks were too great or that the returns did not justify the expenditure, it was because the evaluation of the

previous action showed that the focus had either been inaccurate or that the problem was perceived to have shifted.

9.6.3 Action

Having conducted the planning and risk analysis it remained to actually make those changes on the shop floor. This phase suffered through external uncertainties as described in Sections 4.3 and 4.5 and resource poverty as discussed in Section 4.1. External changes in the business environment delayed the implementation of some ideas and resource poverty led to initially fruitful projects being cancelled through lack of management time.

9.6.4 Evaluation

The evaluation phase was particularly important from a learning perspective and was identified as such in Section 5.9 in discussing design as a learning activity. It was during the evaluation phases that the companies above determined to change their perspective, to incorporate what had been discovered or uncovered during the preceding action phase and to lay the foundation for the subsequent planning phase. The evaluation phase also provided an opportunity to review actions against planning outcomes and to attempt to identify further areas for improvement.

It was originally proposed that the Risk Analysis phase would be used to determine the likely benefit to be gained from a redesign activity and to suggest changes in focus (Section 8.5). These changes have more frequently arisen from the reflection that is part of the Evaluation phase. This development represents one of the few significant changes to the methodology to be taken forward from this research phase.

The Evaluation phase appears to be a more natural point in the methodology for the participants to consider the next iteration. They have the recent Action phase to reflect upon, previous iterations to use as a knowledge base and an opportunity to consider other perspectives on the same issue. This often led to the changes of perspective seen and the development of novel solutions.

9.7 Conclusions

The most significant outcome from the experimentation phase was the affirmation that the methodology was a beneficial one. The iterative method proved valid and stable. It provided for risk minimisation and the rapid translation of planning into action. More significantly the iterations, and the Evaluation phase in particular, provided for a re-evaluation of perspective without admission of initial misdirection. The use of a formal methodology facilitates the move from being a subjective critique of the business owner to an objective development of an improved system. This is important since Bridge *et al* (1998) identify that comments on SME business performance are frequently interpreted as personal criticism. Of the four companies, two were family owned and managed and even the two non-owner managed companies did not have what might be considered 'professional' managers but people who had long and personal associations with the company.

The task perspective as defined by Leavitt (1972) is primarily concerned with established the tasks and activities that the business should be conducting. This is achieved by taking an external consideration and consulting with customers. Since this was not viewed as being practical for internal manufacturing systems development it was decided by the author to re-label the task perspective as 'process'. This was not the result of any single instance in the field studies but rather the experience gained across them all. The process perspective was still concerned with the activities of the manufacturing system but also incorporated a business process focus that allowed activities to be modelled using process modelling techniques (Childe *et al*, 1993; Smart *et al*, 1996)

While the four perspectives proved useful in both guiding and framing consideration of the manufacturing systems, there were concerns over definition and application. In some instances the business was not confident as to whether their situation fell into the structure, people, process or technology perspective. There was generally some confusion over the scope of the structure perspective and this was the least utilised of the

perspectives. The structural perspective was used in combination with other perspectives, most notably people, but not on its own. It may be hypothesised that this is due to the SMEs not having sufficiently complex structures as to warrant exclusive consideration. This is not something that affects the validity of the methodology but might suggest a future avenue of research.

While this methodology cannot alleviate the inherent difficulties associated with being an SME, it does provide a realistic planning and support mechanism for those SMEs seeking to redesign their manufacturing systems. Where difficulties were encountered these were imposed by the business environment. The greatest issues cited were lack of financial resources, managerial time and the security to make changes. These are environmental issues that no methodology will be able to circumvent.

The four cases presented above show that an iterative redesign approach can be used in the domain of manufacturing systems redesign. The cases have also shown that using the four perspectives as described ensures a systemic consideration of the system under investigation. In arriving at this point the methodology was subject to minor alterations and the researcher was closely involved in the change process. To ensure that the methodology is complete in itself and useable by an SME a validation phase is required. In this phase the researcher will maintain a distance from the phenomenon and simply record the activities that are undertaken in the name of manufacturing systems redesign using the proposed methodology.

10. Validation

This chapter describes the validation of the methodology. It sets out the aims of validation and the means by which validation is claimed. Validation will be claimed through the fulfilment of a series of criteria. These criteria have been previously derived from literature and case experience. Evidence of fulfilment will be collected through a longitudinal case study, the design of which is also dealt with here.

10.1 Aims

The principal aim of this phase was to establish the operational validity of the methodology. Landry *et al* (1983) describe operational validity as being the '...*quality and applicability of the solutions and recommendations...*' that are presented to decision-makers. They further comment that '...*operational validity is often considered the ultimate criterion for assessing the validity...*'. To this extent the validation phase will attempt to demonstrate that a company can use the methodology without intervention from the researcher. While some intervention will be required for data collection there will be no input into the process of redesigning the manufacturing system.

Chapter 8 presented new knowledge about SMEs and the redesign of manufacturing systems within them. That knowledge has been applied in four Action Research (AR) studies, as described in Chapter 9. Part of AR is to develop and extend theory (Huxham & Eden, 1996; McNiff *et al*, 1996; Westbrook, 1994). In the Validation phase, the methodology will be implemented 'as-is' to establish if further development is required. If the methodology developed and the underlying theory fulfils the criteria specified later in this chapter, then validity will have been established.

While the case for a structured model for validation has been proposed by Landry *et al* (1983) this is presented in the context of Operational Research (OR), a domain that is highly rationalist (Meredith, 1998). Such an approach is unsuited to the style of research being conducted here since it is assumed that the aim of OR is to construct a

'...*mathematical model to represent the system under study*...' (Dery *et al*, 1993). Such a logico-mathematical model does not have the ability to describe the systems that are under investigation here (see Sections 2.2, 3.5 and 3.6). Meredith discusses the creation of theory from case and field work in his 1998 paper on the subject. In that paper he describes the requirements of rigorous case research and the means by which validity may be established. Primary amongst these is the establishment of generalisability.

Huxham & Eden (1996) suggest that generality in Action Research is drawn out of the tools and techniques developed from the underlying theory. Meredith (1998) develops the concept further by stating that generalisability in case research is established through application of theory rather than replicability of results. The theory underlying the methodology that is the subject of this validation phase has already been applied in four Action Research cases (see Chapter 9). The validation phase, through the use of the case study method, removes the researcher from direct involvement thus ensuring that it the usefulness of the methodology is studied and not the usefulness of the researcher.

During previous research phases, the methodology has been in a state of flux that makes comparison between experiences difficult to justify. There have been no instances where the methodology and its application have been held constant while the actions of the company have been studied. Rather, actions and comments have been fed back in to the development of the methodology.

Yin (1994) describes a holistic case study design as one that deals with a single unit of analysis or phenomenon, in this instance the redesign of manufacturing systems. Meredith (1998) suggests that the case study method is highly appropriate where small numbers of studies are being carried. The case study will allow the methodology to be held constant while the companies use it to redesign their manufacturing systems.

10.2 Criteria

The literature and research experience provide criteria against which this methodology should be validated and evaluated. While these were discussed separately in

earlier chapters, they will be brought together here to provide a framework for considering the proposed methodology (see Table 10-1).

The availability of resources is a theme that runs through many papers on the topic of change within SMEs. Welsh & White first introduce the term 'resource poverty' in their 1981 paper describing the differences between large and small businesses. Ghobadian & Gallear (1997) significantly extend the largely financial resource poverty of Welsh & White to include knowledge and expertise, external information and management time. Recent literature considering entrepreneurship within SMEs (Bridge et al, 1998) and the application of TQM in smaller organizations (Yusof & Aspinwall, 2000) has continued this theme of general resource constraint. A methodology that is applicable within SMEs should, therefore, be resource sensitive to allow SMEs to best utilise those resources available.

SMEs have to be more reactive to their environment than larger companies since they can expect to exert less influence over the marketplace than their larger cousins (Casson, 1982). It is this external uncertainty about the marketplace that Joyce et al (1990) identify as one of the greatest barriers to change for SMEs. Joyce et al (1990) further suggest that a survival strategy to cope with this uncertainty is 'niche hopping' or being highly reactive to market conditions. The implications of this reactive, uncertain environment is that redesign will be a continuous process that will have to meet rapidly changing requirements. The redesign methodology should reflect this and facilitate iterative change.

To cope with this rapidly changing environment the SME manager is coping with a limited skill set (Bridge et al, 1998; Buchanan & Huczynski, 1997; Lee et al, 2000; Lefebvre et al, 1996; Marri et al, 1998; Scott et al, 1995). The constraints on managerial time that are identified as a significant element of resource poverty means that managers of SMEs do not have the time to learn new and complex change approaches and methodologies. One strategy for overcoming this constraint would be to build learning into

the structure of the redesign methodology. Cognitive theories describe a strategy of continual learning through a four stage process with external activity balanced through internal reflection and internalisation (Argyis & Schon, 1978; Ausbel 1963; Kolb, 1984; Larson & Christensen, 1993; Sticht 1976; Thompson *et al*, 1998). This approach has been recorded in industrial case studies as representing the approach that SME managers adopt in learning about their business and the environment they operate in (Gibb, 1997; Julien *et al*, 1997; Savolainen, 1999; Upton & Kim, 1998; Wemmerlov & Johnson, 2000). This is summarised in Table 10-1.

Validation Boundary	Methodological design solutions
Resource Poverty	
Management time	Simple design approach
Knowledge & expertise	Four perspectives
Financial resources	Small iterative changes
External Uncertainty	
Niche hopping	Rapid translation of plan into action
Changing requirements	Rapid evaluation of outcomes
Limited Skill Set	
No time to learn	Simple concepts
Learning Cycles	
External observation/discovery	Planning phase & 4 perspectives
Internalise and assess	Perspectives & Risk Assessment
Externalise and implement	Action phase
Internalise and evaluate	Evaluation phase

Table 10-1 – Validation Boundaries

10.3 Methodology

The research philosophy was discussed in Section 2.2 where it was explained why a qualitative approach to research was being adopted. Part of this discussion dealt exclusively with the choice of the case study methodology. That discussion will not be replicated here except to state that the case study method was chosen for its applicability to the research problem and its alignment with the general research philosophy.

Dery *et al* (1993) provide a comprehensive discussion on the problem of validation within qualitative research. They conclude that there are no universal scientific methods or formal criteria for validation that can guarantee the '*scientificty*' of a model. Meridith (1998) considers case study or field research to be as rigorous as other forms of research

providing attention is paid to detailed observation and triangulation. Triangulation is briefly described as the observation of the same phenomenon from different perspectives with each view providing supporting evidence (Cassell & Symon, 1995; Huxham & Eden, 1996; Romano, 1989).

A single longitudinal case design (Stake, 1995; Yin, 1994) was chosen to provide the depth of research data that would not be present with other designs. This depth and richness of data is a primary reason for choosing the case study method in the first place and '...*single case studies can be influential, especially when they are purposely non-representative, perhaps reporting major innovations...*' (Westbrook, 1994).

The longitudinal approach also provides for an understanding of the phenomenon under investigation as a dynamic rather than static process (Chetty, 1996). Design was identified in Section 5.8 and 5.9 as an ongoing process that has much in common with cognitive learning theory. The depth gained from a single, longitudinal case study would provide more useful evidence on the validity of the methodology than a quantitative survey approach.

A more practical reason for a single study was that the field being addressed is huge, estimates put the proportion of SMEs in the economic environment as being >99% (DTI 1997). To gain access to a realistic sample population and to conduct a quantitatively meaningful analysis of application of the methodology in such a huge sample would require more resources than were available.

The primary point of contact between the researcher and the case company was a change agent within the company. In addition to this point of contact, senior managers, the maintenance engineer and shop floor operators were used as sources for data gathering. Documentation, where available was used to support comments made by these contacts. Visits were conducted during which semi-structured interviews were carried out. The interviews were not recorded as the environment was not conducive to recording equipment (there is substantial background noise, even in the offices). Notes were taken

and supplemented by observations during post-interview factory tours (Appendix Nine). Visits to the shop floor provided validation of actions taken and provided opportunities for opportune interviews with shop floor operators. Field research was conducted over a 16 month period (June 1999 to October 2000) although most activity within the company occurred between June and October 2000 following two Kaizen Days held at the case company.

To help the company a short description of the methodology was provided to management (Appendix Ten). This contained a diagram outlining the approach and descriptions of each phase and the perspectives. This short document was to supplement the description of the methodology provided in initial interviews. Contact was maintained through a combination of email, telephone, company visits and meetings (e.g. email samples in Appendix Ten). Data collection was carried out through semi-structured interviews, unstructured interviews and informal discussions with significant personnel over the course of the longitudinal study. Numerical evidence was gathered by the company through their internal performance measurement system.

The methodology was introduced over three sessions to ensure that the company had a good understanding of the iterative frame and the four perspectives. This ensured that the subsequent changes were conducted using the new methodology rather than some other cyclic change approach. The company did have some experience with cyclic change but this had not led to a sustained period of change activity. Their previous experience was not focused on manufacturing systems change but on discrete and limited process improvements.

10.4 Background of the case company

AGS Home Improvements Ltd. (hereafter known as AGS) are a manufacturer of double-glazed windows and doors. They also manufacture conservatories and other home improvement features. Their primary range consists of either Aluminium or uPVC mouldings into which sealed glazed units are fitted. These are then fitted onsite by AGS

personnel. AGS have long been interested in continuous improvement and Kaizen but have been unable to generate a sustainable change initiative. Since 1997 a programme had been in place but had relied upon the efforts of a single manager to generate and drive the change effort. The programme had moderate success but with only eight projects in three years it did not have the degree of take up that was initially hoped for (Appendix Twelve).

The application of the methodology developed into two distinct change streams that evolved along quite separate paths. These will be described separately to show the possibilities for parallel change initiatives within an SME. Both change streams follow the methodology but start from different positions and with different objectives.

10.5 First Iterative Change initiative

There has long been a concern within the business to improve the efficiency and productivity of various product lines. In the original plans for the factory layout there was an area that was dedicated to producing doors. This area was re-allocated to storage before the move was completed. The Door Line was redistributed around the factory with machines being fitted in as well as possible. The two significant effects of this was that the production of doors came under the responsibility of three Team Leaders, none of which had ownership of the final doors and individual doors were subject to high levels of material handling while being transported around the factory. While improvements had been made to individual machines the sub- system for making doors was incapable of significant improvements until it was reunited as a recognisable system.

A production line had existed to provide glazing facilities. Quality problems with this line had long existed and had proven impossible to solve. The chosen solution was to sell the line and buy in sealed units for glazing. This cleared a space on the shop floor that proved to be the trigger for the first change stream. This provided an empty space into which the Door Line could be established as a production cell.

10.5.1 Planning, Iteration 1

Issue: Process

A plan was developed for relocating the production process that manufactured doors. While this started as a simple relocation it was decided to take the opportunity to change the layout of the line to increase efficiency (Appendix Thirteen). The plan was developed by the Maintenance Engineer with much of the detail being decided by the Team Leaders. In this manner the final plan gained from significant 'buy-in' from the shop-floor operators. This plan contained details regarding machines to be moved, timings, costings and the likely disruption to the production of doors. The move was planned to coincide with a seasonal downturn in orders so that spare capacity could be used to make up lost production.

During this planning phase there was a long term objective to move the Aluminium line to share space with the Door Line. This would establish the Aluminium line in a more central and easily supported position on the shop floor. To achieve this in the space allocated there was a reassessment of the plan as presented and a new plan was devised to house both lines on the shop floor but in a more space efficient layout.

There were also Technology issues to consider since the control of the new door line would be entirely under the management of one Team Leader. This was a significant change from the old approach. The new layout would allow visual control to be applied since all the stages in the manufacture of doors would be in one controlled area. The scheduling of door production would not be effected by the change, at least until the capacity of the new line was fully realised.

10.5.2 Risk Assessment

Issue: Process

Part of the objective was to change the layout so that the production line would be more efficient. This was planned to produce savings of several minutes per door. The lost production spent moving equipment would be recovered through the increased savings and reduced production times. Individual times for door production were

not recorded as several operations were shared with other production lines. This made it impossible to separate out the door production figures.

While there was no budget available for the move there were considerable savings to be reaped from the new layout. These savings could be offset against any materials that would be required. The only significant cost was to be the labour input from the Maintenance Engineer. Having established that there were no inhibiting risks the Maintenance Engineer was authorised to begin the next phase of the redesign and implement the actions determined in the planning phase.

10.5.3 Action

| Issue: Process | Once the existing production line was removed from the allocated bay, the first actions to be carried were the re-routing of services to the new area. The move was conducted in the order that material would flow around the final system. The saws were moved first and located so that they were within easy access of raw material being supplied from stores. The welding equipment was next followed by the rest of the machinery in turn. Finally the assembly benches were moved to the end of the line and the initial move was complete.

All the work was carried out by the maintenance team with the assistance of the operators. The move was spread over a week of production time. In this manner the Maintenance Engineer estimated that only half a day had been lost in production. While the move had gone smoothly the methodology required an evaluation phase to check the new situation against the forecast gains and benefits.

10.5.4 Evaluation

| Issue: Process | An integral element of the relocation was to bring the entire Door Line under a single Team Leader. This had major implications for the Structure of the organisation. The responsibility for door production had previously been distributed

between three Team Leaders, with each having the opportunity to apportion blame to the others. Now that the line was under a single person this was no longer possible.

This change to the organisational Structure of the business was recognised within the project but was not acted upon. The business was facing a period during which there was the potential for significant changes to the organisational structure. It was felt that to begin a redesign looking at Structural issues would be premature and had the potential to create confusion over the direction the business was going in.

In parallel to the consideration of a Structural change iteration the line was 'bedding in' while problems were ironed out. It quickly became apparent that insufficient room had been allowed for operators to move and handle sections of profile. Production efficiencies were not being realised since the flow of material was hampered by the cramped conditions.

The Aluminium market was not performing as planned and it was no longer considered profitable to spend the time and labour on relocating the line. Thus the space that had been reserved for the Aluminium Line became available for the Door Line. The original plan that utilised two bays in the factory was re-instigated with slight modifications from the operators and Team Leaders.

Before the second move could occur the methodology called for a planning and risk assessment. This prevented a knee-jerk reaction and ensured that the second move would proceed as smoothly as the first. The focus would still be on process improvements.

10.5.5 Planning, Iteration 2

Issue: Process A plan was quickly established to modify the layout of the Door line so that the suggestions of the Shop Floor and Team Leaders were included. This produced a floor plan that was a refinement of the original. The new movement would be carried out during normal production since the changes were minor and no new services were required. Disruption to production would be minimal. With the continued downturn in

orders there was sufficient capacity within the line to cope with minor down time while the modifications were carried out.

10.5.6 Risk Assessment

Issue: Process The costs were to be minimal since the internal maintenance engineer would carry out the work. Since the layout of machines was not being radically altered the risks to capacity were minimal. The purpose was to provide the operators with a better working environment and smoother material flow so that the true capacity of the system could be realised. Spare capacity within the line meant that any disruption could be quickly recovered. The whole of the, now available, space was not to be utilised. The plan only called for 85% utilisation, this additional 15% would be used to absorb any WIP. The space would also allow some manoeuvring room when re-positioning the machinery.

10.5.7 Action

Issue: Process The floor plan was implemented immediately. Minimal alterations were required to the services since the machinery was not being moved far. Machinery was typically moved a couple of metres in one direction or another. The short distances coupled with the new cell layout allowed for the moves to take place during machine slack times. During these times the operator would move to another machine. In this manner the production output of the Door Line was not affected by the Action Phase.

10.5.8 Evaluation

Issue: Process The new layout was an immediate success. This success was both in terms of productivity, which increased, and also morale. The Team Leaders had seen the original plan that was proposed by the shop floor modified for reasons that were not immediately apparent. The new plan had not succeeded. This lack of success was not due to sabotage from the shop floor but simply that the plan was flawed in trying to accommodate too much activity into too small an area. The reasoning was originally

sound, the Aluminium Line was to join the Door Line, but the outcome was that projected improvements were not fully realized.

Following a change in situation the original constraints no longer applied. This allowed the original plan to be applied, with suitable modifications gained from the first relocation. This plan was then implemented and found to succeed. This had a positive impact on morale since 'their' plan was now working and they had seen the readiness of management to listen and implement the ideas that were generated from the shop floor.

A brain storming session, at which the author was present, was subsequently conducted to develop ideas for further change projects. The area that appeared to generate the most comments concerned the storage of WIP around the shop floor.

The issue of storage as described did not easily fit into the four perspectives used in the methodology. This caused a degree of unease until it became clear that storage was not a cause of problems within the manufacturing system but an effect of other problems. Further discussion revealed that the problem was not the storage but the bottlenecks that led to the WIP building to the point where storage became an issue. The recent changes to the layout had improved the efficiency of the Door Line and this was causing problems for glazing. This now represented an issue that resided within the Process perspective, a bottleneck had moved and was causing the storage issues that were highly visible.

10.5.9 Planning, Iteration 3

| Issue: Process | The suggestion was made to remove glazing of doors from the main shop floor and include it in the new Door Line. This suggestion led to others and a free discussion ensued around the organization of the activities in the process that would provide the most appropriate use of company resources. In addition to the purely process issues there were training issues that resulted from the need to move personnel towards a multi-skilled environment and the freedom to plan and organize their own work patterns depending on the jobs present.

Training was quickly identified as being important in this Process change since the people within the system did not have the skills to carry out the new tasks that were being assigned to them. The new approach would mean that operators would have to have the confidence and authority to stop work on an area and move to the bottleneck area to help out as required. This would involve further training to ensure that the flexibility existed to make this a viable approach to production scheduling. There was a degree of animated discussion around the subject of the change, scope and associated issues, which was finally resolved when it was clarified that this was an iterative process and they were not expected to get it 100% correct the first time. There would be a period of learning and development, during which time other suggestions that had been floated could be incorporated into the plan.

Towards the end of the discussion it became necessary to name an individual to act as the change agent. There was some reluctance to accept this role until it was made clear that there would be assistance, from the manager and other team members. This role was accepted by the fitter who would eventually have responsibility for running the new operation. Both the team leaders in the meeting offered their assistance in training the operator in the new techniques he would have to master. The other members of the manufacturing team offered their help.

The time frame for action was also specified as being 17 working days. This time frame was chosen as the manager was taking 14 days holiday and the challenge was to complete the change before he came back. This represented a 3 day period while the manager was still on site when the project plan would be formalized and a two week period when the work could be carried out. The operator who was the change agent for the project was to produce a plan within two days and this would then be evaluated by the manager before implementation. Such a short time frame was largely possible due to the slack that was present in the system at the time of instigating this project. It was also seen as

important by all present to make some positive changes quickly to maintain the momentum that had been generated in the meeting.

The metrics chosen were capacity (time to manufacture, queuing time) and reduction in waste. These were already known through previous analysis projects and could easily be measured in the new system. They also represent clear and visible measurements that could be related to the changes made on the production line.

10.5.10 Risk Assessment

Issue: Process | The system had over capacity and no new equipment was required. It was thus considered to exhibit minimal risk for the business. There was some concern that the glazing operation would be too complex or specialised to be integrated in to the Door Line. If this proved to be the case the glazing operation would have to be returned to the main glazing area. The over capacity provided sufficient slack that any back log created could soon be cleared. There would be minor tooling and layout changes but these would not cost much and were likely to be recouped very quickly. The benefits could be substantial. If the approach was successful then it would be extended to other parts of the factory where the savings would be even greater.

10.5.11 Action

Issue: Process | The door line equipment was moved around such that the beading and glazing was carried out as part of the door line and not at a separate glazing station. This led to equipment being freed up which in turn led to more suggestions regarding the cascading of this improvement throughout the factory. The changes were overseen by the factory Maintenance Engineer.

10.5.12 Evaluation

Issue: Process | The productivity per worker was significantly increased through the integration of beading and glazing into the main door line. The most significant improvement was the reduction in Work in Progress (WIP). The reductions in WIP

triggered a reduction in scrap and rework since there was also less material handling and opportunity for damaging products. There were few options for improving the productivity further through layout changes. The control of the production cell was largely visual with doors being progressed through the system as the next operation became free with little scope for improving on this. The organisational structure of the cell was functioning adequately and there was general reluctance to change this given the potential changes that were on the horizon. From a people perspective there was real scope for improving morale and job satisfaction through cross-training. This could also improve productivity through flexibility.

To achieve this flexibility, the new staff required formal training from the existing staff. This was suspected at the planning meeting but it was thought that they might be able to pick it up as they went along. While the tasks are not too complex, working on the equipment does required specialized training.

10.5.13 Planning, Iteration 4

| Issue: People | Having established the new layout, the staff operating it required training. This had been foreseen at the original planning meeting and was expected. The training was to be carried out by the existing glazing staff within AGS and would be focused on the door personnel that would be operating the machine. Once the initial training was supplied by the glaziers within AGS the operators within the Door Line provided cross-training for their colleagues. The visual nature of the new manufacturing system for doors simplified the control requirements so no significant training was required for the Team Leaders to maintain production levels.

10.5.14 Risk Assessment

| Issue: People | There would be some reduction in capacity while the glazing staff were employed in training their colleagues from the door line. However, the factory was still operating at reduced capacity and this was not seen as an issue by the manager. The

benefits would be that the equipment would be used properly and, in addition to increased productivity, scrap levels would be reduced.

It was also a voiced opinion that the increase in flexibility of the staff would have a dual improvement. The possibility for job rotation and hence enrichment was seen as a significant supplementary benefit from this cross-training programme. The current manufacturing and assembly operations were relatively repetitive and some variation was considered to be a good thing. The flexibility of the staff also reduced the dependency of the system on a small number of key personnel. If one operator was taken ill or had holiday booked, the others would be able to adapt and maintain the efficiency of the system.

10.5.15 Action

Issue: People

The training was carried out by the existing glazing staff. This took the form of a half day session for the operators that were to initially take over the operation. This training was carried out on the machines in the Door Line and using door assemblies. There is no formal appraisal system that is linked to training so it was left to the existing glazing staff to assess that the required level of competence was achieved. Once training was complete the glazing staff handed over the complete operation to the door line which now operated independently from the other lines on the shop floor.

Having completed the training, the operators began training their colleagues in each other's tasks. An informal job rotation scheme began with operators moving around once they felt confident on each machine. The aim was to have all the operators capable of completing any of the five major activities involved in door manufacture. While this was seen as important by the operators it was recognised that some would not wish to learn all of the equipment. It was made clear that this would not be the subject of negative appraisals, though this may change in the future. This Action was being continued externally to the change programme since it took some time for all operators to progress through the whole Door Line.

10.5.16 Evaluation

As a result of their training the operators on the door line are now more aware of the difficulties inherent in glazing. They have also experienced the problems that used to result from beading being cut incorrectly. Since they are now carrying out their own beading they are able to cut the material to fit and correct errors immediately. They also express greater job satisfaction and increased feelings of professionalism since they are responsible for the product throughout its production life.

The changes to the Door Line included a shift in responsibility for production and quality. This used to reside with several Team Leaders since a door would pass through many areas during production. There was a temptation to abdicate responsibility to one of the other areas. The new layout placed all the responsibility with a single Team Leader. It also gave that Team Leader the authority to control the production line that made the doors. This was a significant change to the Structure of the business and its organizational culture.

In an interview with the Maintenance Engineer and informal talks with the Door production operators there was a noticeable shift in the culture. There was a new sense of identity. The increasing flexibility of the operators meant that they were able to move around the production line. This enabled them to help out their colleagues when problems arose. Problems could now be tackled by the combined efforts of the team rather than simply awaiting the arrival of the Maintenance Engineer. To demonstrate this new team spirit the Maintenance Engineer recounted an example that '...*they now applaud late comers back from lunch...*' (Appendix Three).

Prior to the changes there was no formal definition of the responsibilities of each Team Leader. This made it difficult for the business to carry out a change to the organizational Structure. It was recognized that Structural issues were of concern and that there were implications from the changes already conducted. The business situation at that

time was particularly volatile. It was concluded that formal changes to the organization would have to wait until the business situation resolved itself.

It was identified that the changes made to the Door Line could be replicated elsewhere within the factory. This was first mooted at an earlier planning phase when the glazing and beading was incorporated in to the Door Line. There was scope for changing all the working practices to reflect this improvement.

10.5.17 Planning, Iteration 5

Issue: Process   Before the roll-out of the developments made within the Door Line could be implemented, there were layout changes that were required in the glazing area. This was to provide more working space with less travelling between stations. The change would also increase safety since it would prevent people taking a short-cut through the glazing section.

The plan was two-fold. To move the glazing area slightly and to re-structure it to follow a more orderly flow pattern. The move was only to remove the short-cut and to better facilitate the flow pattern. The layout would establish a 'U' shape from stores to goods outward.

Since the entire product range (with the exception now of the Door line) depended on glazing it was vital that normal production was not interrupted. This was to be achieved through a phased change. Each section of the line would be moved separately but to a master plan. While a section was being moved a temporary facility would be established to carry out production. This facility would allow the move to be completed without disrupting normal production.

Incorporated in to the new layout were better defined walkways and routes for transporting material. The disruptions to the original layout plans (see Section 10.5 above) led to no defined walkways or clear routes for material handling. These had been introduced later to comply with Health and Safety requirements but were not widely used due to the distributed nature of the production lines. The relocation of the Door Line to a

dedicated area and the changes to the layout of the rest of the factory provided an opportunity to improve the walkways and material handling routes.

10.5.18 Risk Assessment

| Issue: Process | The costs associated were minimal with some expenditure being required. The bulk of the expenditure was in maintenance time and effort. The savings to be recovered were considerable. The new line would be more efficient, effective and flexible. Part of the change, which was to happen in a later iteration, would reduce scrap and increase quality levels across the product range.

10.5.19 Action

| Issue: Process | The changes were conducted over a period of two days. No major incidents were reported and everything proceeded according to the plan developed. Each jig was moved separately and production shifted to a temporary jig or table until the equipment was ready in the new location. All the temporary jigs and tables functioned as required. During the change there was no measurable change in production efficiency or output.

10.5.20 Evaluation

| Issue: Process | There was no measurable drop in productivity during the change-over period. This was testament to the effectiveness of the risk assessment and the contingency plans that were established and implemented. The involvement of the shop floor in the planning and risk assessment phases ensured good buy-in by the operators.

The morale of the shop floor had increased and the flow of products was noticeably more natural. There were no measurements prior to the change that established the time spent moving material but the shop floor report that it is easier to operate the line.

The new walkways and material handing routes have also proved popular. There are now clear routes for raw material to enter the factory and be placed next to the point of use, for material to be moved between operations and walkways for people to get around

the factory. There are fewer instances of people taking 'short-cuts' and compliance is with the spirit as well as the letter of Heath and Safety regulations.

10.5.21 Planning, Iteration 6

Issue: Technology   With the production line in a new formation it was planned to transfer the new best practice from the Door Line to the rest of the factory and include beading with the glazing operation. While planning this out it became clear that the complexity of the product range would cause more problems than it would solve. The company was anticipating the Risk Assessment phase that would follow Planning and decided that the outcome would be negative so did not proceed with comprehensive planning. A new direction was sought and found by considering the technology and control issues of the manufacturing system.

These issues had not been a feature since there were more pressing needs. Since those needs had been largely addressed there was now scope for improving the control features of the system. An issue that quickly became apparent was the control over sill production. All windows require a sill to be cut to provide the outer face for the unit. While the sealed glazed units, windows and doors can be sold as mis-measures should an order be cancelled, the sills cannot since they are made-to measure and cannot easily be altered.

Sills are made up to two weeks before the order is due to be fitted. During this period some orders are cancelled or changed but that information is not transmitted to the sill line. Sills are comparatively low value items and do not take long to produce. They do take up a considerable amount of space on the shop floor prior to fitting and dispatch. With no structured storage area the sills were placed wherever they would fit, leading to long delays when a particular order was to be completed. Cancelled orders were not removed from the production area leading to sills that were no longer required cluttering up the shop floor.

The plan was to introduce segmented storage areas for different shapes and sizes of sill. A coloured and numbered 'T' card planning-board would display the current orders for

sills. Each card would identify the location and position of any manufactured sill in the temporary storage area. The cards would be stored in alphabetical order with the date of manufacture clearly visible. Any order that was two weeks old was moved to a separate section of the card index. After a further two weeks of being in the separate section the sill would be cut up and either scrapped or recycled according to production requirements.

10.5.22 Risk Assessment

Issue: Technology   The space that the sills took up was out of all proportion to their value to the business. Should a live order be scrapped because it was more than 4 weeks late it would not take long to manufacture a new sill. The actual production time for the sills was less than half a day. The two week stock holding was to buffer any orders that were pulled forwards, as sometimes happened. It also meant that all the details for an order were released to the shop floor at the same time.

10.5.23 Action

Issue: Technology   The planning board was installed and the new cards released. The approach worked well with all orders being tracked to ensure that they are not getting too old. Once an order was on the shop floor for more than four weeks it was scrapped. No scrapped orders were later called for.

The new storage areas were produced and labelled clearly. The areas allowed for large units to be stacked such that they were not damaged. Smaller units were stored above the normal working area so that they were completely out of the way.

10.5.24 Evaluation

Issue: Technology   The new storage protocol reduced the time spent looking for sills. The removal of old orders cleared space and reduced stock held. With the old stock removed there was more working area and less clutter, leading to a more pleasing working environment

10.5.25 The Future

As long as there is a business case for improving the manufacturing system then changes will continue to be made using the methodology. There is requirement to extend the technology and control focus into the planning activities to inform the shop floor of delayed or cancelled orders. This will also produce staggered release of production orders. A similar storage approach to that used for sills is being considered for the finished goods store where some units have been held for over four years without being discarded. Several other ideas are being suggested for other change initiatives that either follow on from those identified above or are in response to them.

The factory Maintenance Engineer commented that '...*people used to resist change simply because it was change...now operators and Leading Hands are asking when their area will be changed...*'. This shift in organisational culture was not planned but it does represent a beneficial change. The ease with which the methodology can be communicated is such that the shop floor are now driving many of the changes with management providing a guiding role and assessing the risks of each iteration.

10.6 Second iterative change initiative

The second iterative change initiative was conducted in an identical format to the first but with very different results. The team involved were from a different section of the factory and had different issues to bring to the meeting. Significant work had already been carried out purchasing new equipment and improving the manufacturing system. This was evidenced by the lack of production related issues that were identified in the brain storming session.

The largest cohesive issue set that was identified concerned communications around the factory. This was also evident with the first session but to a lesser extent because there were more pressing production issues. From the discussions that ensued

there emerged two significant areas that were identified as being candidates for improvement within the factory.

10.6.1 Factory communication

Within the factory there was no coherent communications policy with each area having their own notice board and communications channels. This led to terms such as 'tribal', 'us and them', 'gangs' and the like being used to describe the cultural situation pertaining to communications. It was widely believed that each group had their own information and this was not shared with other groups. In some instances this was department specific information in others it was more general company information and in yet others it was entirely unconnected with the company (several ads existed for private vehicle sales).

10.6.2 Cross Training

Another issue was that very few members of the shop floor had adequate skills in areas other than their primary role. This left the factory very vulnerable to skills shortages in the event of holidays or sickness. This was highlighted by several members present. The situation was compounded by several operators stating that they did not have manuals for their machine or equipment and that their knowledge was gained through experience and trial and error.

It was then pointed out that a training manual existed that contained all the information that was requested. This was not widely known and it was considered that certain members of personnel had been failing to communicate information between the shop floor and management. There followed a free discussion regarding role definition and general personnel organization and authority hierarchy.

It was decided that a training programme would be implemented and that clearer job roles were required for members of management. This was not included in the Kaizen project since it was outside the scope of those present to make changes to job description,

however, it was a valuable learning experience for the management team to receive feedback on the effectiveness of the communications channels. Surprise was expressed at several points that were made simply because they were unknown by the management team.

10.6.3 Planning, Iteration 1

Issue: People Discussions around the communications issue resulted in several suggestions being made, the most commonly agreed upon being the removal of local notice boards to be replaced with a single notice board. The location for this single board was a further topic for discussion, the principal reason for multiple boards was so that everyone would have easy access to a board in their area. While the toilets and canteen were suggested as possible locations it was finally decided that the clocking-in machine would be the one point that all members of the shop floor would visit at least twice a day. This then raised the problem that the clocking-in machine was not suitably located.

Relocating the clocking-in machine proved to be a minor issue that was quickly dealt with, resulting in a plan to move the clocking-in machine, erect a single notice board and use it to promulgate information to the shop floor. To ensure that this board was used properly a nominated person was designated as being responsible for maintaining the integrity of the information displayed. This would involve disseminating notices, removing old notices, pruning irrelevant notices and collecting opinion for suitable notices.

10.6.4 Risk Assessment

Issue: People The risks associated with the rationalization of the notice boards and relocation of the clocking in machine were considered to be minimal. There would be some disruption with people having to use the new position but the opinion expressed by the shop floor was that the current position was far from ideal, a considerable crush was reported at clocking on and off. The new position provided more room for queuing and the

notice board would provide something to read while waiting. The changes would be carried out by factory maintenance staff thus minimizing the costs to the business.

10.6.5 Action

Issue: People   The notice board and clocking in machine were relocated to a position within the factory that allowed for easier access and messages to be read while waiting to clock in and out. A single member of the shop floor staff was nominated as the responsible person for maintaining the board. The implementation was carried out by the maintenance engineer with no requirement for external work or spend. The action was completed within two weeks of the decision being made and quickly saw benefits.

10.6.6 Evaluation

Issue: People   The relocation of the notice board has seen two significant benefits for the manufacturing system from a people perspective. The state of 'Chinese whispers' that existed has been largely eliminated, the new notice board has also been brought to the attention of the management within the company and they have decided to use this as an avenue for disseminating information more freely. The management team had previously been too focused on their business situation with the knock-on effect that the staff had not been considered as a major issue. The management have since undertaken to publish more openly discussions and facts as they arise. The number of notices around the factory has been reduced and this has led to less work updating and monitoring them. There is also less clutter leading to a more professional image being portrayed to the shop floor by the management team.

While considering the improvements that the new notice board provides it was suggested that the other communication channels that had lapsed should also be reinvigorated. Primary amongst these were the monthly team leader meetings. These had developed into a session where grievances were aired with no attempt to resolve the

situations described. This was to represent the next iteration of the methodology with a people perspective.

10.6.7 Planning, Iteration 2

Issue: People The Team Leader meetings had been held to collect information from the shop floor and to promulgate information from management. It was also hoped by management that these meetings would result in suggestions being forwarded by the Team Leaders for managerial approval. This had not been the case and the meetings were suspended.

It was suggested that to improve communications throughout the company the meetings should be re-instated but with a different format. Instead of being used to air grievances, the meetings should be scheduled in three parts: the first being for management information or decisions to be disseminated; the second being for Kaizen sheets to be raised and discussed and finally any other issues that did not fit the Kaizen sheets. Exceptional situations that were outside the scope of Kaizen could be included in the last section. The use of the Kaizen sheets would ensure that the meeting discussed solutions to problems rather than simply presenting management with an ever growing list of problems and grievances with no suggested solutions. The Kaizen sheets had a dedicated section where decisions could be recorded and fed back to the originator of the sheet. This would ensure that the Team Leader meetings functioned as a two-way discussion forum.

This new format would firstly help the meetings become more productive and would also help contain the duration of the meetings. Previous meetings had extended beyond two hours with no outcomes.

10.6.8 Risk Analysis

Issue: People The company was experiencing a downturn that was industry wide. To reduce costs during this period there had been a series of reductions in staffing levels. It was recognized that the current staffing levels meant that every member of the shop floor

was contributing to productivity. This meant that for the team leaders to be removed for a period of time would have an impact on production. It was felt that the Team Leaders should be released to carry out the dual function of receiving information from the management team for dissemination and feeding ideas and concerns back to the management team. The benefits to be accrued should outweigh the loss to production.

10.6.9 Action

Issue: People The Team Leader meetings were re-established as a forum for discussing production and manufacturing issues. The Kaizen sheets that had been developed elsewhere within the company were introduced to act as a format for discussions. These sheets were designed so that they presented solutions to issues. This prevented staff from using the opportunity to '...*have a gripe at management or anyone who would listen.*'

10.6.10 The Future

With the Team Leader meetings re-established it was aimed to use them to suggest subjects for future change. This is an example of the iterative nature being continued for as long as a business case exists for change and improvement.

10.7 Discussion

Each of the Validation criteria (Table 10-1) will be discussed later in this section. Firstly some wider comments will be drawn out regarding the Validation phase and the implications for the methodology that may be deduced.

The four perspectives operated well in providing a balanced approach to considering the change focus. While no iteration adopted a Structural focus, this does not show an imbalance in the methodology against any particular perspective. The choice of perspective is at the discretion of the company using the methodology. To assist that choice definitions were provided as part of the methodology and in an accompanying

document (Appendix Four). All the perspectives were considered at some point in the case examples but the choice of adopted focus depended upon the contingent situation. At no point in the case study did the researcher interfere to suggest that a different perspective be adopted.

When the change focus did not appear to fit within the perspectives (see Section 10.5.8), the methodology redirected effort and identified the underlying cause that was leading to the effects that had been highlighted. In the evaluation phase of the change episodes there was a consideration of the next change to occur. Where significant gains had been made it was sometimes difficult to see where further gains could be made using the same perspective (see Section 10.5.12). Adopting a different perspective suggested where these improvements might be found and ideas duly appeared. This is important because it demonstrates that the four perspectives can be used to guide consideration of manufacturing systems, they are not a retrospective classification of change programmes.

While the company had attempted Kaizen and continuous improvement previously, these episodes had not lasted and had really only been sustained through the intervention of the interested manager. The iterative approach demonstrated here has motivated the shop floor personnel to become more involved in the change as they can see the rapid translation of their ideas in to action on the shop floor. The principal stumbling block that was identified with previous change episodes was the complexity of managing the change process and the associated delays. This complexity was eliminated with the new methodology and the result was faster iterations and more confidence from those using the approach.

The methodology has been used to guide the actions of shop floor operators in developing manufacturing systems redesign solutions. The use of the different foci has forced them to consider the wider implications of change (see Section 10.5.4) even when it was considered prudent not to act. The recognition that a layout change can have an impact on the organisational structure of the business is important since it indicates that a systemic

approach has been adopted. Rather than considering the manufacturing system as a series of discrete elements that can be improved in isolation, it has been recognised that the system as a whole must be borne in mind while conducting manufacturing systems redesign.

While a minimum of intervention was carried out by the researcher, all the iterations were initiated, planned, executed and evaluated by the employees of the validation company. They have also gone on to develop further changes using this methodology. The approach is valid in the context of a manufacturing SME that is seeking to carry out manufacturing systems redesign.

In addition to validating the methodology AGS were able to re-layout their factory over a series of iterations. That and the subsequent developments led to a reduction in manufacturing time of approximately one minute per door. The inclusion of beading and glazing has resulted in a 30% reduction in waste (£5000 p.a.) and the reduced Work in Progress is leading to less waiting time and less opportunity for damage to occur to part complete door assemblies.

10.7.1 Management time

The simple design approach has meant that senior managers did not have to oversee the application of the manufacturing systems redesign activity. The approach was explained in a short interview lasting approximately 30 minutes and then the rest of the redesign was carried out between middle management and the shop floor. The simple approach enabled the shop floor to take much of the redesign burden upon themselves. It also meant that all members of staff were aware of what was happening and this helped to ensure employee buy-in.

10.7.2 Knowledge and expertise

The four perspectives are described as 'obvious' when explained to managers. This does not mean that they would have used similar terms to describe the manufacturing

system on their own. It does suggest that they are able to relate their perceptions of the system to those of the perspectives with little additional knowledge. The four perspectives are also a useful descriptive frame for encompassing the whole of the manufacturing system in a manner that was not previously attempted in the validation company or previous evaluation companies.

10.7.3 Financial Resources

The application of the methodology did not require additional financial investment. The work was carried out by members of the management team and operators from the shop floor. Most of the suggestions were also implemented within normal operating budgets. New investment capital has been requested for a later iteration and this is meeting with some resistance due to uncertain business conditions.

As discovered in earlier applications of the methodology (see Section 9.6), financial impositions represent a significant inhibitor to change. The financial situation within AGS was explained to the staff and they were thus able to develop small change suggestions that did not exert too great a strain on the financial resources. It was because the individual changes were kept small and any costs incurred recovered quickly that significant changes to the manufacturing system could be implemented despite the limitations on financial resources.

10.7.4 Niche Hopping

The validation company did not exhibit niche hopping as described by Joyce *et al* (1990). Niche hopping is a coping mechanism in response to uncertainty within the business environment. It replies upon the ability of the business to react to change and quickly realign itself with the new business situation. To achieve this the business must develop, assess and implement change quickly. The methodology translated a vague plan for process change into action in one afternoon. Each iteration has taken between a couple of days to a couple of weeks to complete the cycle. There have been delays between cycles

while the system is allowed to settle before instigating the next change. While there may be features of niche hopping that are unique, the methodology had shown itself capable of implementing rapid and responsive change.

10.7.5 Changing Requirements

The uncertainty surrounding the business has led to several shifts in the business requirements over recent years and months. There is a constant requirement to minimize costs and increase productivity. With orders relatively flat there is little scope for real productivity improvements but there are significant efficiency improvements to be made. Once the uncertainty has lifted there will be significant changes required depending upon the direction in which the business chooses to develop.

10.7.6 No time to learn

The whole process was described to members of the management team in under an hour. This included a discussion about the perspectives and the translation of the methodology into practice. In the case of the operators the methodology was explained as the change progressed. In this way there was no single 'learning' period that had to be scheduled for. The simplicity and 'obviousness' of the approach and perspectives means that the new knowledge is quickly related to their everyday experiences and can be integrated into their understanding of their business environments.

10.7.7 External observation/discovery

The first planning phases were timed to coincide with a Kaizen event where members of the shop floor were invited to 'brainstorm' issues surrounding their working environment. This was held over two days and each session yielded significantly different results. Describing those results in terms of the four perspectives and showing that there are more ways to view the manufacturing system was a discovery moment for many present. The opportunity to calmly observe and reflect upon their manufacturing environment provided several significant insights into the operation of that system.

10.7.8 Internalise and assess

Those present from the shop floor had little experience of Risk Assessment and were sceptical of their ability to carry out this task. It was made clear that assistance would be provided by the management team. The management team were very keen on the Risk Assessment to ensure that limited resources were not committed to changes that were not going to deliver benefits. Most of the suggested changes did not involve significant financial commitment and the risks were disruptions to production and adverse reactions from the shop floor. Since most of the ideas originated from the shop floor there was little evidence of resistance to change emanating from this source.

10.7.9 Externalise and implement

The significant benefit of the methodology was that it delivered implementation plans during the initial Kaizen meetings. These were to make real improvements to the manufacturing system but did not require external assistance or financial commitment. The changes were implemented over a period of several weeks but the actual time spent on implementation was relatively short, in the order of a day or two. This allowed the shop floor to see real changes as a direct result of their discussions.

10.7.10 Internalise and evaluate

Initial feedback from the changes suggests that the hoped for benefits have materialized. The problems that were initially identified have been solved and further improvements have been identified. The savings made from reduced damage caused to parts in the system will more than offset the cost of rearranging the shop floor. In addition the shop floor operators are now expressing a 'more professional' feeling since they are empowered to carry out more of the production process and it was their ideas that led to these improvements. Thus benefits have been reaped that are over and above those identified.

10.8 Conclusions

The methodology was successfully deployed within the company. Two parallel streams of activity were initiated through focused sessions with shop floor staff and business managers. Each of the streams adopted radically different foci for their change activities and the methodology proved robust in application. Although the company was experiencing a period of financial resource poverty, the redesign activity was able to provide solutions that were sensitive to the resources available. This ensured that suggestions made were implemented and the change momentum maintained.

During the course of the changes the company was able to make significant improvements to their manufacturing system. The new Door Line has reduced the production time of a single door by approximately 2 minutes. By moving the glazing activity within the Door Line it is estimated that £5000 p.a. (30%) has been saved through scrap reductions. Although currently un-quantifiable, there has been a rise in final goods quality since WIP and material handling has been reduced. The operators on the Door Line have been quoted as feeling '...*more professional...*' with full ownership over each door that they produce.

The validation phase was conducted through the case study method to provide separation between the phenomenon under investigation, the redesign methodology, and the researcher. This separation was achieved by allowing the company to manage and drive the change episodes. Interpretation of the perspectives was left to the company within the guidelines presented by the researcher.

The methodology was able to focus the company on dealing with systemic redesign of their manufacturing system. It fulfilled the criteria identified in Table 10-1 as discussed in Sections 10.7.1 through 10.7.10 above. Against these criteria and in the context of systemically redesigning manufacturing systems within SMEs the methodology has been successfully validated. The final chapter will present the findings from all the

chapters and make the case for the contribution to knowledge, its derivation, consolidation and validation.

11. Conclusions

This thesis contributes two significant elements to knowledge. The first is the new understanding of the impact that the SME environment has on the process of redesign. The second is the new understanding about the systemic consideration of the manufacturing system and its implications for redesign. These twin streams of knowledge are enshrined in a new and validated methodology. The rest of this chapter will discuss these features in more detail together with an overview of the work carried out.

11.1 Foundation Knowledge

Chapters 3, 4 and 5 considered the primary knowledge domains that were involved in this thesis. These chapters critically evaluated each of the domains of systems theory, the SME business environment and design theory with regard to their application to the problem of manufacturing systems redesign. That knowledge was later extended with field research to provide a new understanding of SMEs' requirements for manufacturing systems redesign.

Chapter 3 introduced systems thinking and its development from Boulding (1956) and Bertalanffy (1968) to modern concepts as described by Checkland & Scholes (1990) and Checkland & Haynes (1994). This was then applied to develop the concept of a manufacturing system. The concepts associated with social systems were introduced and a more expansive consideration of manufacturing systems presented. This consideration was further developed (in Section 3.6) to provide a definition of a manufacturing system that would be used for redesign purposes.

Chapter 4 developed an understanding of SMEs and their particular features. These features are characterised by uncertainty, high rates of change, resource poverty and the need for simple, applicable approaches. This new understanding was related to the redesign requirements of such an SME environment and was used in later chapters to evaluate current redesign methodologies. The later case studies were referred back to the theoretical

understanding presented here to ensure that the assumptions made are valid in the light of empirical evidence.

Chapter 5 introduced design theory from the first distinction of design as separate from manufacture in the early 1700s to the emergence of a recognisable process of design in the mid 1950s. This later work was used as the basis from which modern redesign methodologies were shown to originate. The preponderance of linear strategies was demonstrated and reasons for this suggested (see Section 5.6). Alternative design strategies were also presented and their applicability for manufacturing systems commented upon (see Sections 5.8 to 5.10).

11.2 Manufacturing Systems Redesign within SMEs

The work in Chapters 3, 4 and 5 was complemented by participant observation described in Chapter 6. This sought to combine and extend the learning presented into a new understanding of manufacturing system redesign issues within SMEs. This work allowed the development of seven criteria that should be fulfilled by any methodology that seeks to guide manufacturing systems redesign within SMEs. Those criteria are presented in Chapter 8 and summarised in Section 11.5.

11.3 Critical evaluation of current methodologies

The evaluation of current methodologies was based upon two sets of criteria, the theoretical requirements identified above in Section 11.2 and empirical evidence as described in Chapters 6 & 7. The criteria presented in Section 11.2 are derived from literature on systems thinking (Chapter 3), on the phenomenon of the SME (Chapter 4) and on design theory (Chapter 5).

11.3.1 Theoretical considerations

In reviewing the strategies adopted by current redesign methodologies, Chapter 5 found a predominance of linear approaches. Yet one of the features to arise from the

literature on SMEs was their highly uncertain environment. An identified strength of SMEs was their ability to rapidly adopt to the changing business environment (see Section 4.1). This adaptability appears to be at odds with a linear strategy that seeks to fix the final design requirements at the conception of the change project.

There was also evidence for the unease that SMEs have with formal methodologies (see Section 4.6). This unease is tied to the requirement to fix the change outcomes at the beginning of the project. There is, however, a resource issue associated in that SMEs cannot afford to make mistakes since their reserves are much lower than those of larger companies (Section 4.1).

Conventional methodologies have a tendency to adopt technical solutions to the problem situations that manufacturing systems face (See Sections 5.6 & 5.6). These technical solutions, apart from only addressing one element of the system (as described in Section 3.6) place demands on the resources of SMEs that they are unable to fulfil adequately. Thus, there is a theoretical requirement for a new approach to manufacturing systems redesign.

11.3.2 Empirical considerations

The participant observation reported in Chapter 6 not only provided validation for the understanding of an SME gained in Chapter 4 but also showed that current redesign methodologies were not being implemented. While this is not a survey of a representative sample of the SME population within the UK manufacturing base, the work was conducted with a 'typical' SME. There are real philosophical issues concerning the use of logico-mathematical language for discussing the issues contained within this thesis (Derry *et al*, 1993; see Section 2.2 for a detailed discussion of the research philosophy). The research sought to provide a means for redesigning manufacturing systems, a phenomenon that does not obey logical laws of cause and effect.

By studying an SME over a period of two years, together with the other SMEs that interacted with the primary case company, it became clear that traditional redesign

methodologies were not being utilised. This was most clearly demonstrated in Section 6.4 where an example of manufacturing systems redesign is described as it occurred. This work was followed by the three examples in Chapter 7 where traditional approaches were used to guide manufacturing systems redesigns.

The four step structure derived from Jones (1970) in Section 5.5 was applied to the three projects described in Sections 7.3 to 7.5. In none of these examples was the linear plan developed at the beginning of the redesign adhered to. The primary reasons for deviations was found to be internal and external uncertainty (see Section 7.7). Factors arose during the projects that could not have been planned for and the linear strategy adopted did not provide a coping mechanism for this. The solution was to undertake a period of iterative change, after which the original plan would be dusted off and reapplied to the remaining project.

A clear case is made at the end of Chapter 7 for an approach that provides for an iterative redesign strategy. Section 7.3.4 makes the case for a more systemic approach in that the methodologies derived from Jones (1970; Figure 5-7) tend to focus on technological solutions to the problem of manufacturing systems redesign. Chapter 3 concludes with the observation that manufacturing systems are complex phenomena that require more than one perspective to be fully appreciated (see Section 6.4 for a systemic description of a manufacturing system). This leads to the need for an iterative, systemic methodology for manufacturing systems redesign.

11.4 A methodology for the systemic redesign of manufacturing systems within SMEs

While Jones (1970) presented six different strategies for design in Section 5.4, only the linear approach has found significant favour in current methodologies. Developments in the field of continuous improvement and cyclic design are presented in Section 5.10 to demonstrate that other strategies have been successfully applied. While one of these, the

Pressman cycle (1992; Figure 5-9) may have significant applicability in the realm of manufacturing systems redesign, it does not have the systemicity described in Section 3.6 and specified in Section 8.1.

Perspectives that allow for a systemic consideration of the manufacturing system were developed from the work of Leavitt (1972). While this work is described in Section 3.6, it does not provide a guide for redesigning systems. Indeed, the domain of organisational design tends to shun suggestions that it is possible to design or plan development in a systematic manner (Section 3.5). However, it was the aim of this research to develop a systematic approach for manufacturing systems redesign.

The systematic approach was developed from the helical work of Pressman (1992) and the systemic consideration was provided by Leavitt (1972). These are combined to produce the proposed methodology presented in Section 8.3 (also Figure 11-1, below). This methodology was initially developed using the experiences of four SMEs as described in Sections 9.2 to 9.5 inclusive. This produced the final version of the methodology that was presented in Figure 8-1.

Chapter 10 described the longitudinal case studies that were used to validate the methodology. Validation is important since it establishes a basis for claiming a level of usefulness and credibility for a methodology (Landry *et al*, 1983). Validation is the claim that a methodology is applicable in real world situations without the support provided by the researcher. In Section 10.3 the case study method was described and the philosophical reasons for adopting the approach were discussed.

The primary developments were in the alignment of the Leavitt perspectives to more closely match the perceptions of managers in manufacturing SMEs. This allowed the managers to better understand their systems and to develop new designs for them. The original phases identified by Pressman were adapted to reflect the fact that the methodology was being used to develop internal manufacturing systems rather than products for external customers as Pressman had originally intended.

11.5 Contribution to Knowledge

The first contribution to knowledge has been the identification of the effect that the SME environment has on the redesign process. The second contribution to knowledge has been the identification of a need for systemic redesign of manufacturing systems. These two contributions have been derived from literature on systems theory and SME issues. They been validated through participative observation and action research.

Those needs are presented here again (the full discussion of their origin are found in Section 8.1) by summarising that a systemic methodology for manufacturing systems redesign within SMEs should:

1. allow rapid translation of design concept into implementation;
2. allow for learning about the system under consideration;
3. react to changes in the business environment;
4. explicitly show different perspectives relating to systemic considerations of manufacturing systems;
5. manage resource poverty;
6. be resource sensitive through risk awareness;
7. appear simple yet provide sufficient structure to manage a conceptually complex change.

As shown in Section 10.7 the methodology presented in Chapter 8 and summarised in Figure 11-1 does comply with the requirements identified here.

In addition, a redesign methodology has been developed that fulfils the previously identified needs of SMEs. This methodology will undoubtedly evolve and develop further but currently stands as the only systemic redesign methodology for manufacturing systems within SMEs that conforms to the requirements identified. The methodology comprises four phases of Planning, Risk Analysis, Action and Evaluation. Underlying these phases is a concern for developing a systemic appreciation of the manufacturing system through the four perspectives of Structure, People, Process and Technology. This is summarised in Figure 8-1 and duplicated here as Figure 11-1. The methodology is described more fully in Sections 8.4 to 8.8 inclusive.
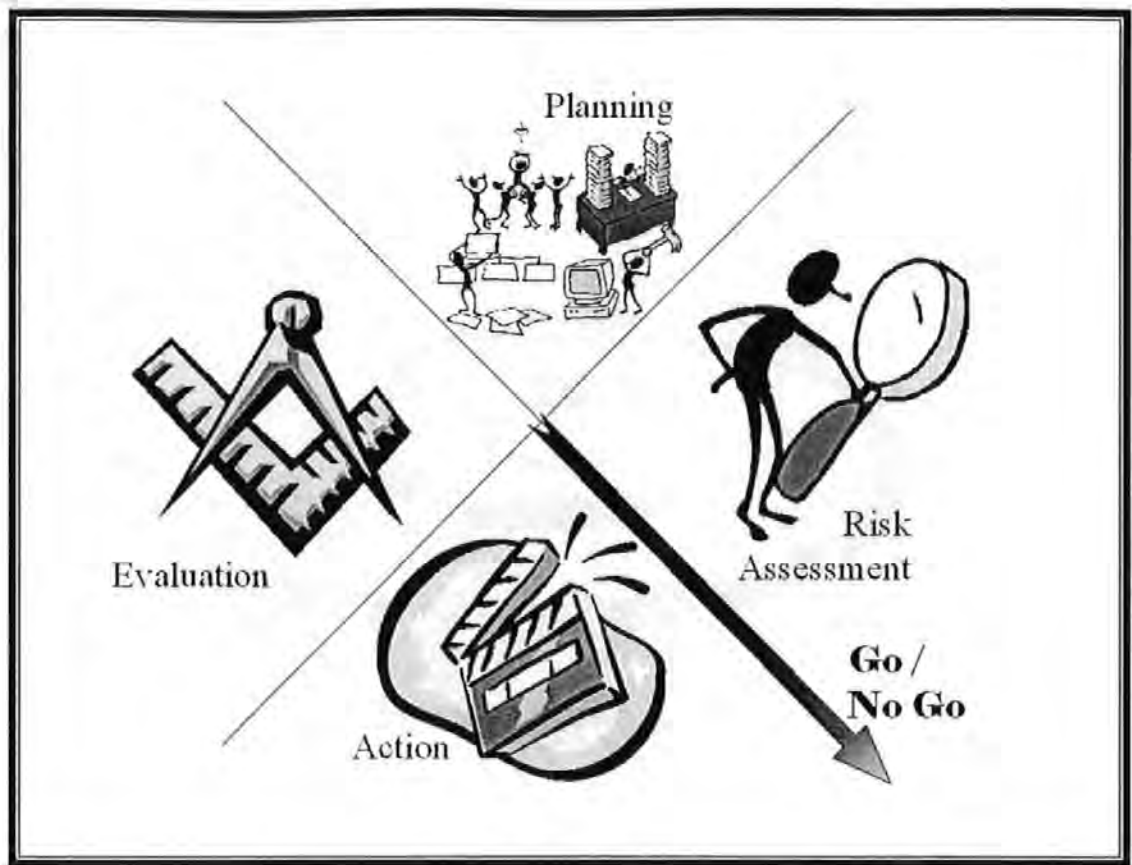
Figure 11-1 Proposed approach

11.6 Future research

This methodology has been developed for the redesign of manufacturing systems. Future research into its applicability for business processes and systems in general would be valuable. The inclusion of the four perspectives might suggest that the methodology has applicability in a wider domain than purely manufacturing systems but this has not been tested.

The four perspectives are derived from an understanding of organisational psychology that was established long before the internet became a reality. While this work has extended those perspectives to deal with manufacturing systems, the impact of the internet on organisational development has not been investigated. Future research would be needed to establish the impact that the new modes of working are having on existing understanding about manufacturing systems.

There is a strong link between this methodology and learning theory, as described in Section 5.9. It would be interesting to evaluate the potential for extending this

methodology in the direction of work being carried out in neural computing to produce learning software. This might produce a methodology that, in addition to redesigning manufacturing systems, redesigns itself at each iteration by learning about target manufacturing system.

11.7 Conclusions

Current methodologies for redesigning manufacturing systems within SMEs were evaluated against the literature and empirical evidence and found wanting in two significant areas. Firstly, the linear strategy that is adopted is unable to cope with the uncertainty and rapidly changing environment that is typical of the SME business position. Secondly the approaches studied did not provide for a systemic consideration of the complex phenomenon that is a manufacturing system.

Theoretical models were evaluated and two previously validated concepts were identified as providing solutions to the issues raised. These were the software development helix of Pressman (1992) and the four perspectives for understanding organisational psychology from Leavitt (1972). Neither were sufficient to provide a methodology for manufacturing systems redesign, nor were they designed for the task proposed.

Experimentation with manufacturing SMEs provided the means by which the two concepts were fused into a single methodology. In the same process the methodology was refined for application. The result from the experimentation phase was an operational methodology for redesigning manufacturing systems within SMEs. During the experimentation phase the methodology had undergone constant, though minor, development. The experimentation phase also involved the researcher closely with the research through Action Research. The methodology had not been held constant and applied to an SME nor had the researcher been removed from the environment.

The final validation applied the methodology to an SME that had not previously seen it. The researcher maintained separation by conducting the validation using the Case

Study method. While this does not completely separate the researcher from the research is did prevent the extensive intervention found in the Experimentation phase.

The methodology was found to be valid and applicable to the problem of redesigning manufacturing systems within SMEs. The new knowledge is represented by the increased understanding of design theories, in particular the design of manufacturing systems and the problem of design within SMEs. These two strands of new knowledge are demonstrated in action through the new methodology for redesigning manufacturing systems within SMEs.

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APPENDIX ONE – SAMPLE CRYDOM MATERIAL

LMC REPORT 21 MAY 1996

COSTS

It is not and never was my intention to change or appraise the accounting system at Douglas Randall Ltd. This point was made in the LMC report and presentation but not the minutes. At the end of the day, week, year if there is more money in the bank that at the beginning then the system is working. My concern is that it may be unclear as to where this money is coming from and going to.

Each product is broken down in to two constituent parts; build times and material costs. Standard build times are used to calculate the labour and overhead costs. Once the costs have been assembled a yield factor is added to represent to output from the shop floor. The profit margin is then added to this figure to arrive at the price the customer sees. Whilst the material costs are accurate the other two fundamental sources of data may be less so. The standard build times are at least two years old. The file V:\OPERATNS\DATA\STRDS\RR\st94rrs.xls has a date of 10/02/95. The data on the FRS32032, 32039, 32110 and 32111 was updated at this time but the majority of information dates from 1992/93. Of the 41 relays that are contained in this file only 18 contain information on winding times and 13 contain no information at all. Where data does exist it does not always reflect the actual times taken on the shop floor. These times themselves, as can be seen in V:\TCS\REPORTS\bldtime.xls, are subject to considerable variation.

The monitoring of scrap rates and failure modes has not been carried out for some time. Initial work carried out at the beginning of the year has suggested that yield figures are subject to quite wide variations. This is contained at V:\TCS\RESULTS\wkybd96.xls. The yields for the FRS12151 during weeks 8, 9 & 10 varied from 63.91% to 81.52%. The FRS12164 showed a variation from 72.79% to 93.06% over a 7 week period. The FRS72222 is quoted as having a 98% yield when over the first 10 weeks it averaged 93.07% (between 88.75% & 97.5%).

I accept that a business decision was made some years ago that monitoring process times was more resource intensive than the gains that could be made from improving these times. However, new designs are being based upon old process times and these may be producing inaccurate costings. The recording of build times has been re-initiated recently by J Mason over concerns relating to the lack of quality information available.

STRATEGY

At no point was the suggestion made that there is no strategy within Douglas Randall Ltd. However, there is no formal, written document that sets out the long term direction of Douglas Randall Ltd.

Strategy Definition

Strategy definition, whether using Terry Hill's work or that of others, begins with the corporate or business objectives, a market analysis, an understating of Order Winners and Order Qualifiers (Hill's terminology) and then the manufacturing strategy to support the above. The business objectives may be expressed in profit terms but should also express a business focus. In this respect and following discussions with G Rogers and M Sturmey it might include statements such as; Douglas Randall Ltd. will maintain its position as a world class manufacturer by focusing on innovative RF reed relay design, developing variations upon a core product range to provide the customer with a tailor made product and carrying out fundamental research to further improve product capability. All of which I belive we are doing to a greater or lesser extent.

The marketing strategy has to relate to the markets in which the company is operating. This has already been highlighted in M Sturmey's Diploma in Manufacturing Management 'IN COMPANY RECOMMENDATIONS'. Using the Terry Hill frame work the problem of Order Winners and Qualifiers is identified in Appendix 11.8 Sections 2 & 3.

When I asked Mark about the Marketing Strategy I was told that the focus was on Profit and then Volume. At no time was there any mention of targeting markets or using our Order Winners to gain new sales. Further discussions with John Mason has shown an awareness of these issues, though without the terminology. This sugests that while a collective decision has not been made 'common sense' decisions, influenced by customer demands have led to a similar strategy.

In deciding a Manufacturing Strategy it is irrelevant whether Terry Hill's work is used or the ideas put forward in my LMC report. I accept the criticism that I did not initially consult with relevant personnel, however, the general understanding of strategy and the direction the business is taking is not clearly understood within the engineering department. While this information may not be vital in the day to day firefighting it causes long term uncertainty for the future and will affect longer term decisions such as those affecting the planned capacity increase.

Manufacturing Requirements

The three projects that I am to be concentrating upon are an Automated Potting System, Automated Latching Set-up and Automated Gettering. These were identified as being areas where a capacity bottleneck would appear as production increased. During the development of these projects events have occurred that will reduce the impact of these projects.

As an interim solution to the potting bottleneck, jigs were introduced to the shop floor. While there is still a scheduling issue to be resolved the ability to increase capacity to meet forecasted demand exists. With four jigs containing 40 relays and each cycle taking approximately 45 minutes the process is capable of 213 relays per hour. The automatic system is being designed with a provisional capacity of 200 relays per hour. There were also cost saving issues with the automated system. Unfortunately these are less than first perceived due to a physical limitation in dispensing to individual relays. The reduction in labour would have been the largest cost saving.

The Automated Latching Set-up is unlikely to increase throughput though it should increase repeatability of process. This is a process limitation with the magnetising equipment. It has a fixed charge time within which the process cannot operate. Without a sophisticated pick and place system an operator will still be required to load and unload test jigs. The process would be de-skilled but re-work would still require a skilled operator.

Developments on the gettering project have gone well and while the system may not be much quicker than manual gettering the need for an operator is removed. This will effectively add an operator to the shop floor while not increasing the direct labour cost.

DESIGN FOR MANUFACTURE

The reed relay product family consists of a very wide number of variations on a simple idea. These have been designed for a wide number of customers with very few products going to more than one. The assembly is very dependant on operator skill with respect to both throughput and quality. Several products have undergone design changes and modifications that have improved the performance but not enhanced the manufacturability. The use of Mu- metal, external screens and polymide tape wraps are an example. There are even doubts as to the engineering requirements for some of these additions. However, to change these designs now might require the products to be resubmitted for approval. Future designs are better in that manufacturing is being considered at design time.

LMC Supporting Evidence

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University of Plymouth/
Douglas Randall Ltd.

**DOUGLAS
RANDALL**

Contents

1. Summary

The Executive summary presented at the LMC (21st May 1996) did not contain a full description of the thoughts behind the conclusions. This document aims to rectify this. Most of this document was written prior to the LMC but where additional material has been added this will be inticated in the text.

The author accepts the criticism that he did not consult fully prior to the LMC. Where subsequent discussions have revealed information that differes from the origonal conclusions this will also be noted in the text.

2. Manufacturing Strategy

The proposed manufacturing strategy will be to:

1) Support marketing by providing engineering expertise to design customer solutions using standard product families where possible;

2) Support designed solutions by providing a flexible manufacturing system to produce the required products in the required volumes at the required time;

3) Support the manufacturing system by providing training for those personnel that require it and machinery and computational systems where required.

2.1 Developements since the LMC

Since the LMC the author has been made aware of an informal strategy for developing the manufacturing facility at Douglas Randall Ltd. The basis of this strategy is the same as point 1 above. To provide customers with what they (the customer) belive to be customised, one-off products. This will allow Douglas Randall Ltd. to charge premium prices for there products. However, to prevent an explosion of designs the aim is to rationalise the design range and offer a number of options to the basic relay design that will be held.

Because of the oportunistic nature of the marketing within Douglas Randall Ltd. there is a need to produce varying volumes and product mixes. To this end the manufacturing facility will need to be 'agile' to the extent that point 2 above indicates. True agility, the ability for rapid proto-typing, small one-off manufacture, rapidly changing markets with one technology field is not, in the author's opinion, the direction that Douglas Randall Ltd. is going. Nor does the author belive that this is the desired route. Previous work by J Mason has indicated that the scope outside the Radio Frequency (RF) market for Douglas Randall Ltd. products is limited.

2.2 Operational Goals

These broad statements can be refined into operational goals as shown below. These goals have been expressed in SMART, (Specific, Measurable, Agreed, Realistic, Time bound), terms. However, the time element has been left out as this is still a discussion document.

1) i) To reduce the time-to-manufacture all new designs should be based upon existing designs.

   ii) Variations should, where possible, be limited to coil and switch characteristics.

   iii) The footprint and pin pitch should be fixed, though this does allow for a number of pin positions, pin type should also be fixed.

   iv) Increased computer integration within Douglas Randall Ltd. to allow CAD, CAE to take place in parallel with product development.

   v) The use of cross functional teams (engineering, support, supervisors, operators and marketing) in developing new products.

2) i) The grouping and development of four product families by process.

   ii) The design of production lines to build the product families.

   iii) The forecasting of volumes and likely product mix to be communicated between marketing and manufacturing as required by either side.

   iv) The reduction of Work in Progress by 50%.

   v) Targeting scrap levels to increase yield to greater than 90% on all lines.

   vi) Meetings as required by manufacturing staff (engineering, supervisors, support and operators where appropriate), to discuss and solve throughput problems, concentrating on causes not effects.

   vii) The use of Rough Cut Capacity Planning to schedule work over a time bucket.

   viii) The compilation and communication of production levels to production lines to allow feedback on variations with suggested solutions being followed up by appropriate staff.

   ix) Introduce Throughput accounting onto the shop floor.

3. Justification

3.1 Implied Strategy

While there is no defined Manufacturing Strategy at present there are several factors which can be used to deduce the implied strategy. The whole manufacturing process, from design to manufacture, is customer driven. The actual marketing input tends to be developing relations with existing customers. Market analysis in the past has suggested that there are few opportunities for developing the product range to satisfy other markets. The predominant obstacle is cost. It is virtually impossible to manufacture the present product range for prices compatible with solid state devices, typically <£1. For this reason products are designed with a customer actually asking for the product.

3.2 Value Set

A recent development in the analysis of manufacturing systems is the Treacey and Wiersema concept of Value sets (see Fig 1). This is used to describe the focus of the manufacturing facility. There are three Value Sets - Product Leader, Customer Intimate and Process Optimisation. In choosing one set the company does not dismiss the others out of hand but there is a distinct shift in focus between the three.
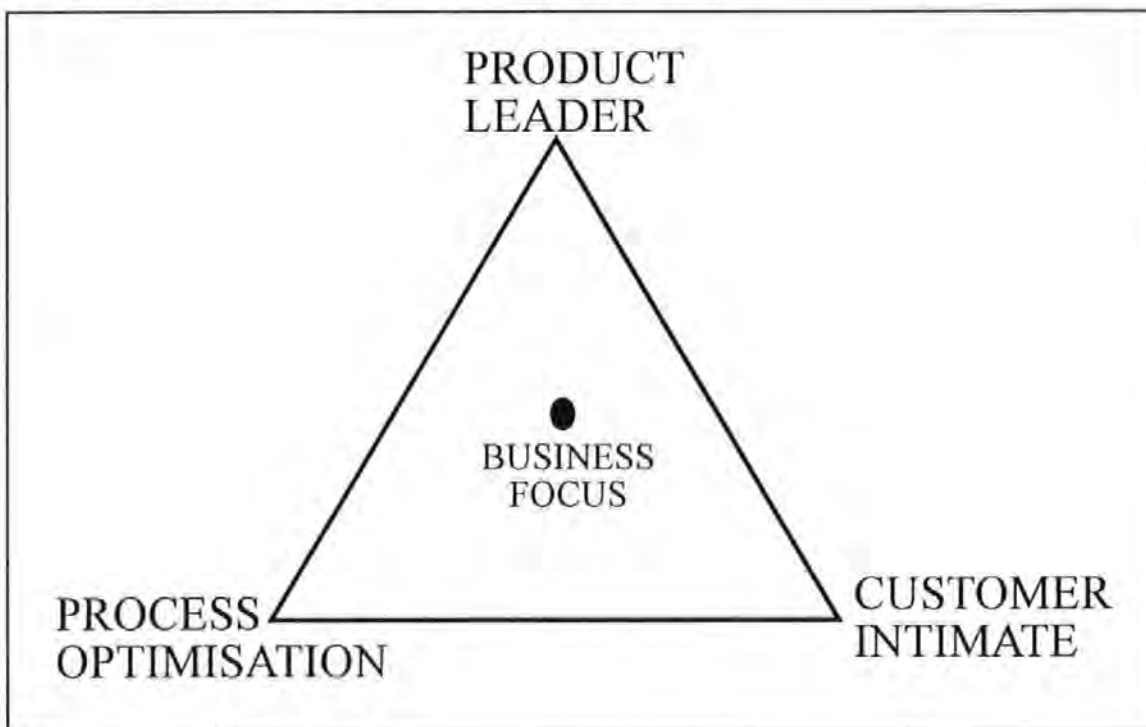
FIG. 1 Treacey and Wiersema value set

3.2.1 Product Leader

While the products are very highly developed and technical they are not designed to pre-empt the market. By way of comparison, Intel has had to continuously developed new computer chips to maintain it's position as a product leader. Douglas Randall Ltd. receives very specific requirements from customers which then form the basis of new designs.

3.2.2 Process Optimisation

Due to the low technology involved in assembly and the low volumes of product there is little to be gained from massive investment in automated machinery. While there is scope for automation the customers are willing to pay for customised products and at present there are no competitors to challenge the market monopoly. In this respect there is little drive to optimise the internal processes more than is required to make a profit.

3.2.3 Customer Intimate

There is however, a real need to develop the relationship between Douglas Randall Ltd. and its customers. The close liaison required to develop the products and the specialisation of those products make it hard for customers to switch between suppliers. In addition production does not begin before a firm order has been received, it is, therefore, impossible for Douglas Randall Ltd. to sell products to a market rather than to a defined customer.

3.3 Internal View

To further develop our understanding of the manufacturing system it is useful to describe the internal view of the manufacturing system and its effects on the business. This may be done using the Hayes and Wheelwright model (see Fig 2).

	Internally Neutral	Externally Neutral	Internally Supporting	Externally Supporting
Description	• Minimise negative impact of manufacturing	• Maintain parity - keep up with the competition	• manufacturing supports the business strategy	• manufacturing capabilities shape business strategy
Characteristics	• JIT • Quality Improvement Programmes • Quality Circles	• Best Practice • Business Process Re-engineering • World Class Manufacturing • Just - In - Time • CAPM • Benchmarking	• Business Process Focus • BPR • WCM • TQM • JIT • CAPM	• Core competence development • Knowledge based organisation • Market creation
	• Functional accountability • Focus on delivery • MRPII • JIT • Scheduling • Variance reports	• TQM • SPC • FMEA • DFM • ABC • Quality Focus • Mixed disciplines	• Strategic investment in : • automation • simulation • CAD CAE • Throughput accounting • Focus on cost • Internal teams	• System Integration • Integrated design for processes • Financial modelling • Focus on product variability • Full 'surgeon' structure
Comparison with Laurie Rumens model	Repeatability • Co-ordination • Taylorism • Specialisation • Functional organisation	Stability • Process control • SPC • Teaming • Quality circles	Flexibility • Process Improvement • Concurrent engineering	Versatility • Systems integration • CIM

Fig 2. The Hayes and Wheelwright model

3.3.1 The Hayes and Wheelwright model

Within this model there are four areas that the manufacturing facility can operate in. In reality these are blurred but they serve a valuable method for determining a strategy and the degree of focus within a business. The four areas are- Internally Neutral, Externally Neutral, Internally Supportive and Externally Supportive. It is important at this stage to note that there are no judgements attached to these descriptions. It is no better to be externally supportive than internally neutral. However, within the context of a business strategy one area may be preferable to another. Thus by identifying the current area one can determine if any changes are required and in what direction they should be.

3.4 Present Position

At present there is strong circumstantial evident that Douglas Randall Ltd. is operating in the Internally Neutral arena. From the discussions with Marketing and Engineering the impression is that Douglas Randall Ltd. would like to be in the Internally Supportive arena. This is more in line with their desire to be Customer Intimate.

3.5 Implied Marketing Strategy

It is the verbally stated aim of the company to become market led and for the manufacturing system to support marketing. From this business focus the marketing strategy is to maintain close links with customers and potential customers. This allows constant dialogue to enable DR to develop components as suppliers develop applications. The priorities from a marketing viewpoint are profit and then volume.

3.6 Requirements for the Manufacturing Strategy

Manufacturing cannot operate in a vacuum as it relies on the marketing function to supply it with orders. In turn the marketing function cannot operate in isolation from the manufacturing function as this will lead to orders being accepted which cannot be fulfilled. Therefore, the manufacturing function must have a strategy which supports the marketing function in both providing products as required and promoting the flow of information in both directions.

3.6.1 Strategy outline

The purpose of the strategy is to provide a context for making decisions on the manufacturing system. At present decisions affecting capital expenditure, shop floor layout, training, etc. are based upon the cost reduction to a product or a capacity increase because an order cannot be met. By agreeing on a strategy decisions can be taken with a wider view of where the business is going. The strategy will also be valuable in determining what we cannot or choose not to do.

3.6.2 Strategy limitations

No strategy can operate without the support of those who control the system. This strategy cannot supply a blueprint for the manufacturing system over the next 20 years. Indeed the strategy is not intended to last for 20 years. What it will do is offer a viewpoint on the direction that the system needs to take if is to fulfil the implied desires of the business in providing a Customer Intimate service and an Internally Supportive manufacturing system. As the business environment changes there will be a need to review the strategy and decide if it needs to be altered or changed entirely.

The actual shape of the manufacturing system will depend on the business decisions taken in the light of the strategy. These decisions can now be taken on the degree to which they further the strategy rather than on their impact on an order, as has been the case in the past.

3.7 Cost implications

There are no cost implications in adopting a strategy. The strategy should be used to justify changes and capital expenditure. The use of the strategy in this manner allows a co-ordinated, focused approach towards the business to be taken. There may be circumstances where investment is required and there is no immediate cost saving on an order. Training of personnel is a good example. It would be very difficult to implement a training programme based upon its saving towards an order. However, based upon the overall strategy there may be many instances where training is vital to ensure that the business follows the path set out in the strategy document.

4. Current situation

In this section the author will discuss some of the reasons for the current situation.

4.1 Past manufacturing history

Originally a part of Flight Refuelling, the division was first sectioned into Flight Refuelling Electronics. This division dealt with reed switches, reed relays, power supplies, keyboards, solid state relays and a number of other product lines. With large customers within the public sector there was little need for competitiveness and a great deal was spent of developing products and production processes.

4.2 Recent manufacturing history

Over the past five years or so FR Electronics, as it was known, reduced its product range to concentrate on three key areas. These were:
1. Reed switches
2. Reed switch related products - reed relays and proximity devices
3. Power supplies

During this time other product lines were still in production, primarily solid states relays, but these were being wound down.

When FR Electronics was taken over to become Douglas Randall Ltd. this scaling down continued until now only the three areas listed above exist.

4.3 Factors affecting strategy

With the scaling down there was little strategy beyond survival. Within the chosen marketplaces this was not a great problem for several reasons.

4.3.1 Market

The market that Douglas Randall Ltd. now operates is a closed one in many respects. There are very few new companies and the ones that are in play have been so for many years. There is a perception that there are no 'new' ideas. All products tend to be variations on existing ones. All the main customers are known and, in general, are larger than the suppliers. All the suppliers know who the other suppliers are and their past history at various products.

4.3.2 Order Winners and Order Qualifiers

It is arguable whether price is an Order Winner or Qualifier. I would suggest that it is a Qualifier and that the Winner is product performance. Douglas Randall Ltd. has a good history for providing customers with the product that has been specified. The other aspects of the order, price, lead time, quantity and even quality have not clinched the order. Whether Douglas Randall Ltd. continues to use performance as a Winner is uncertain. There are indications that price is seen as a Winner. This, I think, puts Douglas Randall Ltd. in direct competition with foreign manufacturers and the truly high volume producers who have much lower operating costs, lower material costs and better optimisation of their processes. Indeed this move would indicate a Process Optimisation value set. Within the lowest price strategy is a need to reduce variation and standardise products. This will remove the existing Winner and force Douglas Randall Ltd. to compete in a market they are not currently capable of competing in.

4.3.3 Confidentiality

There are no effective patents within the reed relay market. Indeed Douglas Randall Ltd. is in the process of challenging a competitors patent. There are no unique processes. The reason that Douglas Randall Ltd. has the RF market largely to itself is that no other manufacturer has made a switch with the same characteristics as the Douglas Randall Ltd. switch. There is nothing to stop a manufacturer from trying.

4.3.4 Volume

Historically this market has not been a large volume market. Typical orders are for a few thousand parts a year. This reflects the type of final assemble the products end up in. There is a limited market for Antenna Tuning Units, ATUs, in the armed services. The key selling point has always been performance linked to customisation. By selling a wide variety of products it has been possible to survive on a series of low volume orders. However, the lead times are often very short with little warning that orders are imminent.

4.4 Potential future problems

There are several orders which may prove to be much larger than those previously experienced within Douglas Randall Ltd. This could lead to a dramatic increase in volume and a need to redesign the manufacturing facility to cope with a step change in volume. At present all the efforts are on incremental changes.
There are no serious competitor to Douglas Randall Ltd. With the new, higher volume, business there is a greater likelihood of a competitor entering the market. With no protection from patents and only customer loyalty to protect Douglas Randall Ltd. the position could become weak.
In reducing the design effort to only meet customer requirements there is no 'blue sky' research being carried out. Therefore, if a competitor brings a new product to market Douglas Randall Ltd. is reduced to reverse engineering to provide a compatible product. The understanding that comes with good research will not be present and the ability to produce new and innovative designs will be lost.

APPENDIX TWO – ENCAPSULATION DETAILS

-216-

AUTOMATED ENCAPSULATION - A SPECIFICATION

This document sets out the requirement by Douglas Randall Ltd. for an automated encapsulation machine.

SCOPE

The following specification covers the technical requirements for purchase of an automated encapsulation machine to replace existing encapsulation techniques.

The machine is designed to be stand alone at this stage. The design of the relays being some way from mass production, there is no ambition to integrate the control system with a larger manufacturing/ computer system.

The machine will not eliminate operator involvement as trays will need to be loaded by operators. It will, however, reduce the operator involvement to a minimum.

PURPOSE

The purpose of encapsulating reed relays is two fold. Firstly it provides increased resistance to high voltage breakdown between internal parts. Secondly it increases the robustness of the design under shock and loading. For both these reasons it is important that there are no voids within the relay after potting. The potting material is to be de-gassed prior to encapsulation and the dispensing is to take place within a vacuum. It may be required to partially release the vacuum during the potting cycle to assist the material in filling all the cavities.

FUNCTION

The machine is to be semi-automatic. That is, it must be capable of operating with the minimum human intervention. This would, where practicable, be limited to loading and unloading jigs of components and refilling raw material containers. This does not include maintenance.

The machine is to dispense a two part silicon encapsulant (GE627) in a vacuum to a reed relay. The number and design of these relays will vary. The encapsulant will not vary between relays. The relays will be presented to the dispense head in an inverted position on a flat plane perpendicular to the dispense head. The relays are to be filled level with the top of the lid within which they are contained. There is to be no overfilling. The typical relay to be potted is a rectangular box shape (approximately l,w,d 30x12x12mm). The pins protrude a further 5-10mm beyond the box. There are three families of relay, each with a different footprint. Within each family there a number of variants which will result in different fill volumes. A typical batch size is 40 relays, though this can be changed with minimal complication.

As different relays will be used on this machine there will be the need to rapidly and simply re-programme to take this into account. Where possible this should not involve a member of engineering though training may be required for the operator. Where possible off-line programming should be available. The facility must exist for programming by 'teaching' the machine where to go and how much to dispense.

Automatic liquid level detection would be an advantage.

The vacuum is to be greater than 25mmHg.

CAPACITY

The machine must be capable of producing 200 filled relays per hour. This is to include loading jigs into the machine, evacuation, filling, re-pressurising and unloading. The loading of jigs with relays can be carried out off-line. The predicted fill volume is to be 3cc, though this will vary between relay designs. Variation between relays of the same design should be small.

CONTROL

Control will be required over shot size, number of relays, relay layout, location of relays within tray and mix ratio. It may be that the system will need to make more than one pass to allow the previous shot to settle. The control system should allow for a relay design to be selected and then the system should be self-contained. This would imply that the system can sense the presence of individual relays within the jig and make a decision on whether to pot or not. No further operator involvement should be required apart from cycle start and emergency stop. Safe guards should be in place to prevent un-authorised alteration to the control system.

JIGS

The jigs can be developed separately to the main machine. There must be some form of quick release to allow jigs to be rapidly changed. This will also assist in changing between relay designs. The details of the fixture must be included in the design so as to allow jigs to developed for other, as yet undesigned, relays.
The relays will be required to undergo a post-process heat cure. For this reason the trays must be capable of withstanding a temperature of more than 125°C.

MAINTENANCE

Due to the abrasive nature of silicon encapsulants all wetted parts should be designed to either withstand abrasion or be easily and cheaply replaceable. Any preventative maintenance should not require specialist tooling or knowledge.

There are five options for the Auto Potting project.

The first is to do nothing above increase present capacity using more bell jars and jigs. This will be by far the cheapest option and the most flexible. We will still have high labour costs. The material wastage is less than 3 to 7 pence per relay. The labour cost is between £1 and £1.43 depending on timings used. By buying new bell jars and referbishing the potting shed a little the facility will remain much as it is. The ovens are capable of well in excess the number of relays that are ever likely to be sent through. The bell jars are a source of possible constraint and to extend much beyond the present capacity will require more bell jars. However, these can be added to the system in a modular manner to allow capacity increses to take place over time and thus illiminate the possibility of over-capacity. The cost is unlikely to exceed £5000.

The next stage up is to purchase a simple vacuum potting system. This would be most like the system in use at Osmor. This will require an operator to drive it. There is still the possibility of overfilling the relays and will depend on operator skill to achive a decent fill. Capacity will be constrainted by the operator skill and the process times of de-vacing and dispensing. To expand the system will not be easy as further automation would most likely have to be purchased from the orial manufacturer. This system is the cheapest of the vacuum potting and offers the most flexible solution from a process control view point. However, the control over dispense volume will be down to the operator. This solution will cost between £8000 and £20000.

The last two solutions offer a fully automated system. These are by far the most expensive and potentially most flexible. Their capacity will be in excess of is currently require though increasing much byeond this will probably require a similar expenditure or a move in to a different technology field. The cost of suct a system will be over £40k and is likely to be nearer £60 - 80k.

For dealing with small volumes (batches of 40, volumes of <8000 per month) the first option is most likely to provide value for money.

Volumes > 8000 per month will probably benefit from the fully automated solution if the variation in footprint and compound are small. There are other factors to be considered.

Hopper size. The components to be filled are small. The shot size is also small, typically 1-2cc. Thus a 4 litre hopper will dispense over 2000 shots. One system has sufficient capacity to carry 2 months worth of compound. Since the material has a cure time of less than 2 hours it will ne nessecary to use mixer dispence heads. These have disposable nozzels which mix the compound at the point of dispensing. To prevent the compound settling stirrers will be required and the hoppers will need to be de-vaced before dispensing. All this adds cost.

Chamber size. The bigger the chamber the longer the pump down time but the more relays that can be filled at once. If large, steady volumes are forcast then it may be possible to use a multi-head dispenser. Inseto have found a company that does 12 head dispensing though 4 heads is the maximum with a two-part compound at present. If the volumes are likely to be smaller then a smaller chamber would be better. In addition mixing relays might not be a good idea as the fill volums are likely to be different.

Dispence volumes. While the fill volume will not vary much between relays there will be some variation. By how much this changes within a batch is uncertain. How accurate the fill is to be is also uncertain. The level will not be as smooth as the current. In addition there may be considerable difficulties in transporting batches of relays between the potting system and the ovens.

Relay mix. There will be a need to handle a variety of different relays. Mixing relays within batches is unlikely to be a good idea. Changing batches will require some form of reprogramming. There are many methods that this can be done but the most simple will be to have a computer next to the system which can store the different programmes and recall them as required. The use of a PLC may not give this flexibility. There will need to be a facility whereby a part filled batch can be placed in the system. This will allow smaller batches to be proccesed. Therefore, some detection circuitry and decision making will be required. Where data collection is required is uncertain, though it is unlikely.

Reed Relay Encapulation at Douglas Randal Ltd.

Once final assembly is complete the majority, by volume, of reed relays are encapsulated. This process takes one form or another. The first method is to apply a cover to the relay wchi also forms the external shell into which the encapsulant, known as potting compound, is poured. The second method is to place the relays in a mould, once the compound has cured the relays are removed and the compound itself forms the external shell, exihbiting mechanical and asthetic properties. There are two major compounds is use at present, both are two part silicone compounds. The first is called RTV 627, this is a dark grey material and the second is Sylgard 182, which is colourless. Data sheets for these materials may be found in Annexes 1 and 2.

The moulds for Sylgard 182 are made from a sheet of thermoplastic which is vacuum formed in to the shape required. The relays are then inserted in the mould and the compound applied. To assist removal and cleaning an extra tape layer is applied to the relays prior to potting. This tape extends above the potting compound. It used to assist in extracting the relays and to remove excess compound from the central bobbin area.

By volume most relays are potting in RTV 627. The process is identical for all but a few relays. A container of relays, this may be a jig or a cardboard box of suitable dimentions (one of the packaging lids is specified in procedures), is placed in a vacuum chamber and filled with liquid compound. The chanber is then cycled between vacuum and atmospheric over time. This causes the air pockets within the relays to 'boil' to the surface. After 30 - 40 min the 'boiling' has subsided and the container is taken to ovens where the curing process is accelerated by raising the temperature to 85C. This reduces the cure time from 24 hours to 30 mins. Upon removal from the oven the relays are contained within a solid mass of RTV 627. This is not an adhesive compound and, therefore, the relays can be cut from the mass and cleaned up. This is very labour intensive as the compound, while not adhesive, does require considerable effort in removal from all areas where it is not required.

The actual process time is very hard to calculate. There is no operator with responsibility for this process. It tends, but not exclusively, to fall to the last person in the assembly chain to oversee potting. This involves ensuring that the covers are fitted properly, the jigs are clean, there are enough relays to fill a jig (typically 40), there is enough compound to complete the cycle and that there is a vacuum chamber free. Once the jig, or cardboard box, is full the operator then prepares the compound. The two part compound is measured out in equal measures. This is done using two ladels and electronic scales, while accuracy is possible with experience there is no certainty. The compound is measured in to a paper cup and the mixture stirred witha wooden spatular. This is to ensure that a homogeaneous mixture results, though the final mix varies in quality. The cup is then placed in a vacuum chamber and cycled for approximately 6 to 10 minutes or until the mixture has ceased 'boiling'. During this time the operator will return to other tasks. When the first evacuation cycle is complete the loaded jig is placed in the chamber and the compound poured over it until it is full. The cup and spatular are then disposed of and the jig cycled in the vacuum chamber. After approximately 20 - 30 minutes the jig is removed and placed in the oven for a further 30 minutes. The actual process time is between 70 - 75 minutes including mixing and moving of jigs. Each jig holds 40 relays. There are three vacuum chambers which can be run, independantely, for this process. The labour times for potting vary from 1.9 to 3.25 minutes per relay. The longer times are due to the moulded style of potting being much more difficult to clean up afterwards. Having spent some time carrying out the potting process there is nothing to sugest that these figures are wildly inaccurate. There will be fluctuations in times for several reasons. Firstly the more aggresively the compound is mixed the longer the first cycle will take, the less aggresively mixed the greater risk of poor quality curing. As the operators are engaged in other tasked between cycles, and timers as such are not used, the cycles may run for continued periods of time. This does not harm the relays as the total cure time, un-accelerated, is much longer than the process time.

On this basis the capcity of the system is 1/1.9x60 = 31.5 relays/hour. It is not unusual to run two or more jigs in a cycle together or to stagger the jigs, in this instance capcity can be doubles to 60, 90 etc an hour. There is a practical limitation in that the chambers will only hold four jigs comfortably and it can be quite difficult to 'top up' any but the top jig should the level fall. The jig are not perfectly sealed and excess compound sometimes leaks out. This causes the total in the jig to fall and can fall to below the tops of the relays. In this instance no more compound can find it's way into the relays and the air pockets will raise to form bubbles or voids on the surface. While these may not constitue a inability to conform to specification these relays are rejected on consmetic grounds. The voids are dug out, to increase the ability of the next flow of compound to adhere, and recycled through the potting process.From potting the relays pass through final test and then on to the customer .

DISPENSED VOLUMETRIC ACCURACY

Using AutoCad Lite the following calculations were made.

The area at the top of the 1080 dbl relay is 10x14mm approximately. There are 0.3mm standoffs on the base of this relay. Therefore, no overfill can be allowed beyond this. Assuming a spherical bead developing above the desired fill volume we can simplify the problem to one of circles and subtended areas.

From the Machiners Handbook 22nd Ed. the following equations were used to determine the bead volume.

$$V = \pi h^2 \left(r - \frac{h}{3} \right)$$

$$r = \frac{c^2 + 4h^2}{8h}$$

These were combined to give;

$$V = \pi h^2 \left(\frac{c^2 + 4h^2}{8h} - \frac{h}{3} \right)$$

Where V=Volume, C=Chord length and h=bead height

This was then used in an Excel table to produce the graph below.

Bead Volume by Chord lenght and bead height
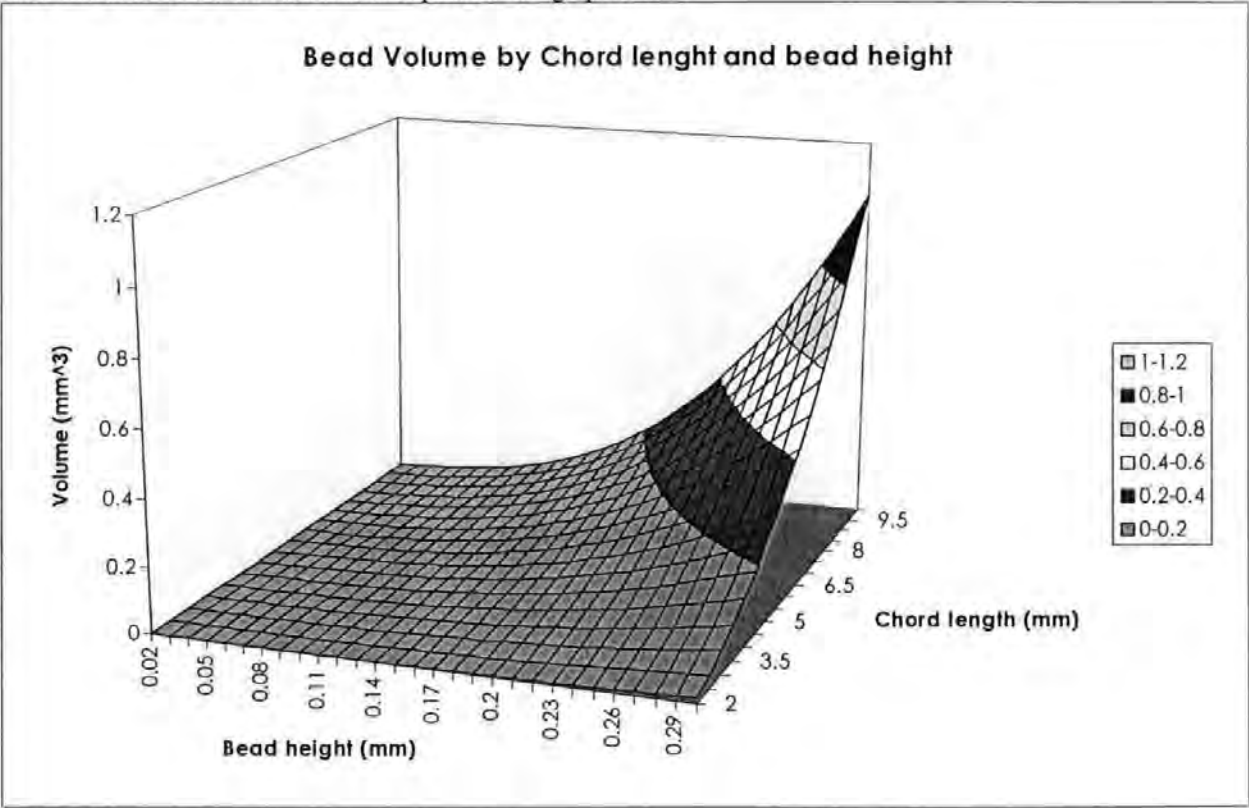
Note: the volume is in mm^3, and must be reduce by a factor of 3 to arrive at cc. Thus the maximum bead volume is 0.0012cc. Most dispensing systems claim accuracy at around 0.07cc ± 1% or 0.0007cc. Thus two shots could introduce suffiecient error to result in an over fill.

APS TRIAL WITH GE627

The following trial was carried out on 11/07/96. Only four relays were potted, all in the 1080 single footprint. Three contained reedswitches and one had coil windings only. The relay with coil windings only also had the 'top' corners on the former removed to aid fluid flow.

EQUIPMENT

A standard plastic bell jar on the shop floor was modified to allow basic vacuum potting to be carried out. The modification consisted of a cork bung and tubing (OD4.40mm ID3.30mm), through which compound could be introduced to the relays. The compound was held in a Plastipak 10ml syringe reserve and a clip acted as a valve to control the flow of compound.

PROCEDURE

The cork bung was shaped to give a rough fit around the opening at the top of the bell jar. This seal was further improved using PTFE tape and High Vacuum putty. A hole was drilled through the bung through which the tube was introduced to the bell jar. This was sealed with PTFE tape and putty. Copper wire was wrapped around the tube to give it stability and rigidity.
A single relay was positioned below the tube and the chamber evacuated. The syringe was filled with de-aerated compound and attached to the tube. The clip was sealing the vacuum within the bell jar. Once the syringe was attached the clip was removed and the compound introduced to the relay.
When the relay was full the clip was re-applied and the chamber pressurised. The relay was then removed and replaced with the next specimen.

OBSERVATIONS

The cork bung and sealing arrangement did not provide a high vacuum seal. This chamber has been noticed to provide a lower vacuum than usual in recent production runs and is no longer used for production. In the trial there was barely sufficient pressure differential to force the compound through the syringe and tubing.
The actual flow pattern around the relay showed that the compound did not flow easily (it has a viscosity of 1270 cPs). The compound was introduced to the central coil winding space. This quickly filled due to the constriction between the coil and lid surface. After a period of time the compound flowed down to the bottom of the lid. More compound was introduced to maintain the head. Slowly the compound flowed around the former into all spaces. As the head in the coil space was depleted it was replaced with fresh material.
The final top ups were small in volume and resulted in a positive meniscus with all the relays. In two cases the filled volume was exceeded during filling and material flowed down the side of the relay. The process took nearly 3 minutes to complete each relay. This was due to the flow pattern. The final relay had the corners of the former removed to improve the flow from the coil space in to the ends of the relay. This had minimal effect on the flow pattern as the main constriction was between the coil and the lid sides. Once the compound reached the bottom it was free to spread out but without sufficient head this was slow. The head could not be effectively maintained due to the constriction between the coil and the lid sides.
Once the relays were cured and examined the fill quality was good but post-process operations would be required to achieve a flat surface.

CONCLUSIONS

Individual filling of relays with GE627 does not appear to be a viable commercial process. Bulk potting in a vacuum using GE627 may be viable. Using another, less viscose compound may be viable.
Cost analyses have shown that bulk potting in vacuum could save 41p per relay. A fully automated system could save 85p per relay but this would be very difficult to achieve using GE627.

FURTHER TRIALS WITH GE627

The following trial was carried out on 18/7/96. Two relays were potted using different apparatus to earlier trials (11/7/96) though the process was the same.

EQUIPMENT

A stand alone glass bell jar with two holes through the top bung was used to provide the vacuum chamber. A rubber tube with the same dimensions as in the previous trial was used to introduce the compound.

PROCEDURE

The compound was de-gassed prior to the experiment. The vacuum tube was connected to the 'wrong' connection on the bell jar. To achieve an air tight seal high vacuum putty was used. More putty was used to seal the gap between the dispense tube and the other connection to the bell jar.
The syringe was filled with compound and attached to the dispense tube. A clip was used to seal the dispense tube. With the vacuum tube in place the vacuum pump was turned on and the bell jar evacuated. Initial attempts to achieve a vacuum were unsuccessful as air leaks around the vacuum tube prevented this. More putty was applied to improve the seal and high vacuum was achieved. The lack of a gauge means that the actual vacuum could not be measured.
Once a vacuum had been achieved the clip was removed and the compound was observed to be travelling along the dispense tube. This indicated a fair degree of vacuum. The relay was then filled with compound in several shots.
The relay could not be filled in one shot as the time taken for the first shot to disperse throughout the relay slowed the process down.

CONCLUSIONS

At this time there are no new conclusions to be drawn. The process still does not look as if it will be suitable for the proposed product range.
The possibility of a drop in viscosity with increased temperature is being investigated.

Cost analysis of Auto Potting System (APS)

The proposed system will cost approximately £60k to £80k. This means that it is likely to have a long pay back period. Therefore, it is important that the implications are considered before an order is placed.

The present system costs very little to run and maintain due to the simple nature, it does have a high labour content. The breakdown of these costs can be seen below. These are for a single relay design but the potting process is uniform across designs.

From standard labour times - labour per relay = 1.9 - 3.25 min.
Using standard labour costs - cost per relay = 18.37p - 31.42p
A standard jig holds 40 relays, therefore, cost per jig = 7.3467 pounds to 12.56677

From standard material costing potting costs 10p per relay
RTV 627 (the potting compound) costs 112.85 per 22lb delivery. Each jigs takes approximately 200g of compound. Thus there are 9.979kg per batch or 49 jigs. This translates into 1960 relays which share the purchase price making each share = 5.8p
One candidate for replacing RTV 627 is RTV 12 which costs 15.57 for a 40lb delivery. This translates to 3600 relays at a cost of 0.4p per relay
.
However, approximately a third of this compound is wasted under the present system. Therefore as no waste is envisaged under the new system these costs can be further reduced to 0.2677p per relays.

The new system will also have a reduced labour input which at a first estimate could be 5 min. per jig. This equates to 48.33p. Thus, the total saving per relays with the new system is between 22 and 35p.

With the present system paper cups and wooden spatulas are used to mix the compound, though these will not be required there will be some disposable items in the new system so these costs have not been removed.

Excluding power consumption the payback period for a 80k system will be between 6,700 and 11,500 cycles, based upon a 40 relay jig.

The system has been specified to have a capacity of at least 200/hr. Assuming the system is running 8 hours a day 5 days a week it will payback in between 34 and 58 weeks. This does not take into account inflation, any changes in overhead or the state of the order book.

Using inflation at 3.6% and a saving of 22p/relay the system will need to process > 1092 relays per month to break-even and show no Return on Investment. If 20,000 relays per month are processed, as Sales have forecast, then the system will have paid back in 21 months and will show an ROI of 5.5%.

This is based upon a system that pots in a two part silicone encapsulate. There is the possibility that a single part conformal coating may be applicable. In this case the labour costs will be lowered. There will also be savings as the relays will not need to be oven baked to accelerate curing, typical cure time in ambient air is 1 to 5 minutes. The cost of the coating material will probably be greater than two part silicone but this should be offset by the reductions elsewhere.

Cost Implications of Automated Potting System

Executive Summary

A customer request has led to the commissioning of an Automated Potting System. This has been carried out because there was no other foreseeable method for resolving the conflict between ourselves and the customer. There was, however, no cost analysis carried out. It was, therefore, impossible to say whether the selling price of the relays should be altered. Indeed it was impossible to say whether the system could pay for itself.

From the analysis it can be shown that the new system will cost between 22p and 35p less per relay. This in turn leads to a payback period of 11500 cycles. Which, at present forecasts, is a 21 month payback period.

The cost analysis project was carried out to ensure that the effects on the selling price of the relay were known. The project has also highlighted those areas where the savings will be made as well as those areas where extra costs may have to be endured.

From data sheets and engineering standard times it was possible to determine the cost of the present system. This is not as laid out in the documentation. Investigation suggested that initial engineering estimates had not been backed up by measurements from the actual system. Once the current system had been analysed it was necessary to determine the effect of the new system.

The new system will be designed to have a lower labour involvement than the present. This seamed like good engineering practise and is borne out by the high labour content of the present system. The new system will probably use cheaper materials. There will still be a portion of costs going on disposable parts but this cannot be removed.

It is evident that the new system is a benefit from a cost point of view. It will not increase the capacity of the manufacturing system. It will rather limit the capacity in a manner which is not present now. This will mean that the scheduling will need to be more uniform and take in to account the loading of the shop floor.

There may be repercussions on the customer/sales interface in that when orders are accepted the salesperson can see whether the target date is realistic.

FAX MESSAGE

TO: Fred Hope	FAX No: 01425 461463
CC:	
FROM: John Bradford	DATE: 22/7/96
CC:	Ref: Vacuum Potting

Dear Fred,

Further to our earlier conversations concerning vacuum potting we have conducted initial trials here using bell jars. Unfortunately we cannot achieve a satisfactory flow pattern. The design of the relay appears to prohibit rapid filling. However, we are not sure whether this is a design or process feature.

Would it be possible for either some samples to be trial filled using your equipment or test facilities or for you to visit us here and offer advice as to the next stage of development.

Yours

John Bradford

RTV627	£ 473.96	No. of shots @		360g			Invested		Relays	Saving	
88lb=	39.92kg		111	£	4.27		£	-	15000	£	6,323
							-£	6,323	15000	£	6,323
							-£	12,664	15000	£	6,323
	min / relay	hours / jig		cost/jig			-£	19,025	15000	£	6,323
Labour Min	0.75	0.50		£	16.15		-£	25,405	15000	£	6,323
Max	2.5	1.67		£	53.83		-£	31,804	15000	£	6,323
Labour cost	£ 5.80						-£	38,222	15000	£	6,323
O/H cost	£ 26.50						-£	44,659	15000	£	6,323
						Difference	-£	51,116	15000	£	6,323
Time per jig (mins)		30.00		100.00		70.00	-£	57,592	15000	£	6,323
Average (relay/jig/cost)		1.53		61.32	£	33.01	-£	64,088	15000	£	6,323
Cost/jig	RTV 627	£	20.42	£	58.11	£ 37.68	-£	70,603	15000	£	6,323
							-£	77,137	15000	£	6,323
Standard	RTV 627	£	0.12				-£	83,691	15000	£	6,323
Actual	RTV 627	£	0.107				-£	90,265	15000	£	6,323
							-£	96,859	15000	£	6,323
Used	0.5	£	0.053				-£	103,472	15000	£	6,323
							-£	110,105	15000	£	6,323
Labour Saving				31.32		mins	-£	116,758	15000	£	6,323
Total saving per jig				£	16.861		-£	123,431	15000	£	6,323
Total saving per relay				£	0.422		-£	130,124	15000	£	6,323
							-£	136,837	15000	£	6,323
Investment	Payback (cycles)						-£	143,570	15000	£	6,323
£ -	0						-£	150,324	15000	£	6,323
							-£	157,098	15000	£	6,323
Inflation =	3.60%						-£	163,892	15000	£	6,323
Monthly cost		No. relays/month	to breakeven				-£	170,706	15000	£	6,323
£ -		0					-£	177,541	15000	£	6,323

RTV627	£ 473.96	No. of shots	360g
88lb=	39.92kg	111	£ 4.27

	min / relay	hours / jig	cost/jig	
Labour Min	0.75	0.50	£ 16.15	
Max	2.5	1.67	£ 53.83	
Labour cost	£ 5.80			
O/H cost	£ 26.50			
				Difference
Time per jig (mins)		30.00	100.00	70.00
Average (relay/jig/cost)		1.53	61.32	£ 33.01
Cost/jig	RTV 627	£ 20.42	£ 58.11	£ 37.68
Standard	RTV 627	£ 0.12		
Actual	RTV 627	£ 0.107		
Used	0.5	£ 0.053		

Labour esimate based upon 5sec shot cycle (x40), 2.5min vac (from brochure) 2.5min de-vac and 1min jig change. These values can be found @ A,B,C,D21

New labour est. (min/jig)	9.33	£ 5.024	
Labour Saving (min/jig) [ave.]	29.32	£ 15.784	
Total saving per jig		£ 18.446	
Total saving per relay		£ 0.461	

Investment	Payback (cycles)			
£ 20,000	1084.219314			Month 24
Inflation =	3.60%			
Monthly cost		No. relays/month to breakeven		
£ 60		130		

Invested	Relays	Saving
£ 20,000	15000	£ 6,917
£ 13,143	15000	£ 6,917
£ 6,265	15000	£ 6,917
-£ 634	15000	£ 6,917
-£ 7,553	15000	£ 6,917
-£ 14,493	15000	£ 6,917
-£ 21,454	15000	£ 6,917
-£ 28,436	15000	£ 6,917
-£ 35,439	15000	£ 6,917
-£ 42,463	15000	£ 6,917
-£ 49,507	15000	£ 6,917
-£ 56,573	15000	£ 6,917
-£ 63,660	15000	£ 6,917
-£ 70,769	15000	£ 6,917
-£ 77,899	15000	£ 6,917
-£ 85,050	15000	£ 6,917
-£ 92,222	15000	£ 6,917
-£ 99,416	15000	£ 6,917
-£ 106,632	15000	£ 6,917
-£ 113,869	15000	£ 6,917
-£ 121,128	15000	£ 6,917
-£ 128,409	15000	£ 6,917
-£ 135,712	15000	£ 6,917
-£ 143,036	15000	£ 6,917
-£ 150,383	15000	£ 6,917
-£ 157,751	15000	£ 6,917
-£ 165,142	15000	£ 6,917
-£ 172,555	15000	£ 6,917
-£ 179,990	15000	£ 6,917
-£ 187,447	15000	£ 6,917
-£ 194,927	15000	£ 6,917
-£ 202,429	15000	£ 6,917

RTV627	£ 473.96	No. of shots @	360g			Invested	Relays	Saving
88lb=	39.92kg		111	£ 4.27		£ 28,000	15000	£ 1,311
						£ 26,773	15000	£ 1,311
						£ 25,542	15000	£ 1,311
	min / relay	hours / jig	cost/jig			£ 24,308	15000	£ 1,311
Labour Min	0.75	0.50	£ 16.15			£ 23,070	15000	£ 1,311
Max	2.5	1.67	£ 53.83			£ 21,828	15000	£ 1,311
Labour cost	£ 5.80					£ 20,582	15000	£ 1,311
O/H cost	£ 26.50					£ 19,333	15000	£ 1,311
					Difference	£ 18,080	15000	£ 1,311
Time per jig (mins)		30.00	100.00		70.00	£ 16,823	15000	£ 1,311
Average (relay/jig/cost)		0.97	38.67	£	20.82	£ 15,563	15000	£ 1,311
Cost/jig	RTV 627	£	20.42	£ 58.11	£ 37.68	£ 14,298	15000	£ 1,311
New labour est. base upon 2.5mins to load a jig, place it in the						£ 13,030	15000	£ 1,311
machine, press start, open the machine and place in oven.						£ 11,758	15000	£ 1,311
						£ 10,482	15000	£ 1,311
						£ 9,203	15000	£ 1,311
Jig Size				40		£ 7,919	15000	£ 1,311
New labour est.			2.5	£ 0.242		£ 6,632	15000	£ 1,311
Labour Saving			36.17	£ 3.496		£ 5,341	15000	£ 1,311
Total saving per relay				£ 0.087		£ 4,046	15000	£ 1,311
Figures do not include Overhead or breakout					ex mat	£ 2,747	15000	£ 1,311
						£ 1,444	15000	£ 1,311
Investment	Payback (cycles)			Payback (relays)		£ 137	15000	£ 1,311
£ 28,000	8009			320,360		-£ 1,173	15000	£ 1,311
Inflation =	3.60%							
Monthly cost		No. relays/month	to breakeven					
£ 84		962						

RTV627	£	473.96	No. of shots		360g			Invested		Relays
88lb=		39.92kg	111	£	4.27			£	29,551	15000
								£	27,820	15000
								£	26,085	15000
	min / relay		hours / jig	cost/jig				£	24,344	15000
Labour Min		0.75	0.50	£	16.15			£	22,598	15000
Max		2.5	1.67	£	53.83			£	20,847	15000
Labour cost	£	5.80						£	19,091	15000
O/H cost	£	26.50						£	17,329	15000
						Difference		£	15,562	15000
Time per jig (mins)			30.00		100.00	70.00		£	13,790	15000
Average (relay/jig/cost)			1.00		39.87	£	21.46	£	12,012	15000
Cost/jig	RTV 627		£	20.42	£	58.11	£ 37.68	£	10,229	15000
								£	8,441	15000
Standard	RTV 627		£	0.12				£	6,647	15000
Actual	RTV 627		£	0.107				£	4,848	15000
								£	3,044	15000
Used	0.5		£	0.053				£	1,234	15000

Labour esimate based upon 10sec bulk dispense cycle x 4 jigs, 2.5min settling time, 2.5 min vac (from brochure) 2.5min de-vac and 1min jig change. These values can be found @ A,B,C,D,E21

							Invested		Relays
Number of Jigs				4			-£	581	15000
Jig size				40			-£	2,402	15000
New labour est. (min/jig)		9.17	£	4.935			-£	4,228	15000
Labour Saving (min/jig) (inc clean)		8.03	£	4.325			-£	6,060	15000
Total saving per jig			£	4.851			-£	7,897	15000
Total saving per relay			£	0.121			-£	9,739	15000
System Capacity /hr				1,047			-£	11,588	15000
							-£	13,441	15000
Investment	Payback (cycles)				Month 24		-£	15,301	15000
£ 29,551	6092.251646						-£	17,165	15000
							-£	19,036	15000
Inflation =	3.60%						-£	20,912	15000
Monthly cost		No. relays/month to breakeven					-£	22,794	15000
£ 89		731					-£	24,681	15000
							-£	26,574	15000
							-£	28,473	15000
							-£	30,377	15000
							-£	32,287	15000

Saving
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Break out S	31.32	Break out S	£	6,323
Semi-Auto	29.32	Semi-Auto	£	6,917
Automatic	36.17	Automatic	£	1,311
Semi-Auto	8.03	Semi-Auto	£	1,819

Labour Savings for different solutions

Cost s

avings per 15000 relays

Automatic | Semi-Automatic
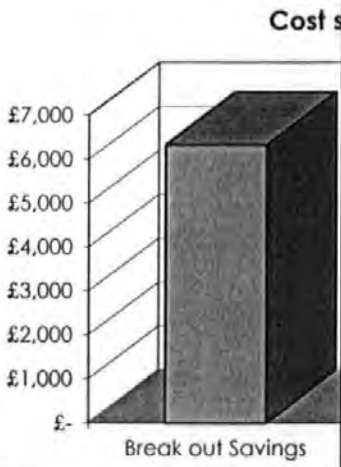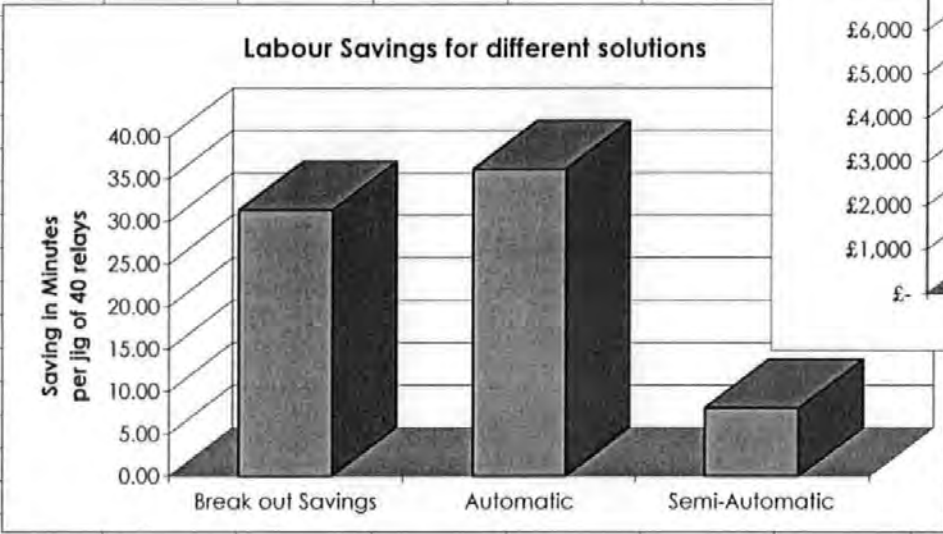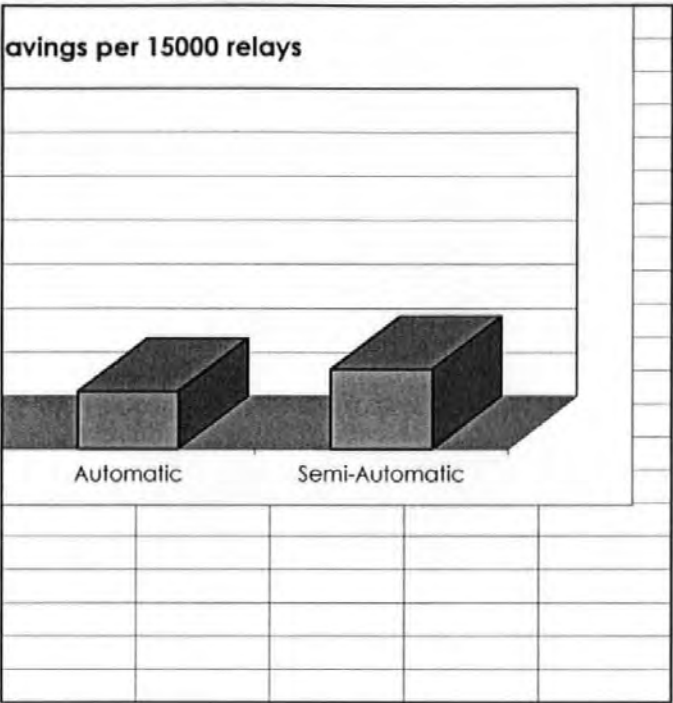
CRYDOM
Control over power

ECHANICAL
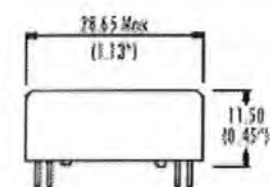
SINGLE AND DOUBLE WITH COVER

SINGLE
WITH COVER

DOUBLE
WITH COVER
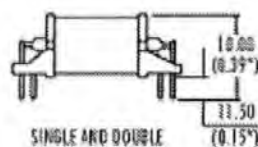
SINGLE AND DOUBLE
OPEN FRAME

SINGLE
OPEN FRAME
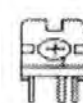
DOUBLE EXTENDED
FOOT OPEN FRAME
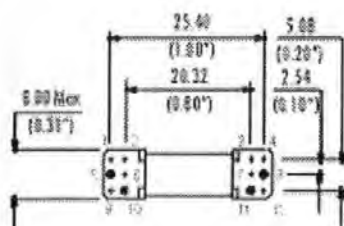
PIN SIZE (SINGLE)
PINS 9, 10 & 11   0.60 SQUARE (0.024")
PINS 5 & 8   0.7 (0.027") dia
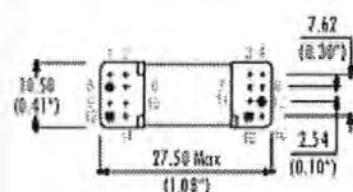
PIN SIZE (DOUBLE)
PINS 4, 13 & 15   0.60 SQUARE (0.024")
PINS 5 & 10   0.7 (0.027") dia
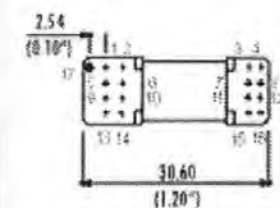
PIN SIZE (DOUBLE-EXTENDED FOOT)
PINS 3, 11 & 17   0.60 SQUARE (0.024")
PINS 6 & 8   0.7 (0.027") dia

FM02050

FRS12516
Miniature Covered Latching RF Reed Relay

Based on the standard FRS12000 footprint, this design offers an in-house manufactured bistable reedswitch contact, optimised for latching relays capable of carrying 1.5A at 30MHz and withstanding 2kVDC. Originally designed for antenna tuning in portable HF radios, the FRS12516 is ideal for applications where power is limited as changing the state of the relay is accomplished by a coil pulse of only 2mS. Housed in a fully encapsulated package, the relay has been designed to withstand MIL standards of bump, shock and vibration.

COIL at 20°C	UNITS	CONDITIONS	FRS12516
Nom. Working Voltage	VDC		12
Working Voltage Range	VDC		9-16
Nominal Resistance	Ohms	+/10%	500
*RF Screening Connection	Inner & Outer	pin number	4
Coil Connections	Set	pin number	10 & 11(+)
	Reset	pin number	2 & 3(+)

CONTACT	UNITS	CONDITIONS	FRS12516
Action (form A, B or Latching)			Latching
Switching Voltage	V	DC max	20
Switching Current	A	DC max	0.5
Carry Current	A	RMS at 30MHz	1.5
Isolation	kV	DC max	2
Capacitance	pf	coil/screen gnd	0.1
Contact Connections		pin number	7 & 8

RELAY	UNITS	CONDITIONS	FRS12516
Latching pulse length	ms	min	2
Isolation contact to all other terminals	kV	DC max	2
Isolation coil to screen	kV	DC max	0.5
Capacitance contact to all other terms	pf		2.0

ENVIRONMENTAL	UNITS	CONDITIONS	
Storage temperature range	°C		-55°C to +125°C
Operating temperature range	°C		-40°C to +85°C
Lifetime	ops.	dry switching	10⁹
	ops.	Rated Load	Consult Factory
Shock	g	11ms 1/2 sine pk	100
Bump	g	6ms 1/2 sine pk	40
Vibration	g	10-500Hz	10
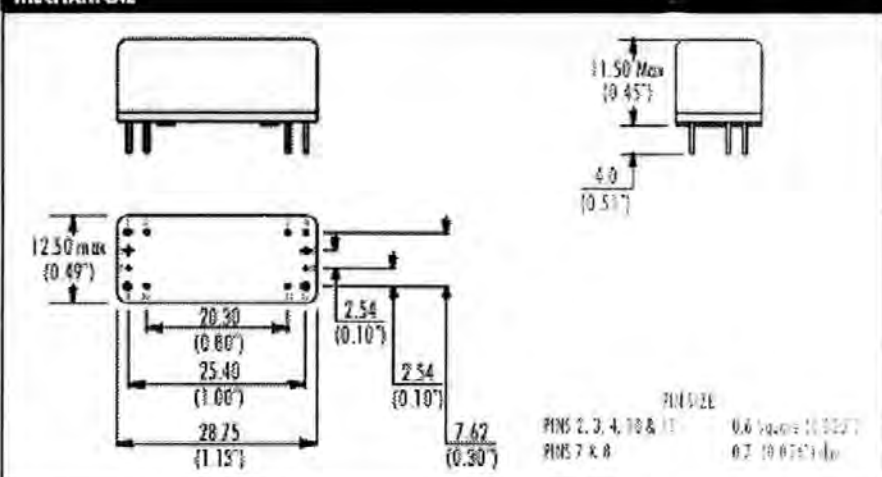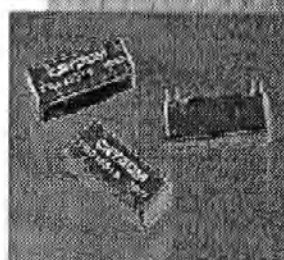
- Bistable (Latching) Relay
- RF and Magnetically Screened
- 2kVDC isolation
- 1.5A Carry Current at 30MHz
- Suitable For Portable Radio Applications

MECHANICAL

11.50 Max (0.45")
4.0 (0.51")
12.50 max (0.49")
20.30 (0.80")
25.40 (1.00")
28.75 (1.13")
2.54 (0.10")
2.54 (0.10")
7.62 (0.30")

PIN SIZE
PINS 2, 3, 4, 10 & 11   0.6 square (0.025")
PINS 7 & 8   0.7 (0.076") dia

APPENDIX THREE – GETTERING SOURCE CODE

```
{Gettering Program V4.15b 14/5/97}
{By John Bradford in Borland TurboPascal 7.0 for Dos}

program Getter;

uses crt, dos, johnb;

const
  mx : integer = 23;
  my : integer = 6;   {all addresess and numbers beginning $ are in hex}
  index_addr : integer = $300; {port select address}
  data_addr : integer = $301;   {data word address}
  port_a0 : byte = $0;   {i/p not used}
  port_b0 : byte = $1;    {o/p n/a, DrEn, n/a, n/a, n/a, not used, not used, not
used}
  port_c0 : byte = $2;    {i/p Imon, Vmon, ES, Dr, n/a, n/a, n/a, Rx}
  cntrl_gp0 : byte = $3; {control address for group 0}
  port_a1 : byte = $4;    {bit position sol_cntl}
  {store, door, gate, selec, test_pos, clamp, Vpos, Vneg}
  port_b1 : byte = $5;    {bit position DAC_cntl}
  {Iset, Vset, Irst, Vrst, Ven, Rxrst, n/a, n/a}
  port_c1 : byte = $6;    {o/p to DACs, which one is controlled by Iset & Vset}
  cntrl_gp1 : byte = $7; {control address for group 1}
  store : byte = $80;    {open on high}
  door : byte = $40;    {disabled}
  gate : byte = $20;    {closed on high}
  selec : byte = $10;    {pass on high}
  test_pos : byte = $8; {open on low}
  clamp : byte = $4;    {open on high}
  Vpos : byte = $2;        {made on high, change over relay control}
  Vneg. : byte = $1;        {made on high, change over relay control}
  Iset : byte = $80;      {latch on high, read on low}
  Vset : byte = $40;      {latch on high, read on low}
  Irst : byte = $20;      {clears latch on low, arms on high}
  Vrst : byte = $10;      {clears latch on low, arms on high}
  Ven : byte = $8;        {psu disabled on Ven=1}
  Rxrst : byte = $4;      {clears latch on low, arms on high}
  DrEn : byte = $40;      {enabled on high (to look for door detect)}
  NumberOfSwitches : byte = 99;

type
  MainFile = text;
  TestParameters = (Vmax, Vmin, Vinc, Spread, Vstart, Ilimit, Iduration,
Passes);

var
  DataStore, SaveStore : MainFile;

  sol_cntl, DAC_cntl : byte;

  SwitchType : array[0..100] of string;
  {number of switches for which data is held}
  SwitchParameter : array[TestParameters] of integer;

  Mode, answer : Char;

  Test, Stop : boolean;
```

```pascal
  passed, failed, SwitchCode : integer;

procedure Quit(QuitVar : integer);
begin
  case QuitVar of
  0 : begin
  {controlled exit procedure}
        textcolor(yellow+blink);
        gotoxy(30,20);write('Exit now? (Y/N)');
        cursor(0);
        textcolor(white);
        repeat
          answer:=upcase(readkey);
          if answer='Y' then
          begin
            port[index_addr]:=port_cl; port[data_addr]:=$0; {DACs to zero}
            DAC_cntl:=$0+Ven; {psu off}
            port[index_addr]:=port_bl; port[data_addr]:=DAC_cntl;
            Sol_cntl:=$0+gate; {solendoids in 'safe' position}
            port[index_addr]:=port_al; port[data_addr]:=Sol_cntl;
            textcolor(white);
            textbackground(black);
            cursor(1);
            window(1,1,80,25);
            clrscr;
            halt;
          end;
        until answer in ['N',#27];
        gotoxy(30,20);write('                       ');
      end;
  1 : begin
  {rapid exit procedure}
        textcolor(white);
        textbackground(black);
        cursor(1);
        window(1,1,80,25);
        clrscr;
        halt;
      end;
  end;
end;

procedure save_data(variable, pass:integer; name:string);
var
  leave : boolean;
  count : integer;
  Year, Month, Day, DayOfWeek: Word;
  Hour, Minute, Second, Sec100: Word;
begin
  append(SaveStore); {open save file to add data}
  if name<>' ' then {first pass saves the switch type}
  begin                {and header fields}
    writeln(SaveStore,'"',name,'"'); {switch type}
    if name<>'error' then begin
      GetDate(Year, Month, Day, DayOfWeek);
      GetTime(Hour, Minute, Second, Sec100);
```

```pascal
        writeln(SaveStore,'"',Day,'/',Month,'/',Year,'"');
        writeln(SaveStore,'"',Hour,':',Minute,':',Second,'"');

write(SaveStore,'"Vmax",',SwitchParameter[Vmax],',"Vmin",',SwitchParameter[Vmin]
);

write(SaveStore,',"Vinc",',SwitchParameter[Vinc],',"Vspread",',SwitchParameter[S
pread]);

write(SaveStore,',"Vstart",',SwitchParameter[Vstart],',"Ilimit",',SwitchParamete
r[Ilimit]);

writeln(SaveStore,',"Iduration",',SwitchParameter[Iduration],',"Passes",',Switch
Parameter[Passes]);
      count:=1;
      repeat
        write(SaveStore,'"Pass ',count,'",'); {header fields}
        inc(count);
      until count=SwitchParameter[Passes];
      writeln(SaveStore,'"Pass ',count,'"');
    end;
  end else begin {note - saved as 0 - 255, NOT 0 - 10kV}
    if variable=0 then leave:=true else leave:=false;
    if (pass>0) and (leave=false) then write(SaveStore,variable,', ');
    if (pass=0) and (leave=false) then writeln(SaveStore,variable);
    if leave=true then
    repeat
      if pass>0 then write(SaveStore,'0, ');
      if pass=0 then writeln(SaveStore,'0');
      dec(pass);
    until pass<0;
  end;
  close(SaveStore); {close save file to prevent multiple open files}
end;


procedure Emergency_Stop;
var
  title : string;
  answer : char;
  temp : integer;
begin
  port[index_addr]:=port_cl; port[data_addr]:=$0; {set the DACs to zero}
  DAC_cntl:=$0+Ven;{both DACs to read, r/set Vmon & Imon and disable psu}
  port[index_addr]:=port_bl; port[data_addr]:=DAC_cntl;
  sol_cntl:=$0+gate+store+clamp+Vpos+Vneg; {Emergency safe pos}
  port[index_addr]:=port_al; port[data_addr]:=sol_cntl;
  save_data(0,0,'error'); {terminate save file}
  title:='Emergency Stop - Press a key to continue';
  repeat    {flashing screen sequence}
    temp:=750;
    setscreen(title,red,white,yellow,white);
    while (not keypressed) and (temp>0) do dec(temp);
    temp:=750;
    setscreen(title,cyan,white,red,white);
    while (not keypressed) and (temp>0) do dec(temp);
  until keypressed;
```

```
readkey; {clear keypressed}
setscreen(title,blue,white,yellow,white);
gotoxy(mx,my-3); write('PSU disabled');
gotoxy(mx-4,my-2); write('What do you wish to do?');
gotoxy(mx,my+1); write('(1) Release gate');
gotoxy(mx,my+2); write('(2) Open store');
gotoxy(mx,my+3); write('(3) Release clamps');
gotoxy(mx,my+4); write('(4) Move support');
gotoxy(mx,my+5); write('(5) Change selector');
gotoxy(mx,my+6); write('(6) Energise Positive polarity');
gotoxy(mx,my+7); write('(7) Energise Negative polarity');
gotoxy(mx,my+9); write('(X) Exit to DOS');
gotoxy(mx,my+10); write('(R) Return to program');
repeat
  answer:=upcase(readkey);
  case answer of
    '1' : if copy(convert(Sol_cntl),3,1)='1' then
        begin
          Sol_cntl:=Sol_cntl-gate;
          gotoxy(mx-2,my+1); write(0);
        end else begin
          Sol_cntl:=Sol_cntl+gate;
          gotoxy(mx-2,my+1); write(1);
        end;
    '2' : if copy(convert(Sol_cntl),1,1)='1' then
        begin
          Sol_cntl:=Sol_cntl-store;
          gotoxy(mx-2,my+2); write(0);
        end else begin
          Sol_cntl:=Sol_cntl+store;
          gotoxy(mx-2,my+2); write(1);
        end;
    '3' : if copy(convert(Sol_cntl),6,1)='1' then
        begin
          Sol_cntl:=Sol_cntl-clamp;
          gotoxy(mx-2,my+3); write(0);
        end else begin
          Sol_cntl:=Sol_cntl+clamp;
          gotoxy(mx-2,my+3); write(1);
        end;
    '4' : if copy(convert(Sol_cntl),5,1)='1' then
        begin
          Sol_cntl:=Sol_cntl-test_pos;
          gotoxy(mx-2,my+4); write(0);
        end else begin
          Sol_cntl:=Sol_cntl+test_pos;
          gotoxy(mx-2,my+4); write(1);
        end;
    '5' : if copy(convert(Sol_cntl),4,1)='1' then
        begin
          Sol_cntl:=Sol_cntl-selec;
          gotoxy(mx-2,my+5); write(0);
        end else begin
          Sol_cntl:=Sol_cntl+selec;
          gotoxy(mx-2,my+5); write(1);
        end;
    '6' : if copy(convert(Sol_cntl),7,1)='1' then
```

```pascal
           begin
             Sol_cntl:=Sol_cntl-Vpos;
             gotoxy(mx-2,my+6); write(0);
           end else begin
             Sol_cntl:=Sol_cntl+Vpos;
             gotoxy(mx-2,my+6); write(1);
           end;
      '7' : if copy(convert(Sol_cntl),8,1)='1' then
           begin
             Sol_cntl:=Sol_cntl-Vneg;
             gotoxy(mx-2,my+7); write(0);
           end else begin
             Sol_cntl:=Sol_cntl+Vneg;
             gotoxy(mx-2,my+7); write(1);
           end;
      'R', #27 : begin
                     clrscr;
                     Stop:=true;
                     exit;
                 end;
      'X' : Quit(1);
      #0 : readkey; {ignor function keys}
    end;
    port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  until 1=2;
end;

procedure Controlled_Stop;
begin
  port[index_addr]:=port_c1; port[data_addr]:=$0; {set the DACs to zero}
  DAC_cntl:=$0+Ven;{both DACs to read, r/set Vmon & Imon and disable psu}
  port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
  sol_cntl:=$0+gate+store+clamp+Vpos+Vneg; {Emergency safe pos}
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  save_data(0,0,'error'); {terminate save file}
  Stop:=true;
  delay(2500); {approximately 2.5 seconds to let the switch drop}
end;

procedure Set_Clock;
var  Year, Month, Day, DayOfWeek : Word;
     Hour, Minute, Second, Sec100 : Word;
     date, temp_str : string;
     num, err : integer;
begin
  GetDate(Year, Month, Day, DayOfWeek);
  gotoxy(mx,my); write(Day,'/',Month,'/',Year);
  gotoxy(mx,my+1); write('Accept? '); readln(date);
  if date<>'' then begin     {only accepts dd/mm/yy format}
    temp_str:=copy(date,1,2);
    val(temp_str,num,err);
    if err=0 then Day:=num;
    temp_str:=copy(date,4,2);
    val(temp_str,num,err);
    if err=0 then Month:=num;
    temp_str:=copy(date,7,4);
    val(temp_str,num,err);
```

```
    if err=0 then Year:=num;
    SetDate(Year, Month, Day);
  end;
  GetTime(Hour, Minute, Second, Sec100);
  gotoxy(mx,my+2); write(Hour,':',Minute,':',Second);
  gotoxy(mx,my+3); write('Accept? '); readln(date);
  if date<>'' then begin    {only accepts hh/mm/ss format}
    temp_str:=copy(date,1,2);
    val(temp_str,num,err);
    if err=0 then Hour:=num;
    temp_str:=copy(date,4,2);
    val(temp_str,num,err);
    if err=0 then Minute:=num;
    temp_str:=copy(date,7,2);
    val(temp_str,num,err);
    if err=0 then Second:=num;
    SetTime(Hour, Minute, Second, Sec100);
  end;
end;

procedure Initialise;
var
  error : integer;
  DataFileName, title : string;
begin {port assignment}
  port[index_addr]:=cntrl_gp0; {group #0 control word}
  port[data_addr]:=$89; {pa0 & pb0 o/p, pc0 i/p}
  port[index_addr]:=cntrl_gp1; {group #1 control word}
  port[data_addr]:=$80; {all o/p}
  {DAC/control set up}
  port[index_addr]:=port_c1; {DAC i/p}
  port[data_addr]:=$0; {set the DACs to zero}
  port[index_addr]:=port_b1; {DAC control}
  DAC_cntl:=$0+Ven+Iset+Vset+Irst+Vrst;
  {both DACs to read, r/set Vmon & Imon and disable psu}
  port[data_addr]:=DAC_cntl;
  {solenoid set up}
  sol_cntl:=$0+gate;
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
   {close gate & store, open clamps & test_pos to fail}
  port[index_addr]:=port_b0; port[data_addr]:=DrEn;
  cursor(0); {off}
  title:='Gettering / BDV Test program - Ver 4.15';
  setscreen(title,blue,white,yellow,white);
  if Mode='I' then begin
    Set_Clock; {first pass only}
    DataFileName:='c:\data\datafile.dat'; {sets default gettering data file
name}
    repeat
      error:=Openfile(DataStore,DataFileName); {opens default data file}
      if error<>0 then
      begin
        clrscr;
        gotoxy(mx,my);write('Data file not found.');
        repeat
          gotoxy(mx,my+1);write('Enter full path');
          gotoxy(mx,my+2);write('or ''ESC'' to exit. ');
```

```pascal
            gotoxy(mx,my+4);write(DataFileName);
            cursor(1); {on}
            DataFileName:=readfilename(DataFileName);
            cursor(0);
            if DataFileName='' then
            begin
              DataFileName:='Exit';
              error:=0;
              clrscr;
            end;
          until DataFileName<>'';
        end;
    until error=0;
  end;
  passed:=0; {to count passed switches}
  failed:=0; {to count failed switches}
  Stop:=false;
end;

function Get_Save_File: string;
var TempName :string;
    TempFile:MainFile;
    er: integer;
    TempNumber:longint;
    S:string[12];
begin
  TempName:='c:\save\0.sav';
  TempNumber:=0;
  er:=Openfile(TempFile,TempName); {tries to open and close default save file}
  while er=0 do                    {if it exists er=0}
  begin
    delete(TempName,10,12);
    inc(TempNumber);
    str(TempNumber, S);
    insert(S, TempName, 10);
    TempName:=concat(TempName, '.sav');
    if length(TempName)>21 then quit(0);
    er:=Openfile(TempFile,TempName);
  end;
  Get_Save_File:=TempName;
end;

procedure OperatingMode;
begin
  Test:=false;
  repeat
    clrscr;
    gotoxy(mx,my);write('(G). Getter');
    gotoxy(mx,my+1);write('(V). Voltage Breakdown');
    gotoxy(mx,my+3);write('(X). Quit');
    Mode:=upcase(readkey);
    case Mode of
      'V', 'G' : Test:=true;
      #27, #88, #120 : Quit(0);
      #0: readkey;      {function key or extended keyboard key}
    end;                {reads the key press but does nothing}
  until Test;
```

```pascal
end;

procedure LoadParameters;
var
   parameters, error, count : integer;
   SwitchName : string;
   temp : real;
begin
  clrscr;
  reset(DataStore);   {resets the data file}
  count:=-1;         {reset counter}
  parameters:=8;
  repeat
    readln(DataStore,SwitchName);    {read data $ from file}
    if pos('[' , SwitchName)=1 then
     inc(count);
  until count=SwitchCode;     {until reaches chosen switch type}
  count:=0;          {reset counter}
  repeat
    readln(DataStore,SwitchName); {load the string with a number}
    val(SwitchName,temp,error); {convert to a real number}
    if count<5 then {scales 10kV - 0kV to 255 - 0}
       SwitchParameter[TestParameters(count)]:=round(temp/40*1.02)
    else {scales 1mA - 0 to 255 - 0}
       if count=5 then SwitchParameter[TestParameters(count)]:=round(temp/4*1020)
{converts to int.}
       else SwitchParameter[TestParameters(count)]:=round(temp);
    inc(count);
  until count=parameters;
  if mode='V' then begin
    SwitchParameter[Ilimit]:=124; {measure VBD - leakage current}
    SwitchParameter[Passes]:=2; {for save_data}
    SwitchParameter[Iduration]:=1; {minimum setting}
  end;
end;

procedure IdentifySwitchType;
var
  counter : integer;
  SaveFile : string;
begin
  counter:=0;
  reset(DataStore);
  clrscr;
  repeat
    SwitchType[counter]:=readpart(DataStore); {get the available types from
file}
    if not Eof(DataStore) then
    begin
      if counter<7 then begin
        gotoxy(mx,my+counter);write(counter,'. ',SwitchType[counter]);
      end;
      if counter>=7 then begin
        gotoxy(mx+20,my-7+counter);write(counter,'. ',SwitchType[counter]);
      end;
      inc(counter);
    end;
```

```
      until Eof(DataStore);
   repeat
      gotoxy(mx,my+counter+1);write('Type ''99'' to exit or');
      gotoxy(mx,my+counter+2);write('Enter Switch type to be Gettered: ');
      cursor(1);
      SwitchCode:=readint(2,false);
      cursor(0);
   until (SwitchCode in [0..(counter-1)]) or (SwitchCode=NumberOfSwitches);
   if SwitchCode in [0..(counter-1)] then
   begin
      LoadParameters;
      SaveFile:=Get_Save_File; {find next save file name}
      assign(SaveStore, SaveFile); {assign it}
      rewrite(SaveStore); {opens latest data save file}
      close(SaveStore); {close it to prevent multiple open files}
      if mode='V' then save_data(0,0,concat(SwitchType[SwitchCode],' VBD'))
      else save_data(0,0,SwitchType[SwitchCode]);
   end;
end;


procedure CloseGate;
begin
   if copy(convert(sol_cntl),3,1)='0' then begin
      delay(100); {let the switch through}
      sol_cntl:=sol_cntl+gate; {close gate}
      port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
   end;
   DAC_cntl:=DAC_cntl-Rxrst;   {reset Rx detector}
   port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
   delay(100); {arm Rx detector}
   DAC_cntl:=DAC_cntl+Rxrst; port[data_addr]:=DAC_cntl;
end;   {the resetting and arming of the Rx detector deals with 'bounce'}
{once the switch has gone through the detector it may still set off the latch}

procedure LoadRx;
var temp : char;
begin
   port[index_addr]:=port_c0;
   if copy(convert(port[data_addr]),3,1)='0' then begin
      Emergency_Stop; {door may be open, to load switches, but check for}
      exit;   {Emergency Stop button}
   end;
   clrscr;
   if copy(convert(DAC_cntl),5,1)='0' then begin
      DAC_cntl:=DAC_cntl+Ven; {turn psu off}
      port[index_addr]:=port_b1;port[data_addr]:=DAC_cntl;
   end;
   gotoxy(mx,my+1);write('Load hopper and press');
   gotoxy(mx,my+2);write('any key when finished.');
   readkey;
   port[index_addr]:=port_c0;
    while copy(convert(port[data_addr]),4,1)='0' do {Door open signal}
   begin
      clrscr;
      gotoxy(mx,my);write('Please close the door');
      gotoxy(mx,my+1);write('Press any key when done');
      gotoxy(mx,my+2);write('Or Esc to exit');
```

```
      temp:=readkey;
      if temp=#27 then begin
        Stop:=true; exit; {drop back to top level menu}
      end;
    end;
    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),3,1)='0' then begin
      Emergency_Stop;
      exit;
    end;
    if copy(convert(sol_cntl),3,1)='1' then sol_cntl:=sol_cntl-gate;
    if copy(convert(sol_cntl),6,1)='0' then sol_cntl:=sol_cntl+clamp;
    if copy(convert(sol_cntl),5,1)='0' then sol_cntl:=sol_cntl+test_pos;
    port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
    if copy(convert(DAC_cntl),6,1)='0' then begin
      DAC_cntl:=DAC_cntl+Rxrst; {arm Rx detector}
      port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
    end;
    port[index_addr]:=port_c0;
    clrscr;
    while copy(convert(port[data_addr]),8,1)='0' do
    begin
      gotoxy(mx,my); write('Waiting for first switch');
      if copy(convert(port[data_addr]),3,1)='0' then begin
        Emergency_Stop;
        exit;
      end;
      if copy(convert(port[data_addr]),4,1)='0' then begin
        Controlled_Stop;
        exit;
      end;
    end;
    CloseGate;
end;

procedure SetCurrent;
begin
  if copy(convert(DAC_cntl),2,1)='0' then begin
    DAC_cntl:=DAC_cntl+Vset;
    port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
  {latches the voltage DAC to prevent it seeing I limit value}
  end;
  port[index_addr]:=port_c1; port[data_addr]:=SwitchParameter[Ilimit];
  if copy(convert(DAC_cntl),1,1)='1' then   DAC_cntl:=DAC_cntl-Iset;
  {DAC to read on zero}
  delay(100); {settle time}
  port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
  DAC_cntl:=DAC_cntl+Iset;
  port[data_addr]:=DAC_cntl; {latch}
end;

procedure CheckInterLocks;
var
  data_word  : string;
  temp : integer;
begin
  if Stop=true then exit;
```

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    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),3,1)='0' then begin
      Emergency_Stop;
      exit;
    end;
    clrscr;
    {@ Proc Init both Vpos and Vneg are 'off' so this checks to see that Vneg}
    {is 'on' before turning it off. If Vpos is 'on' then Vneg must be off}
    if copy(convert(sol_cntl),7,1)='0' then
      if copy(convert(sol_cntl),8,1)='1' then sol_cntl:=Sol_cntl+Vpos-Vneg
      else sol_cntl:=sol_cntl+Vpos {set voltage polarity change-over to +ve}
    else sol_cntl:=sol_cntl-Vpos+Vneg; {set voltage polarity change-over to -ve}
    port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
    port[index_addr]:=port_c0; {i/p port}
    data_word:=convert(port[data_addr]); {reads the input port}
    answer:=' '; {clears of previous usage}
    while ( ((copy(data_word,3,1)='0') or (copy(data_word,4,1)='0'))
            and (answer<>#88) ) do
    begin {checks emergency stop & door closed}
      port[index_addr]:=port_c0;
      if copy(convert(port[data_addr]),3,1)='0' then begin
        Emergency_Stop;
        exit;
      end;
      clrscr;
      if copy(convert(port[data_addr]),4,1)='0' then begin
        gotoxy(mx,my);write('Please close the door.');
        gotoxy(mx,my+1);write('Press x to eXit, any key to continue.');
        answer:=upcase(readkey);
      end;
      clrscr;
    end;         {'X'}                {Esc}
    if (answer<>#88) and (answer<>#27) then begin
      gotoxy(mx-10,my);write('The Minimum VBD for the ',SwitchType[SwitchCode],
        ' is ',(SwitchParameter[Vmin]*0.04/1.02):3:1,'kV');
      SetCurrent; {see above}
      delay(5000);
      port[index_addr]:=port_c1; port[data_addr]:=$0; {DAC to zero}
      DAC_cntl:=DAC_cntl-Vset; {set to read, latched high in SetCurrent}
      port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
    end;
end;

procedure CurrentFlow;
var
  timer : integer;
  temp : string;
begin
  clrscr;
  gotoxy(mx,my);write('Arcing and sparking');
  gotoxy(mx,my+1);write('Maximum current flowing
:',(switchParameter[Ilimit]*4/1020):3:2,'mA');
  timer:=SwitchParameter[Iduration]; {from datafile}
  repeat
    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),3,2)<>'11' then begin
      Emergency_Stop;
```

```
      exit;
    end;
    if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
    gotoxy(mx,my+2);write('    ');
    gotoxy(mx,my+2);write(timer);
    dec(timer); delay(10);
  until timer=0;
  if copy(convert(DAC_cntl),5,1)='0' then begin
    DAC_cntl:=DAC_cntl+Ven; {psu off}
    port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
  end;
  port[index_addr]:=port_c0;
  if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
  gotoxy(mx,my+3);write('Current off');delay(1000); {settle time}
end;

procedure BeginGetter;
var
  RxFail, output_voltage : byte;
  BreakDownVoltage : array[0..3] of byte;
  data_word : string;
  answer:char;
begin
  port[index_addr]:=port_c0;
  if copy(convert(port[data_addr]),3,1)='0' then begin
    Emergency_Stop; {exit on Emergency Stop button}
    exit;
  end;
  if copy(convert(port[data_addr]),4,1)='0' then begin
    Controlled_Stop; {exit on opening the door}
    exit;
  end;
  clrscr;
  sol_cntl:=sol_cntl+store; {let the first switch through}
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  delay(1000); sol_cntl:=sol_cntl-store-gate-clamp;
  {close the store and open gate to let next switch in to store}
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  if mode='G' then RxFail:=SwitchParameter[Passes]
  else RxFail:=1; {only one go on VDB check}
  BreakDownVoltage[0]:=$0; {clears of previous use}
  BreakDownVoltage[1]:=$0; {clears of previous use}
  BreakDownVoltage[2]:=$0; {clears of previous use}
  BreakDownVoltage[3]:=$0; {clears of previous use}
  Test:=false; {to keep a track of switches that fail}
  port[index_addr]:=port_c0;
  if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
  repeat
    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),3,1)='0' then begin
      Emergency_Stop;
      exit;
    end;
  if copy(convert(port[data_addr]),4,1)='0' then begin
    Controlled_Stop;
    exit;
  end;
```

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if copy(convert(DAC_cntl),5,1)='1' then begin
  output_voltage:=$0; {controlled enable of psu}
  port[index_addr]:=port_c1; port[data_addr]:=output_voltage;
  DAC_cntl:=DAC_cntl-Ven;   {psu on}
  port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
end;
if RxFail>=1 then delay(1000); {allows psu to settle}
output_voltage:=SwitchParameter[Vstart];
port[index_addr]:=port_c1; port[data_addr]:=output_voltage;
if copy(convert(Sol_cntl),7,1)='1' then
  BreakDownVoltage[0]:=BreakDownVoltage[1] {resets VBD inc}
else BreakDownVoltage[2]:=BreakDownVoltage[3]; {resets VBD inc}
clrscr;
if copy(convert(DAC_cntl),3,1)='1' then DAC_cntl:=DAC_cntl-Irst;
{reset current trip latch}
if copy(convert(DAC_cntl),4,1)='1' then DAC_cntl:=DAC_cntl-Vrst;
{reset voltage monitor latch}
port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
port[index_addr]:=port_c0; data_word:=convert(port[data_addr]);
if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
gotoxy(mx,my-5); write(SwitchType[SwitchCode],' Minimum BDV :',
  (SwitchParameter[Vmin]*0.04/1.02):3:1,'kV');
gotoxy(mx+20,my); write(passed,' switches passed'); {for operators benifit}
gotoxy(mx+20,my+2); write(failed,' switches failed');
while (output_voltage<SwitchParameter[Vmax]) and
  (copy(data_word,1,1)='0') do {while < Vmax and not current limit}
begin
  port[index_addr]:=port_c0;
  if copy(convert(port[data_addr]),3,1)='0' then begin
    Emergency_Stop;
    exit;
  end;
  if copy(convert(port[data_addr]),4,1)='0' then begin
    Controlled_Stop;
    exit;
  end;
  delay(25); {artifically slows ramp}
  output_voltage:=output_voltage+SwitchParameter[Vinc];
  if output_voltage>=SwitchParameter[Vmax] then begin
    if copy(convert(DAC_cntl),5,1)='0' then begin
      DAC_cntl:=DAC_cntl+Ven; {psu off}
      port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
    end;
    output_voltage:=$0; {clear voltage DAC}
    port[index_addr]:=port_c1; port[data_addr]:=output_voltage;
    delay(3000); {let psu settle}
    clrscr;
    if RxFail<SwitchParameter[Passes] then save_data(0,0,'error')
    else Test:=true; {if o/p reach Vmax on first pass there is no Rx}
    exit; {and try again, this is to account for jams in the system}
  end;
  port[index_addr]:=port_c1; port[data_addr]:=output_voltage;
  if copy(convert(DAC_cntl),3,1)='0' then DAC_cntl:=DAC_cntl+Irst;
  {arms current trip latch}
  if copy(convert(DAC_cntl),4,1)='0' then DAC_cntl:=DAC_cntl+Vrst;
  {arms voltage monitor latch}
  port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
```

```
    port[index_addr]:=port_c0; {reads i/p and latch states}
    while copy(convert(port[data_addr]),7,2)='00' do begin
      if copy(convert(port[data_addr]),3,1)='0' then begin
        Emergency_Stop;
        exit;
      end;
      if copy(convert(port[data_addr]),4,1)='0' then begin
        Controlled_Stop;
        exit;
      end;
    end;
    data_word:=convert(port[data_addr]); {read i/p latch state}
    gotoxy(mx-5,my);write('Output = ',output_voltage);
    if copy(convert(DAC_cntl),3,1)='1' then DAC_cntl:=DAC_cntl-Irst;
    {resets current trip latch}
    if copy(convert(DAC_cntl),4,1)='1' then DAC_cntl:=DAC_cntl-Vrst;
    {resets voltage monitor latch}
    port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
    if keypressed then begin
      answer:=readkey; {exit on Esc only}
      if answer=#27 then Controlled_Stop;
      exit;
    end;
  end;
  if copy(data_word,1,1)='1' then CurrentFlow;{CurrentFlow; in current limit}
  if (copy(data_word,1,1)='1') and (mode='V') and
    (output_voltage<SwitchParameter[Vmin]) then dec(RxFail);
  if copy(convert(Sol_cntl),7,1)='1' then
    if (output_voltage-BreakdownVoltage[0]<SwitchParameter[Spread])
      then dec(RxFail)
  else
    if (output_voltage-BreakdownVoltage[2]<SwitchParameter[Spread])
      then dec(RxFail);
  if RxFail=0 then Test:=true;
  if copy(convert(Sol_cntl),7,1)='1' then
  begin
    Sol_cntl:=Sol_cntl-Vpos+Vneg;      {polarity change over}
    BreakdownVoltage[1]:=output_voltage;
  end
  else begin
    Sol_cntl:=Sol_cntl+Vpos-Vneg;
    BreakdownVoltage[3]:=output_voltage;
  end; {sets the change over relays}
  port[index_addr]:=port_a1; port[data_addr]:=Sol_cntl;
  port[index_addr]:=port_c0;
  if copy(convert(port[data_addr]),8,1)='1' then CloseGate;
  save_data(output_voltage,RxFail,' '); {save data to file}
until ((((BreakDownVoltage[1]-BreakDownVoltage[0])<SwitchParameter[Spread])
  and (BreakdownVoltage[0]>SwitchParameter[Vmin]) and
  (BreakDownVoltage[1]>SwitchParameter[Vmin]))
    {within spread and > min both times}
  and (((BreakDownVoltage[3]-BreakDownVoltage[2])<SwitchParameter[Spread])
  and (BreakDownVoltage[2]>SwitchParameter[Vmin]) and
  (BreakDownVoltage[3]>SwitchParameter[Vmin])))
    {within spread and > min both times, this ensures that the rx is fully}
```

```
           (gettered in both directions to the best that can be achieved)
      or ((Mode='V') and (output_voltage>SwitchParameter[Vmin])) or Test;
        {the test is for VBD and not Gettering}
    if RxFail>0 then save_data(0,RxFail,' ');          {fill in the blanks}
    if copy(convert(DAC_cntl),5,1)='0' then begin   {in the .sav file}
      DAC_cntl:=DAC_cntl+Ven; {psu off}
      port[index_addr]:=port_b1; port[data_addr]:=DAC_cntl;
    end;
    output_voltage:=$0; {clear voltage DAC}
    port[index_addr]:=port_c1; port[data_addr]:=output_voltage;
    clrscr;
end;

procedure SwitchTest;
var temp:string;
begin
  if Stop then exit;
  if Test then
  begin
    gotoxy(mx,my);write('Switch Failed');
    inc(failed);
    sol_cntl:=sol_cntl+clamp;
    port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  end else
  begin
    gotoxy(mx,my);write('Switch Passed');
    inc(passed);
    sol_cntl:=sol_cntl+clamp+selec;
    port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  end;
  sol_cntl:=sol_cntl-test_pos;
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  delay(500); {let tested switch drop}
  if copy(convert(sol_cntl),4,1)='1' then sol_cntl:=sol_cntl-selec;
  sol_cntl:=sol_cntl+test_pos;
  port[index_addr]:=port_a1; port[data_addr]:=sol_cntl;
  while copy(convert(sol_cntl),3,1)='0' do begin {gate open, wating for Rx}
    gotoxy(mx,my); write('Waiting for next switch');
    gotoxy(mx,my+1); write('Press any key to exit.');
    gotoxy(mx,my+3);
    if passed=1 then write(passed,' switch passed')
    else write(passed,' switches passed');
    case mode of
      'G' :  write(' Gettering');
      'V' :  write(' BDV');
    end;
    gotoxy(mx,my+4);
    if failed=1 then write(failed,' switch failed')
    else write(failed,' switches failed');
    case mode of
      'G' : write(' Gettering');
      'V' :  write(' BDV');
    end;
    gotoxy(mx,my+5); write('Total :', passed+failed);
    if keypressed then
    begin
      readkey;
```

```
      answer:=#88; ( 'X' for eXit)
      exit;
    end;
    port[index_addr]:=port_c0;
    if copy(convert(port[data_addr]),3,1)='0' then begin
      Emergency_Stop;
      exit;
    end;
    if copy(convert(port[data_addr]),4,1)='0' then begin
      Controlled_Stop;
      exit;
    end;
    if copy(convert(port[data_addr]),8,1)='1' then begin
      CloseGate;
      delay(5000); (let the switch fall in to the store)
    end;
  end;
end;

begin
  Mode:='I'; (first pass only)
  repeat
    Initialise;
    OperatingMode;
    IdentifySwitchType;
    answer:=#0; (clears previous usage)
    while (SwitchCode < NumberOfSwitches) and (answer<>#88) and
    (Stop=false) do (#88 = 'X')
    begin
      LoadRx;
      CheckInterlocks;
      while (answer<>#88) and (Stop=false) do
      begin
        BeginGetter;
        SwitchTest;
      end;
    end;
  until 1=2;
end.
```

```
{Gettering Program V2.2, May 98 - Getter1.}
{Based on original software by John Bradford}
{Coded in Borland TurboPascal 7.0 for Dos.}

{Written by D. R. Blandford}

program Getter1;

uses crt,dos,gett1,gett2,gett3,gett4;

const                                          {all addresses and
numbers beginning $ are in hex}
  cntrl_gp0 : byte = $3;                        {control address for
group 0}
  cntrl_gp1 : byte = $7;                        {control address for
group 1}
  numswits : byte = 99;
  esc : char = #27;
  parameters : integer = 8;                     {must match the
number of parameters in TestParameters below}

type
  MainFile = text;
  TestParameters = (Ibd, Vmin, Vinc, Spread, Vstart, Ilimit, Iduration, Passes);

var
  dataStore : mainFile;      col : integer;
  switchType : array[0..100] of string;          {number of switch
types for which data is held}
  switparam : array[TestParameters] of integer;
  temp,keyp,ch,mode : char;
  ithresh,nobreak,short,attempts,passed,failed,total,switchCode : integer;
  mechs,title : string;
  kp,nogood,stop,dooropen,imon,vmon,gotswit,novolts,storeopen,gateclosed,
  highv,supportopen,selectpass,clampopen,texton,catchshorts,catchopens :
boolean;
  itrip,maxvplus,maxvminus : real;


procedure safe;
{Zero DACs, HT off, short relays, clear switch path, stop switch feed, select
fail}
 begin;
  setvolts($0);
  htoff;
  shortrelays;
  shutgate;
  openstore;
  ungrip;
  dropswitch;
  fail;
  stop:=true;
end;

procedure setcurrent(current : byte);
{Writes breakdown current to DAC}
begin
```

```
  holdv;                                          {Latches voltage DAC
to prevent it seeing the current data}
  readi;                                          {DAC to read}
  port[ia]:=portdacword; port[da]:=current;
  holdi;                                          {Latch the current
DAC}
end;

procedure initialise;
{Sets up ports, makes system safe}
begin
  {Port assignment}
  port[ia]:=cntrl_gp0;                            {group #0 control
word}
  port[da]:=$89;                                  {port_a0 & portdooren
o/p, portinputs i/p}
  port[ia]:=cntrl_gp1;                            {group #1 control
word}
  port[da]:=$80;                                  {all o/p}

  {Hardware setup}
  safe;
  short:=0;                                       {reset counter for
shorted switches}
  nobreak:=0;                                     {reset counter for
missing switches}
  texton:=true;
  highv:=false;                                   {flag for max volts
on bd - remove in due course}
  ithresh:=64;
end;

procedure readinputs;
{Reads input ports, sets flags accord. Sets kp if esc key pressed.}
{Sets gotswit if G pressed - for fooling feeder in feedswitch routine}
begin;
  kp:=false;
  port[ia]:=portinputs;                                    {i/p port}
  if copy(convert(port[da]),1,1)='1' then imon:=true else imon:=false;
  if copy(convert(port[da]),2,1)='1' then vmon:=true else vmon:=false;
  if copy(convert(port[da]),3,1)='0' then novolts:=true else novolts:=false;
  if copy(convert(port[da]),4,1)='0' then dooropen:=true else dooropen:=false;
  if copy(convert(port[da]),8,1)='1' then gotswit:=true else gotswit:=false;
  if keypressed then begin;
    ch:=upcase(readkey);
    if ch=esc then kp:=true else kp:=false;
    if ch='G' then gotswit:=true;
  end;
end;

procedure readmechanics;
{Reads mechanics (output) port. Used to toggle o/ps in mechanics proc & to check
gate status in esc proc.}
begin;
  port[ia]:=portmechs;
  mechs:=convert(port[da]);
  if copy(mechs,1,1)='1' then storeopen:=true else storeopen:=false;
```

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  if copy(mechs,3,1)='1' then gateclosed:=true else gateclosed:=false;
  if copy(mechs,4,1)='1' then selectpass:=true else selectpass:=false;
  if copy(mechs,5,1)='0' then supportopen:=true else supportopen:=false;
  if copy(mechs,6,1)='1' then clampopen:=true else clampopen:=false;
end;

procedure drawscreen;
{Draws screen box with main menu title}
begin;
  cursor(0);                                                    {off}
  title:='Gettering / BDV Test Program - Ver 2.20';
  setscreen(title,blue,white,lightcyan,white);
end;

procedure quit;
{Exit messages, makes system safe, resets DOS screen. Only way is out from
here.}
begin;
  setscreen('Exiting gettering program...',darkgray,lightcyan,yellow,white);
  safe;
  if total>1 then begin
    gotoxy(16,6);write(total-1,' switches were tested on the last run.');
    gotoxy(25,7);write(passed,' passed,  ',failed,' failed.');
  end;
  centre(10,'System is safe. Press Esc to exit to DOS.');
  centre(11,'To restart program type ''Getter1'' and press enter at the C
prompt.');
  if texton then witter;
  repeat
    ch:=upcase(readkey);
  until ch=esc;
  window(1,1,80,25);
  textcolor(lightgray);
  textbackground(black);
  clrscr;
  cursor(1);
  halt;
end;

procedure syserror;
{Displays error message if dooropen or psu dies, waits for keypress then exits
to main menu}
begin;
  stop:=true;
  clrscr;
  textcolor(yellow + blink);
  textbackground(red);
  if dooropen then centre(8,' Fatal hardware error - Door has been opened... ');
  if novolts then centre(8,' Fatal hardware error - HT power supply not
present... ');
  centre(10,' Making safe and returning to main menu. ');
  centre(11,' Current switch will be failed. ');
  centre(13,' Press any key to continue. ');
  safe;
  readkey;
  textcolor(white);
  textbackground(blue);
```

```
  drawscreen;
end;

procedure escape;
{Called on Esc pressed. Stops processing, shuts gate to prevent store jamming
with switches}
{Requests stop or continue, if stop makes safe and returns to main menu}
var
  ch : char;
  gatestate : boolean;

begin;
  readmechanics;
  if gateclosed then gatestate:=true else gatestate:=false;
  shutgate;
  textcolor(yellow+blink);
  clear(4);centre(4,'Do you wish to stop processing switches?');
  clear(5);centre(5,'Press ''S'' to stop, ''C'' to continue.');
  textcolor(white);
  repeat
    repeat
      readinputs;
      if not dooropen then beep(300,10);
      if dooropen then begin
        syserror;
        exit;
      end;
      delay(300);
    until keypressed;
    if keypressed then begin;
      ch:=upcase(readkey);
    end;
    if ch='C' then begin;                               {do nothing, continue
processing}
      clear(4);
      clear(5);
      stop:=false;
      if gatestate then shutgate else opengate;
      exit;
    end;
    if ch='S' then begin;                               {escape to main menu}
      stop:=true;
      clrscr;
      centre(10,'Making safe and returning to main menu.');
      centre(11,'Current switch will be failed.');
      safe;
      delay(2000);
      drawscreen;
    end;
    kp:=false;
  until ch in ['C','S'];
end;

procedure passfail;
{Displays  pass/fail status and figures}
begin;
  clear(10);
```

```
      clear(11);
      win2;
      if passed=1 then begin;
         gotoxy(16,1);clreol;
         write(passed,' switch passed, ');
      end
      else begin;
         gotoxy(16,1);clreol;
         write(passed,' switches passed, ');
      end;
      if failed=1 then begin;
         gotoxy(16+22,1);
         write(failed,' switch failed.');
      end
      else begin;
         gotoxy(16+22,1);
         write(failed,' switches failed.');
      end;
      win1;
   end;

   procedure getdatafile;
   {Locates datafile on disc. Requests file name if not found}
   var
      error : integer;
      DataFileName : string;

   begin;
      DataFileName:='c:\ver22\data.dat';                        {sets default gettering
   data file name}
      repeat
         error:=Openfile(DataStore,DataFileName);               {opens default data
   file}
         if error<>0 then
         begin
            clrscr;
            centre(10,'Data file not found.');
            repeat
               centre(12,'Enter full path,');
               centre(13,'or Esc to exit.');
               centre(15,DataFileName);
               cursor(1);                                        {on}
               DataFileName:=readfilename(DataFileName);
               cursor(0);
               if DataFileName='' then
               begin
                  DataFileName:='Exit';
                  error:=0;
                  clrscr;
               end;
            until DataFileName<>'';
         end;
      until error=0;
   end;

   procedure loadswitches;
   {Displays loading screen and checks door closed}
```

```pascal
begin
  clrscr;
  htoff;
  centre(10,'Load feeder bowl and close door.');
  centre(11,'Press any key when done,');
  centre(12,'or Esc to exit.');
  if texton then witter;
  ch:=readkey;
  if ch=esc then begin
    drawscreen;
    exit;                                         {to mainmenu}
  end;
  readinputs;
  while dooropen do begin
    clrscr;
    centre(10,'Please close the door.');
    centre(11,'Press any key when done,');
    centre(12,'or Esc to exit.');
    beep(700,100);delay(50);beep(700,100);
    ch:=readkey;
    if ch=esc then begin
      drawscreen;
      exit;
    end;
    readinputs;
  end;
  if ch=esc then begin
    stop:=true;
    drawscreen;
    exit;                                         {to mainmenu}
  end;
end;

procedure mechanics;
{Allows mechanics to be moved at will. Exits to DOS or main menu.}
{Mechanics can be reset or left as changed}
var
  cd : char;
  col1,col2,pos : integer;
  mechstr : string;

begin;
  htoff;
  pos:=45;col1:=lightred;col2:=lightgreen;
  centre(3,'Toggle testhead mechanics as required.');
  centre(4,'Ensure bowl feeder is turned off to avoid switch jams.');
  textcolor(lightgray);
  centre(5,'Note that a green status represents a safe condition.');
  textcolor(white);
  centre(7,'1. Bowl Feeder Gate              ');
  centre(8,'2. Temporary Store               ');
  centre(9,'3. Testhead Clamps               ');
  centre(10,'4. Switch Support               ');
  centre(11,'5. Pass/Fail Selector           ');
  centre(12,'6. Positive Relay               ');
  centre(13,'7. Negative Relay               ');
  centre(15,'K. Keep Selection & Exit        ');
```

```
    centre(16,'R. Reset to Safe & Exit       ');
    readmechanics;
    if gateclosed then begin
      gotoxy(pos,7);textcolor(col2);write('(closed)  ');
    end
    else begin
      gotoxy(pos,7);textcolor(col1);write('(open)  ');
    end;
    if storeopen then begin
      gotoxy(pos,8);textcolor(col2);write('(open)  ');
    end
    else begin
      gotoxy(pos,8);textcolor(col1);write('(closed)  ');
    end;
    if clampopen then begin
      gotoxy(pos,9);textcolor(col2);write('(open)  ');
    end
    else begin
      gotoxy(pos,9);textcolor(col1);write('(closed)  ');
    end;
    if supportopen then begin
      gotoxy(pos,10);textcolor(col2);write('(open)  ');
    end
    else begin
      gotoxy(pos,10);textcolor(col1);write('(closed)  ');
    end;
    if selectpass then begin
      gotoxy(pos,11);textcolor(col1);write('(pass)  ');
    end
    else begin
      gotoxy(pos,11);textcolor(col2);write('(fail)  ');
    end;
    if plus then begin
      gotoxy(pos,12);textcolor(col2);write('(closed)  ');
    end
    else begin
      gotoxy(pos,12);textcolor(col1);write('(open)  ');
    end;
    if minus then begin
      gotoxy(pos,13);textcolor(col2);write('(closed)  ');
    end
    else begin
      gotoxy(pos,13);textcolor(col1);write('(open)  ');
    end;
    repeat
      readmechanics;
      if keypressed then begin                              {empty keyboard
buffer to stop overrun}
        repeat readkey; until not keypressed;
      end;
    ch:=upcase(readkey);
    case ch of
      '1' : if gateclosed then begin
              opengate;gotoxy(pos,7);textcolor(col1);write('(open)  ');
            end
            else begin
              shutgate;gotoxy(pos,7);textcolor(col2);write('(closed)  ');
```

```
                end;
      '2' : if storeopen then begin
               shutstore;gotoxy(pos,8);textcolor(col1);write('(closed)  ');
            end
            else begin
               openstore;gotoxy(pos,8);textcolor(col2);write('(open)  ');
            end;
      '3' : if clampopen then begin
               grip;gotoxy(pos,9);textcolor(col1);write('(closed)  ');
             end
             else begin
                ungrip;gotoxy(pos,9);textcolor(col2);write('(open)  ');
             end;
      '4' : if supportopen then begin
               supportswitch;gotoxy(pos,10);textcolor(col1);write('(closed)  ');
             end
             else begin
                dropswitch;gotoxy(pos,10);textcolor(col2);write('(open)  ');
             end;
      '5' : if selectpass then begin
               fail;gotoxy(pos,11);textcolor(col2);write('(fail)  ');
            end
            else begin
               pass;gotoxy(pos,11);textcolor(col1);write('(pass)  ');
            end;
      '6' : if plus then begin
               openpos;gotoxy(pos,12);textcolor(col1);write('(open)  ');
            end
            else begin
               closepos;gotoxy(pos,12);textcolor(col2);write('(closed)  ');
            end;
      '7' : if minus then begin
               openneg;gotoxy(pos,13);textcolor(col1);write('(open)  ');
            end
            else begin
               closeneg;gotoxy(pos,13);textcolor(col2);write('(closed)  ');
            end;
      'K' : begin
               textcolor(yellow);
               centre(18,'To exit to DOS with with mechanics as displayed, press
''D'',');
               centre(19,'otherwise press any key to return to main menu.');
               repeat
                 temp:=upcase(readkey);
                 if temp='D' then begin
                   textbackground(black);textcolor(lightgray);
                   window(1,1,80,25);clrscr;cursor(1);
                   centre(12,'    Mechanics be not be in jam-proof state. Ensure
bowl feeder is off.');
                   centre(13,'    To restart program type ''Getter1'' and press
Enter.');
                   gotoxy(1,20);
                   halt;
                 end
                 else begin
                   clear(18);clear(19);
                   textcolor(lightred);
```

```
                        centre(18,'Mechanics remaining as displayed.');
                        centre(19,'Beware potential jams if bowl feeder turned on.');
                        textcolor(white);
                        beep(300,300);
                        break;
                      end;
                   until keypressed;
                end;
         'R' : begin
                 textcolor(lightgreen);
                 safe;
                 centre(18,'Mechanics returned to safe condition.');
               end;
      end;
      delay(300);                                        (prevents a held-down
key thrashing mechanics)
    until ch in ['K','R'];
    textcolor(white);
    delay(3000);
    drawscreen;
end;

procedure mainmenu;
{Displays main menu to allow choice of operation}

var
    xpos : integer;
    ch : char;

begin
    xpos:=24;
    itrip:=ithresh/256;                                 (ithresh = integer
(64), itrip = real}
    catchshorts:=true;
    catchopens:=true;
    win3;clrscr;win2;clrscr;window(5,4,76,24);          (As setscreen}
    nogood:=false;                                      (Flag for failed
switch)
    kp:=false;
    repeat

      if highv then begin
        textcolor(yellow);                              (remove in due
course}
        centre(2,'   Now in high voltage breakdown mode.');
        textcolor(white);
      end;

      centre(4,'Main Menu');
      centre(5,'~~~~~~~~~~~~');
      gotoxy(xpos,7); write('(G). Gettering');
      gotoxy(xpos,8); write('(V). Voltage Breakdown');
      gotoxy(xpos,9);
      if catchshorts then write('(S). Shorted Switches Warning ON ')
        else write('(S). Shorted Switches Warning OFF ');
      gotoxy(xpos,10);
      if catchopens then write('(O). Open Switches Warning ON ')
```

```
      else write('(O). Open Switches Warning OFF ');
    gotoxy(xpos,11);write('(M). Move Mechanics');
    gotoxy(xpos,13);write('(X). Quit');
    if (mode in ['G','V','M']) and (texton) then witter;
    textcolor(yellow);
    centre(18,'To stop processing in an emergency, switch off HT supply.');
    textcolor(white);
    mode:=upcase(readkey);
    case mode of
      '?' : begin
               setscreen('Witter Test ',blue,white,lightgreen,white);
               repeat clrscr;witter; until keypressed;
               drawscreen;
             end;
      'G' : begin;
        nogood:=true;
        if highv then title:='Gettering Mode - High Voltage Version'
        else title:='Gettering Mode';
        setscreen(title,blue,white,lightgreen,white);
        loadswitches;
      end;
      'V' : begin;
        nogood:=true;
        title:='Voltage Breakdown Mode';
        setscreen(title,blue,white,yellow,white);
        loadswitches;
      end;
      'S' : begin
        if catchshorts then catchshorts:=false
          else catchshorts:=true;
        beep(300,30);
      end;
      'O' : begin
        if catchopens then catchopens:=false
          else catchopens:=true;
        beep(300,30);
      end;
      'M' : begin;
        title:='Servicing Mode - HT Power Supply is Disabled ';
        setscreen(title,darkgray,lightcyan,yellow,white);
        mechanics;
      end;
      'X' : begin;
        if exitnow(lightgreen)='Y' then quit;
      end;
      'Q' : texton:=false;
      'W' : texton:=true;
      #5 : begin {Control E}                              {remove in due
course}
        if highv then begin
          highv:=false;
          clear(2);
        end
        else begin
          highv:=true;
          textcolor(yellow);
          centre(2,'   Now in high voltage breakdown mode.');
```

```pascal
          textcolor(white);
        end;
        beep(300,300);
      end;
      #9 : begin {Control I}
        repeat
          textcolor(white);
          gotoxy(29,15);clreol;
          itrip:=ithresh/256;
          write('Itrip = ',itrip:5:3,' mA.');
          ch:=upcase(readkey);
          if ch='U' then ithresh:=ithresh+1;
          if ch='D' then ithresh:=ithresh-1;
          if ithresh<1 then ithresh:=1;
          if ithresh>254 then ithresh:=255;
          gotoxy(29,15);clreol;
          write('Itrip = ',itrip:5:3,' mA.');
        until ch=#27;
        textcolor(white);
        gotoxy(29,15);clreol;
      end;
      #0: readkey;                              {ignore function key}
    end;
  until (nogood) and (ch<>'X') and (ch<>esc);   {esc exits
loadswitches}
end;


procedure LoadParameters;
{Loads switch parameters from datafile}
var
   error, count : integer;
   SwitchName : string;
   temp : real;

begin
  clrscr;
  reset(DataStore);                             {resets the data
file}
  count:=-1;                                     {reset counter}
  repeat
    readln(DataStore,SwitchName);               {read data $ from
file}
    if pos('[' , SwitchName)=1 then             {a [ indicates switch
names}
      inc(count);
  until count=SwitchCode;                       {until reaches chosen
switch type}
  count:=0;                                     {reset counter}
  repeat                                        {wish someone would
reset mine}
    readln(DataStore,SwitchName);               {load the string with
a number}
    val(SwitchName,temp,error);                 {convert to a real
number}
    if count<5 then                             {scales 10kV - 0kV to
255 - 0 and saves as an integer}
      switparam[TestParameters(count)]:=round(temp/40*1.02)
```

```
    else                                               {scales 1mA - 0 to
255 - 0}
      if count=5 then switparam[TestParameters(count)]:=round(temp/4*1020)
      else switparam[TestParameters(count)]:=round(temp);  {converts to int.}
    inc(count);
  until count=parameters;
  if mode='V' then begin
    switparam[Ilimit]:=124;                            {measure VBD -
leakage current}
    switparam[Passes]:=2;
    switparam[Iduration]:=1;                           {minimum setting}
  end;
end;

procedure switchmenu;
{Displays available switch types. Note that display is controlled by datafile}
var
  mx,my,counter : integer;

begin
  case mode of
    'V' : begin
      counter:=0;mx:=18;my:=6;
      reset(DataStore);
      clrscr;
      repeat
        SwitchType[counter]:=readpart(DataStore);      {get the
available types from file}
        if not Eof(DataStore) then
        begin
          if counter<3 then begin
            gotoxy(mx,my+counter);write(counter,'. ',SwitchType[counter]);
          end;
          if counter>=3 then begin
            gotoxy(mx+22,my-3+counter);write(counter,'. ',SwitchType[counter]);
          end;
          inc(counter);
        end;
      until Eof(DataStore);
      repeat
        centre(19,'Enter switch type to be tested:');
        centre(20,'Esc to exit.');
        gotoxy(53,19);
        cursor(1);
        SwitchCode:=readint(2,false);                  {Readint allows
exit on Esc, sets switchcode to 99}
        cursor(0);
      until (SwitchCode in [0..(counter-1)]) or (SwitchCode=numswits);
      if SwitchCode in [0..(counter-1)] then LoadParameters;
      if switchcode=99 then drawscreen;                {Redo main title
on esc}
    end;
    'G' : begin
      clrscr;
      centre(6,'1. SRA 830');
      centre(7,'2. TDA 832');
      centre(8,'3. SRA 831');
```

```
      repeat
        centre(19,'Enter switch type to be tested:');
        centre(20,'Esc to exit.');
        gotoxy(53,19);
        cursor(1);
        SwitchCode:=readint(2,false);                    {Readint allows
exit on Esc, sets switchcode to 99}
      until (switchcode in [1..3]) or (switchcode=numswits);
      cursor(0);
      if switchcode=1 then switchcode:=0;                {aligns
switchcode with that obtained in VBD so correct}
      if switchcode in [0,2,3] then loadparameters;      {datafile entry
is used}
      if switchcode=99 then drawscreen;
      win3;
      case switchcode of
        0 : centre(1,'Processing SRA830 switches.');
        2 : centre(1,'Processing TDA832 switches.');
        3 : centre(1,'Processing SRA831 switches.');
      end;
      win1;
    end;
  end;
end;

procedure checkdoor;
{Ensures door closed before continuing}
begin
  if stop then exit;
  ch:=' ';                                               {clears of previous
usage}
  repeat
    readinputs;
    if novolts then syserror;                            {HT psu gone away}
    if dooropen then begin
      clrscr;
      centre(10,'Please close the door.');
      centre(11,'Press Esc to exit, any key to continue.');
      beep(300,300);delay(100);beep(300,300);
      ch:=upcase(readkey);
    end;
    if ch=esc then exit;                                 {Does not start
gettering unless ch not esc}
  until (not dooropen) and (ch<>esc);                    {Door closed and ch
not esc}
  clrscr;
end;

procedure showbdv;
{Displays minimum required BDV for switch being tested (from datafile)}
begin;
  if mode='G' then exit;                                 {only do if VBD, exit
if gettering}
  win3;textcolor(lightcyan);
  gotoxy(21,1);write('Processing ',SwitchType[SwitchCode],' switches.');
  textcolor(white);win1;
end;
```

```
procedure CurrentFlow;
{Determines duration of breakdown discharge}
var
  timer : integer;

begin
  timer:=switparam[Iduration];                              {from datafile}
  repeat
    readinputs;
    if novolts then syserror;
    if dooropen then syserror;
    if stop then exit;
    if gotswit then begin;
      shutgate;
      armgotswit;
    end;
    dec(timer); delay(10);
  until timer=0;
  setvolts($0);
  {htoff;{use vout=0 as htoff shorts relay, upsetting relay flags, and hence
logic}
  clear(10);centre(10,'Power supply off...');
  delay(1000);                                              {allows psu to
settle}
  clear(10);
  readinputs;
  if gotswit then begin;
    shutgate;
    armgotswit;
  end;
end;

procedure showvolts;
{Displays program parameters - ramp polarity, switch no, attempt no, output
voltage}
begin;
  clear(6);gotoxy(20,6);
  write('Switch ',total:6,',            Pass ',attempts:2,'.');
  if plus then begin;
    textcolor(lightred);
    clear(10);centre(10,'Power supply ramping positive...');
  end
  else begin;
    textcolor(lightcyan);
    clear(10);centre(10,'Power supply ramping negative...');
  end;
  textcolor(white);
  clear(11);gotoxy(18,11);
  write('Output word = ',voltsout :3,', Voltage = ',voltsout*39.2/1000 :3:2,'
kV');
end;

procedure showmaxvolts;
{Displays max attained voltage in each direction for DUT}
begin;
  clear(8);gotoxy(6,8);
```

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  write('Max Vplus achieved = ',maxvplus:5:2,' kV,','');
  gotoxy(38,8);
  write('Max Vminus achieved = ',maxvminus:5:2,' kV','.');
end;

procedure feedswitch;
{Fills store, testhead remains empty as yet}
var
  ch : char;

begin;
  clear(10);centre(10,'Waiting for a switch...');
  clear(11);centre(11,'Press Esc to exit.');
  readinputs;
  if dooropen then syserror;
  if novolts then syserror;                              {HT psu gone away}
  if stop then exit;
  armgotswit;                                            {ready to detect
switch}
  shutstore;                                             {ready to catch
switch}
  opengate;                                              {feed a switch}
  readinputs;                                            {I'd rather have a
beer}
  while not gotswit do begin                             {if not got a switch
yet}
    readinputs;
    if dooropen then syserror;
    if novolts then syserror;                            {HT psu gone away}
    if kp then begin;                                    {Esc key pressed -
checked for in readinputs}
      escape;
    end;
    if stop then exit;                                   {To main program}
  end;
  shutgate;                                              {stop feeding
switches}
  armgotswit;                                            {ready for next
switch}
end;                                                     {switch in store,
gate closed testhead empty}

procedure readytogetter;
{Places switch in testhead, grips and enables next switch to be fed to store}
begin;
  clear(10);centre(10,'Setting up ready to getter...');
  supportswitch;
  pluspol;
  hton;
  ungrip;
  fail;
  openstore;
  delay(2000);
  grip;
  shutstore;
  armgotswit;
end;
```

```
procedure processdut;
{Display pass/fail message, inc p/f counters, select bin, reset attempts counter
& fail flag}
begin
  if stop then exit;
  inc(total);
  attempts:=0;                                             {Reset attempts
counter for next switch}
  win2;clrscr;win1;                                        {Remove 'Press esc to
stop'}
  if nogood then begin                                     {Switch failed}
    failit;
    inc(failed);
    fail;
  end
  else begin
    passit;
    inc(passed);
    pass;
  end;
  passfail;                                                {Display score at
bottom}
  ungrip;
  dropswitch;
  clear(10);centre(10,'Switch dropping to pass/fail bins...');
  delay(2000);                                             {let tested switch
drop}
  clrscr;
  clear(10);
  fail;                                                    {Return to default
fail selection}
  nogood:=false;
end;

procedure BeginGetter;                                     {The big one!}

{The main processing procedure - all else is here to support this.}
{Stand back, ye mortals and be amazed...}

var
  ntries : byte;
  bdvolts : array[0..3] of byte;
  initvolts,tempvp,tempvm : real;
  str1 : string;
  shortcount,nobreakcount : integer;
  getteredplus,getteredminus : boolean;

begin
  {At this point there should be a switch in testhead.}

  {======== Once-off initialisation for procedure  ========}

  {Initialise variables used each time through procedure, arm v/i latches}
  getteredplus:=false;
  getteredminus:=false;
```

```
  maxvplus:=0;maxvminus:=0;                                      {reset peak hold
stores}
  tempvp:=0;tempvm:=0;                                           {ditto temp stores)
  bdvolts[0]:=$0;                                                {set to successive
BDV values}
  bdvolts[1]:=$0;                                                {0 & 1 for pos, 2 & 3
for neg}
  bdvolts[2]:=$0;                                                {here cleared after
previous use}
  bdvolts[3]:=$0;                                                {good, these
comments, eh?)
  nogood:=false;                                                 {true if switch
failed}
  armi;

  {If gettering set no. ramps to that defined in datafile. If VBD set to 1 as
only testing, not gettering.)
  if mode='G' then ntries:=switparam[Passes]
    else ntries:=1;                                              {No fails allowed on
BDV check}

  {Write messages}
  clrscr;
  centre(10,'Starting main gettering procedure...');
  delay(1000);clear(10);                                         {hold message 1 sec}
  win2;textcolor(lightcyan);
  centre(3,'Press Esc to stop.');
  win1;textcolor(white);

  {Check for door, stop button and esc key. Used sev. times but exit precludes a
procedure.}
  readinputs;                                                    {I want to be a
spaceman when I grow up...}
  if dooropen then syserror;
  if novolts then syserror;                                      {HT psu gone away}
  if kp then begin                                               {kp set in readinputs
if esc pressed}
    clrscr;                                                      {reset in escape}
    escape;
  end;
  if stop then exit;                                             {to main prog loop}

  {Initialise power supply and relays}
  setvolts($0);                                                  {HT set to zero
volts, but not yet enabled}
  setcurrent(switparam[ibd]);                                    {define ilimit for at
BD threshold, based on datafile}
  hton;                                                          {enable power supply
- opens relays}
  pluspol;                                                       {switch relays to
plus polarity - do after hton}

  {======== End once-off initialisation for procedure  ========}

  {Main gettering loop, ends at end of procedure}
  repeat  {Until some 'orrible combination of logic that defies unravelling}
```

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      (Check for door, stop, esc)
      readinputs;
      if dooropen then syserror;
      if novolts then syserror;                          {HT psu gone away}
      if kp then begin
        clrscr;
        escape;
      end;
      if stop then exit;                                 (to main prog loop)

      {Arm ilatch ready for BD, clear fail flag & set power supply to initial
  volts}
      armi;                                              {arm current latch}
      nogood:=false;                                     {clear fail flag}
      voltsout:=switparam[vstart];                       {set voltage data
  word to initial value, set in datafile}
      setvolts(voltsout);                                {set power supply to
  initial value}
      setcurrent(ithresh);{(switparam[ibd]);                      {define
  ilimit for at BD threshold, based on datafile}
      initvolts:=switparam[Vstart]*39.2/1000;            {convert data to real
  voltage for display}
      clear(10);centre(10,'Power supply set to start voltage and Ibd detect
  current...');
      clear(11);gotoxy(33,11);
      write(initvolts :3:2,' kV');                       {display voltage}
      delay(1000);                                       {to read message}

      {Breakdown on application of initial volts - catch shorts, low BDV etc.}
      readinputs;                                        {check for imon in if
  statement below}
      if (imon) and (voltsout=switparam[vstart]) then begin; {if BD at init volts}
      setvolts($0);                                      {zero volts prior to
  exit}
        textcolor(lightcyan);
        clear(12);centre(12,'Switch breakdown at initial voltage - will be
  failed.');
        delay(1000);
        textcolor(white);

      {Shorted switch detect}
      if catchshorts then inc(short);                    (inc shorted switch
  counter}
      for shortcount:=1 to short do begin                {beep for each
  consecutive shorted switch}
          beep(500,100);delay(100);
        end;
        if (catchshorts) and (short>=5) then begin
          textcolor(yellow+blink);
          short:=0;
          clear(14);centre(14,'5 successive switches are short circuit or have low
  BDV...');
          clear(15);centre(15,'Press any key to continue.');
          delay(100);
          repeat
            comehither;
          until keypressed;
```

```
       textcolor(white);
     end;
     nogood:=true;                                    {set flag to fail
switch}
     if nogood then break;                            {exit to processdut
at end of begingetter}
   end;

   {Inc attempts count & reset BDV peak hold stores}
   if plus then begin;                                {if pos ramp}
     inc(attempts);                                   {inc counter for num
of ramps - only done on pos ramp}
     bdvolts[0]:=bdvolts[1];                          {reset pos VBD store}
   end
   else bdvolts[2]:=bdvolts[3];                       {if neg ramp reset
neg BDV store}

   {While breakdown not occurred and vout < 10kV - prevents rollover if no
switch present, ie. no breakdown}
   while (not imon) and (voltsout<9950) do begin
     readinputs;                                      {check for door,
stop, switch fed, esc}
     if dooropen then syserror;
     if novolts then syserror;                        {HT psu gone away}
     if gotswit then shutgate;                        {if switch fed then
no more switches yet}
     if kp then begin
       clrscr;
       escape;
     end;
     if stop then exit;                               {to main prog loop}

     {Inc vout to create ramp}
     {If a delay to slow down ramp is required it goes here}
     inc(voltsout,switparam[Vinc]);                   {inc voltage by
defined amount}
     setvolts(voltsout);                              {output new voltage}
     short:=0;                                        {no early breakdown
so reset counter}
     showvolts;                                       {display current
voltage}
   end;                                               {end while not
breakdown}

   {If switch broken down}
   if imon then nobreak:=0;                           {breakdown so reset
missing switch counter}
   if (imon) or (voltsout=255) then begin
     if plus then begin                               {plus}
       bdvolts[1]:=voltsout;                          {peak hold routine}
       tempvp:=bdvolts[1]*39.2/1000;                  {store last real kV
value}
       if tempvp>maxvplus then maxvplus:=tempvp;      {if larger than
maxvplus update maxvplus}
     end
     else begin                                       {minus}
       bdvolts[3]:=voltsout;                          {peak hold routine}
```

```
        tempvm:=bdvolts[3]*39.2/1000;
        if tempvm>maxvminus then maxvminus:=tempvm;
      end;                                              {of change over
relays}
      clear(10);textcolor(yellow);
      centre(10,'Passing breakdown current...');
      textcolor(white);
      showmaxvolts;

      if highv then setvolts(255);                     {set max voltage so
bd current is not voltage limited}
      setcurrent(switparam[ilimit]);                   {set ilimit for
gettering current}
      currentflow;                                     {current limit for
set time}
    end;

    if (imon) and (mode='V')                           {If in VBD mode and
BD at less than vmin}
      and (voltsout<switparam[Vmin])
        then dec(ntries);

    {Check for repeated non-breakdowns - is there a switch present?}
      if (catchopens) and (bdvolts[0]=255) and (bdvolts[1]=255) and
        (bdvolts[2]=255) and (bdvolts[3]=255) then begin    {no breakdown}
        inc(nobreak);                                  {inc missing switch
counter}
        for nobreakcount:=1 to nobreak do begin        {beep for each
consecutive missing switch}
          beep(500,100);delay(100);
        end;
        if (nobreak>=5) then begin
          nobreak:=0;
          textcolor(yellow+blink);
          clear(14);centre(14,'5 successive switches have failed to breakdown -
check feed...');
          clear(15);centre(15,'Press any key to continue.');
          delay(100);
          repeat
            comehither;
          until keypressed;
          textcolor(white);
        end;
      end;

    {Check for gettering complete in each direction}
    if plus then                                       {plus direction}
      if (voltsout-bdvolts[0]<switparam[Spread]) then getteredplus:=true;
      {successive pos BDVs close enough to call it done?}
    if minus then                                      {minus direction}
      if (voltsout-bdvolts[2]<switparam[Spread]) then getteredminus:=true;
      {ditto neg BDVs?}
    if (getteredplus) and (getteredminus) then dec(ntries);
    if ntries=0 then nogood:=true;                     {fail switch as has
been ramped set no. of times}

    {Polarity changeover}
```

```pascal
    if plus then begin
      minuspol;
      bdvolts[1]:=voltsout;                                {plus to minus}
    end
    else begin
      pluspol;                                             {minus to plus}
      bdvolts[3]:=voltsout;
    end;

    {Check for esc and switch fed}
    readinputs;
    if gotswit then shutgate;
    if dooropen then syserror;
    if novolts then syserror;                              {HT psu gone away}
    if kp then begin
      clrscr;
      escape;
      if stop then exit;                                   {to main prog loop}
    end;                                                   {end if kp}

  {Conditions for end of loop}
  until (((((bdvolts[1]-bdvolts[0])<switparam[Spread])
    and (bdvolts[0]>switparam[Vmin])
      and (bdvolts[1]>switparam[Vmin]))
      {within spread and > vmin both times in pos direction}

        and (((bdvolts[3]-bdvolts[2])<switparam[Spread])
          and (bdvolts[2]>switparam[Vmin])
            and (bdvolts[3]>switparam[Vmin]))))
      {within spread and > vmin both times in neg direction, this ensures
      that the rx is fully gettered in both directions}

    or ((Mode='V') and (voltsout>switparam[Vmin]))
      {BDV mode and vmin exceeded}

      or nogood;
      {fail flag set}

  {Tidy up and processdut}
  htoff;                                                   {kill power supply}
  setvolts($0);                                            {zero voltage DAC}
  processdut;                                              {the break assoc.
with early breakdown exits here}
  clrscr;
end;                                                       {at last!}

procedure resetvariables;
{Er, reset variables}
begin;
  total:=1;                                                {Total switch count}
  passed:=0;                                               {Pass/fail counters}
  failed:=0;
  attempts:=0;
  stop:=false;
end;
```

```
begin;  {Program}
  clrscr;
  initialise;
  drawscreen;
  getdatafile;
  repeat                                          {Main program loop}
    mainmenu;                                     {Test or exit}
    resetvariables;
    switchmenu;                                   {Switchtype}
    if switchcode<>99 then showbdv;               {Only if a switch
type was selected}

    while (SwitchCode < numswits) and (stop=false) do begin{Gettering loop}
      while not stop do begin
        feedswitch;                               {Pass a switch to the
store}
        if stop then break;                       {stop set in escape -
exit loop early}
        checkdoor;                                {If okay, start}
        readytogetter;                            {Set up mechanics &
deliver switch into testhead}
        begingetter;                              {do the buis}
      end;
    end;
  until 1=2;
end.
```

APPENDIX FOUR – COMPANY A – MISSING KAN-BAN

Errors/sht	Quantity	Start Date	01/01/1997
5	34	Finish Date	01/06/1997
2	27		
7	81		
6	35		
7	112		
8	64		
7	252		
8	37		
5	120		
5	151		
6	46		
5	93		
3	11		
9	104		
7	122		
8	87		
8	71		
4	19		
13	107		
3	9		
2	13		
3	8		
1	21		
2	2		
5	46		
2	6		
2	5		
3	26		
5	57		
5	29		

Total	156	1795
Average	-	12

Recorded	566
Missing	156
Total	722
% Missing	21.61%

APPENDIX FIVE – COMPANY B – SAMPLE VISIT REPORT

VISIT REPORT

The visit took place on Tuesday 7th May 1998. Present were John Kiff (Works Director for Company B) and John Bradford.

Purpose

The visit was to establish contact between the two parties. This was to enable a relationship to form and to determine the range and scope of the relationship.

Initial Impressions

Company B is a family owned concern. It has been trading for over 50 years and has always had machine tools as the principle product range. The management structure is very flat with a Chairman, Managing Director, Financial Director, Works Director and Marketing Director. The company in total employ 18 people, most have been with the company for more than 10 years.

The product range has not changed fundamentally during the life time of the business. There are still parts being used today that were designed many years ago. This reflects the simplicity of the original designs. There is a move towards Computer Numerical Controlled (CNC) machines. This is the focus of a new product development programme.

To assist the improvement of the manufacturing system and to enable production of the new products to commence, new machinery is being purchased. This will in turn lead to a re-layout of the shop floor. The current shop floor layout has grown up with the business and could be improved. The shop floor is divided by the main stores which separates piece part work from the assembly area. There is no clear route for material to follow during production.

At present the production levels are such that these issues do not hinder the ability of the business to meet orders. Typical production levels are 25 machines per month. In addition there are some jig-saws, CNC drills and specials that are produced. Each drill is modified to customer specification from the standard base model. This modification takes the shape of illumination, belt ratios and other features.

Possible areas of action

Discussions with John Kiff have highlighted several areas where the PhD might be useful. These look at different aspects of the manufacturing system at Meddings and will allow the PhD to be tested in differing circumstances.

ISO9000

The marketing department have identified a clear need for the business to become ISO 9000 accredited. This is seen as an Order Qualifier (Hill 1989) in several markets that they wish to operate in. Previous attempts to obtain accreditation have foundered due to the scale of the problem and the approach taken by consultants. John Kiff feels that by breaking the problem down and tackling it in a iterative manner there is a better chance of success. This is an organisational change that will have repercussions in many areas of the business.

New product

An existing scheme with the Teaching Company is developing a CNC machine centre for Meddings. This will require production and scheduling facilities. These in turn will need to be designed and this might be a candidate for the PhD.

New machine centres

John Kiff has ordered several new machine centres to improve the manufacturing system. These will replace dedicated machine centres using several machines. While total machining times will go up, the current production volumes allow this. The increased quality, flexibility and technical capacity have been used to justify the expenditure. Where the machines are placed on the shop floor and how they are integrated in to the existing manufacturing system is a possible application of the PhD.

Follow up action

The researcher will contact John Kiff on Friday 15th May 1998.

APPENDIX SIX – COMPANY C – PROCESS MODELS

- 285 -

University of Plymouth / Company C

PROJECT: Company C

REV: 03/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

TOP

Order

Regulations

Raw Material

Fulfil Order

A0

Request for info (ABS)

Request for materials

Boat as ordered

NODE:	TITLE:		NUMBER:
A-0		Fulfil Order	1

PROJECT: Company C

NOTES: 1 2 3 4 5 6 7 8 9 10

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

A-0

Order

Regulations

Ensure Buildability

A1

Request for info (ABS)

Buildable design

Plan Project

A2

Project plan

Purchase materials

A3

Request for materials

Orders for scaffolding

Raw Material

Build Boat

A4

Built Boat

Conduct sea trials

A5

Boat as ordered

Project plan   Buildable design

Testing Requirements

Regulations

Orders for scaffolding

Raw Material

Make Hull and Deck

A41

Hull & Deck

Make Structure

A42

Cured Structures

Fit structures

A43

Assembled boat

fit out

A44

Built Boat

Buildable design   Project plan   Regulations   Testing Requirements

Design Hull & Deck mould   A411

Mould Design

Mould templates

Raw Material

Make Hull & Deck mould   A412

Shells

Laminate Hull & Deck   A413

Laminated hull & deck

Orders for scaffolding

Post cure   A414

Hull & Deck

NODE: A41	TITLE:	Make Hull and Deck	NUMBER:

PROJECT: Company C   REV: 03/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A41

Mould Design   Project plan   Regulations

Raw Material

Make steel frame   Steel frame

A4121

Laser cut frames

Assemble mould   Skeleton mould

A4122

Battens   Fit battens   Planked frame

A4123

Finish mould   Shells

A4124

[|] Personnel

NODE:	TITLE:	NUMBER:
A412	Make Hull & Deck mould	

PROJECT: Company C

NOTES: 1 2 3 4 5 6 7 8 9 10

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

A412

Planked frame

Project plan

Regulations

Raw Material

Lay up glass

A41241

Laid up glass

Fit vac system

A41242

Fitted vac system

Apply fairing
compound

A41243

Faired system

Apply impervious
paint

A41244

Painted system

Apply release
agent

A41245

Fit and check
vac

A41246

Shells

NODE:	TITLE:	Finish mould	NUMBER:
A4124			

PROJECT: Company C   REV: 03/12/1998

NOTES: 1 2 3 4 5 6 7 8 9 10

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RECOMMENDED

PUBLICATION

A41

Shells

Project plan

Buildable design

Testing Requirements

Raw Material

Build scaffolding

A4131

Scaffolding surround

Orders for scaffolding

Set-up laminating station

A4132

Scaffolding & station

Lay-up materials

Layup boat

A4133

Laminated hull & deck

NODE:	TITLE:	NUMBER:
A413	Laminate Hull & Deck	

PROJECT: Company C

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A413

Scaffolding surround

Buildable design

Testing Requirements

Build mezzanine

A41321

Scaffolding & station

Install laminating machine

A41322

Raw Material

Glass cloth

Get & check cloth

A41323

Lay-up materials

Resins

Get & check resin

A41324

Misc info

Gloves, towels, brushes etc

Get consumables

A41325

Setup test & cotrol station

A41326

NODE:

A4132

TITLE:

Set-up laminating station

NUMBER:

PROJECT: Company C   REV: 07/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A413

Scaffolding & station   Project plan   Buildable design

Lay-up materials

Layup inner skin

A41331

Resin usage form

Material Usage

Time check

Inner skin

Pull Vac

A41332

Poor pull down, consider new bag for next time

Set inner

Remove vac stack

A41333

Bare inner

Layup core

A41334

Inner & core

Layup outer skin

A41335

Inner, core & outer

Finish laid up hull & deck

A41336

Laminated hull & deck

NODE: A4133   TITLE: Layup boat   NUMBER:

PROJECT: Company C

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

A4133

NOTES: 1 2 3 4 5 6 7 8 9 10

Scaffolding & station

Project plan

Temp, humidity ref QA manual

[ ]

Buildable design

Nominate 1st half

A413311

1st hull half

Check conditions

A413312

conditions fine

Lay-up materials

Pre-wet resin

Pre-wet

A413313

Resin usage form

Time check

wetted mould

Layup resin & cloth

Layup inner cloth

A413314

laid up inner

Material Usage

Fit vac stack

A413315

Inner skin

NODE:	TITLE:	Layup inner skin	NUMBER:
A41331			

PROJECT: Company C

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A41331

conditions fine

Pre-wet resin

Make mix

A4133131

Take sample

A4133132

Measure and issue quantities

A4133133

Apply to hull

A4133134

weigh buckets

A4133135

Time check

Resin usage form

Inspection (storage)

wetted mould

NODE: A413313

TITLE: Pre-wet

NUMBER:

PROJECT: Company C

REV: 07/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A41331

wetted mould

Time check

Buildable design

Layup resin & cloth

Wet out cloth
A4133141

Wet cloth

Weigh wet cloth
A4133142

Weighed cloth

Material Usage

Lay on hull
A4133143

Wet hull

Remove air
A4133144

Consolidated hull

Trim & collect scrap
A4133145

laid up inner

Scrap Material

Scrap to bin

Weigh scrap
A4133146

Scrap details

Laminating machine

Cloth weight

Compute wet out adjust
A4133147

Wetout adjust

[ ]

[ ] computer program

NODE:	TITLE:		NUMBER:
A413314		Layup inner cloth	

PROJECT: Company C   REV: 03/12/1998

DRAFT	
RECOMMENDED	
PUBLICATION	

A41331

NOTES: 1 2 3 4 5 6 7 8 9 10

laid up inner   Time check

Weigh & fit peel ply
A4133151

Peel ply fitted

Weight & fit breather layer
A4133152

Breather layer fitted

weigh & fit bleed cloth
A4133153

Bleed cloth fitted

Weigh & fit yellow polythene
A4133154

Yellow polythene fitted

Weigh & fit carrot netting
A4133155

carrot netting fitted

Fit vacuum bag
A4133156

Inner skin

Material usage log

| NODE: | TITLE: | NUMBER: |
| A413315 | Fit vac stack | |

PROJECT: Company C

REV: 04/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A4133

Time check

Until resin gels

Every 1/2 hour

Inner skin

Pull down

A413321

Poor pull down, consider
new bag for next time

Vac watch

A413322

Bad vac /no gel -
error condition

Good vac

Record vac levels

A413323

Vac record
to office

Set inner

People

NODE:	TITLE:	NUMBER:
A41332	Pull Vac	

PROJECT: Company C   REV: 07/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A4133

Set inner

Poor pull down,
consider new bag for
next time

Material Usage

Resin usage form

Save or build
new bag

Remove vac bag

A413331

Laminated vac stack

Bare inner

Cut off impregnated
vac stack

A413332

Vac stack cut offs

Weigh VS

A413333

Weights

vac stack scrap

Reconcile weights

A413334

hull weight

Scrap materials

A413335

Scrap

PC programme

NODE:

A41333

TITLE:

Remove vac stack

NUMBER:

PROJECT: Company C

REV: 07/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A4133

Project plan   Buildable design

Bare inner
Lay-up
materials

core pieces

Make core

A413341

Prepared core

Pre-gel resin

Pre-gel and fit core

A413342

fitted core

Vac inner

A413343

Inner & core

2nd core required

NODE:

A41334

TITLE:

Layup core

NUMBER:

Buildable design

Design (core weights0

Project plan

Bare inner → **Mark out inner skin** A4133411 → marked out skin

core pieces → **cut core** A4133412

weighed scrap usage

core pieces → **Dry fit core** A4133413

off-cuts

fitted core → **stack core off mould** A4133414 → Prepared core

NODE: A413341	TITLE:	Make core	NUMBER:

PROJECT: Company C

REV: 07/12/1998

DRAFT

RECOMMENDED

PUBLICATION

NOTES: 1 2 3 4 5 6 7 8 9 10

A41334

Project plan

Material usage log

Bare inner

2nd core required

Pre-gel resin

Pre-gel inner skin

A4133421

1/2 hour limit

Gelled inner skin

Pre-gel core

A4133422

Prepared core

gelled core

Roll core

A4133423

Rolled inner & core

Fit core

A4133424

fitted core

>1/2 hour

NODE:	TITLE:	NUMBER:
A413342	Pre-gel and fit core	

fitted core

Vac stack core

A4133431

Vac core

A4133432

Remove stack

A4133433

2nd core required

Plane & finish

A4133434

Inner & core

| NODE: | TITLE: | | NUMBER: |
| A413343 | | Vac inner | |

Project plan   Buildable design   Regulations

Design structure
moulds

A421

Other shapes

Flat panels

Raw Material

Make moulds

A422

Coated moulds

Laminate Structures   Pre-preg parts   Cured Structures

A423   Normal Parts

Normal parts for post cure

Post cure structure   cured parts

A424

NODE:	TITLE:	Make Structure	NUMBER:
A42			

PROJECT: Company C

REV: 03/12/1998

DRAFT	
RECOMMENDED	
PUBLICATION	

NOTES: 1 2 3 4 5 6 7 8 9 10

A42

Other shapes

Regulations

Raw Material

Conctruct mould

A4221

check dimentions

A4222

components not requiring good finish at this time

visible moulding

Fair & paint mould

A4223

pre-coat with release agent

A4224

Coated moulds

| NODE: | TITLE: | NUMBER: |
| A422 | Make moulds | |

Coated moulds

Flat panels

Get materials & workspace

A4231

Request for materials & space

Pre-preg

Wet cloth

Raw Material

Lay up pre-preg

A4232

Pre-preg parts

Normal Parts

Lay up wet cloth

A4233

Normal parts for post cure

NODE: A423	TITLE: Laminate Structures	NUMBER:

Pre-preg

Check available
equipment

A42321

Available equipment

Raw Material

Layup pre-preg part

A42322

Laid up prepreg

[ ]<0.68 bar

Apply vac stack

A42323

Check vac

A42324

Vac'd part

Prepreg finish

A42325

Pre-preg parts

NODE: A4232

TITLE: Lay up pre-preg

NUMBER:

Pre-preg

Check boiler fuel

A423211

Check
Thermocouples work

A423212

Check data logger

A423213

Check compressor

A423214

ensure personnel
available for vac
watch

A423215

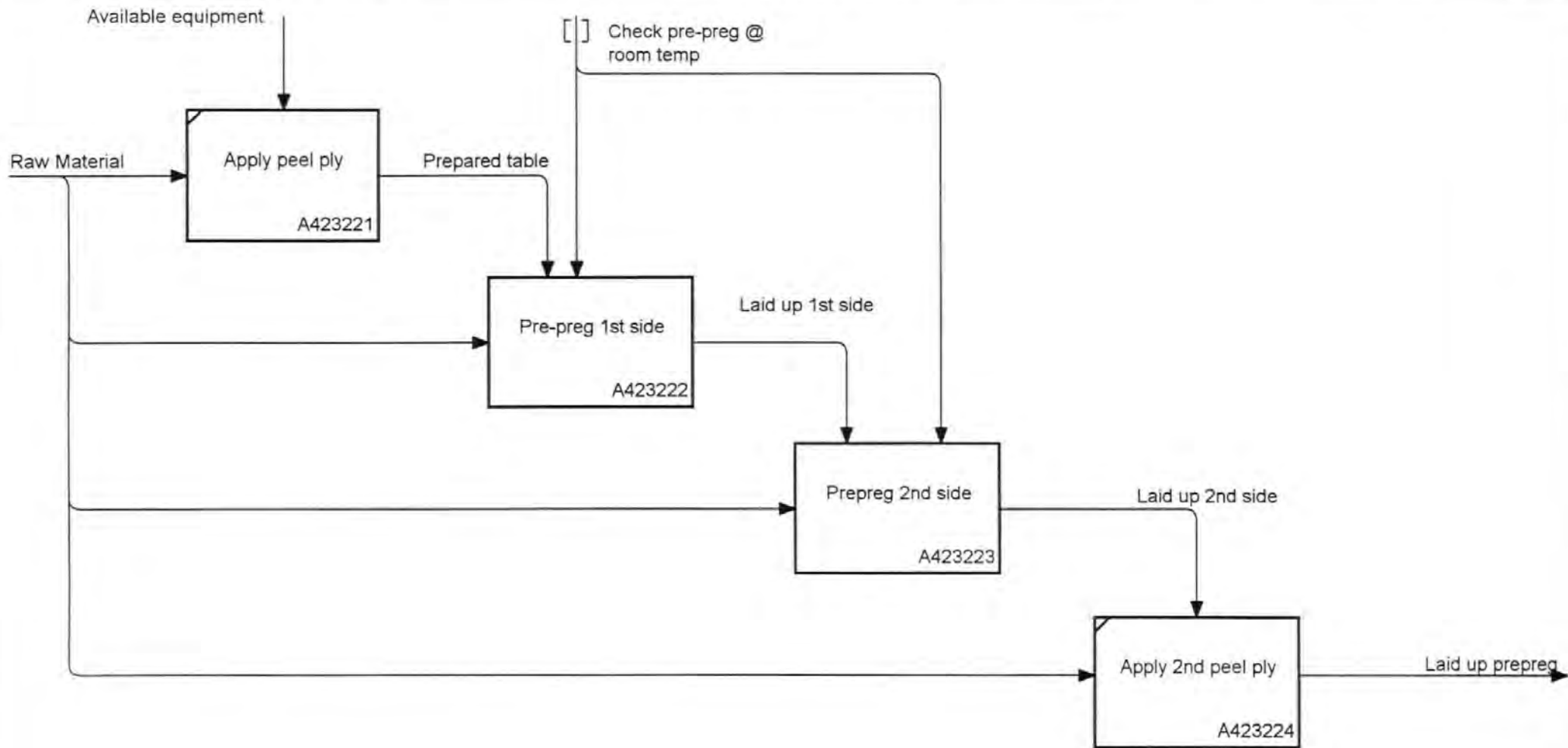Available equipment

NODE: TITLE: Check available equipment   NUMBER:

A42321

Available equipment

[ ] Check pre-preg @ room temp

Raw Material

Apply peel ply

A423221

Prepared table

Pre-preg 1st side

A423222

Laid up 1st side

Prepreg 2nd side

A423223

Laid up 2nd side

Apply 2nd peel ply

A423224

Laid up prepreg

| NODE: | TITLE: | | NUMBER: |
| A42322 | | Layup pre-preg part | |

PROJECT: Company C

REV: 04/12/1998

NOTES: 1 2 3 4 5 6 7 8 9 10

DRAFT	
RECOMMENDED	
PUBLICATION	

A42322

Prepared table

Check pre-preg @ room temp

Raw Material

Add core if required

A4232221

Apply glue film 1st side

A4232222

Layup to 6 layers

A4232223

Consolidate

A4232224

consolidated prepreg

More than 6 layers required

Turn over

A4232225

Laid up 1st side

NODE: A423222	TITLE: Pre-preg 1st side	NUMBER:

Laid up 1st side   Check pre-preg @ room temp   [ ] check working

Raw Material

Glue film 2nd side

A4232231

Layup 2nd side

A4232232

Consolidate 2nd side

A4232233

Consolidated 2nd side

More than 6 layers

fit thermocouples

A4232234

Laid up 2nd side

NODE:	TITLE:	NUMBER:
A423223	Prepreg 2nd side	

PROJECT: Company C   REV: 04/12/1998

NOTES: 1 2 3 4 5 6 7 8 9 10

DRAFT

RECOMMENDED

PUBLICATION

A4232

Vac'd part

10 hrs @ 85C

Set Data loggers

A423251

Data loggers
running

turn on oven

A423252

At temp

Monitor oven

A423253

Monitor o/p

Cured part

Trim

A423254

Scrap

Pre-preg parts

Determine weight

A423255

Weights

Post cure watch

NODE:	TITLE:	NUMBER:
A42325	Prepreg finish	

Project plan   Buildable design   Regulations

Hull
&
Deck   Deck   Level Deck

A431

Cured
Structures

2nd bond deck

A432

Bonded Deck

Hull   Level hull

A433

2nd bond hull

A434

Bonded hull

2nd bond hull to
deck

A435

Raw Material

post cure boat   Assembled
boat

A436

NODE:	TITLE:	Fit structures	NUMBER:
A43			

APPENDIX SEVEN – COMPANY C – CASE MATERIAL

COMPANY C

Present at the meeting were Nick Haywood and Andy Wyke from Company C and John Bradford from the University of Plymouth. The visit was to establish what the current system at Company C was and how the University (through John Bradford) could assist in a manufacturing systems redesign.

Company C have recently introduced a new manufacturing procedures manual. This has been purchased from Marten Marine and is being used to replace the system that was in place. There are, already, some elements of the new system that are not compatible with Company C. These are mostly in the fine detail of individual procedures in the manufacture of composite boats. As yet, no vessel has been built completely using the new system and thus, not all the procedures have been evaluated for practicality. While this process is going on there is little scope for redesign using the proposed methodology as there are no issues that have arisen that warrant a change to the fundamental system that is now in place. Where there are differences these are being resolved in a manner that allows Company C to manufacture boats. Care is being taken to mould the new system to the Company C culture.

Areas of possible scope

During the discussions there were three areas that offer the potential for mutual benefits. These cover material testing and the development of new materials within composite boat construction; process modelling to evaluate how the system actually works and what it is doing; and Soft Systems analysis to model how the workforce are being treated and how they are, in turn, behaving towards the businesses management.

Material Testing

Traditionally, Company C have used a particular supplier for their resins. These are used within composite boat manufacture to bind layers of fabric together and to foam elements. The performance of the resins is critical if the boat is to be strong, light and rigid. Until recently there was no work to evaluate the different resins available on the market and no tendering process to evaluate the costs of different resin suppliers.

In addition to the material requirements there are the requirements of the American Bureau of Shipping (ABS). The ABS certify the boats that Company C make and any materials used have also to be certified. At present the resins use toxic Phynols to enable the curing of resin compound. Manufacturers are developing hardeners that are phynol free in anticipation of legislation that outlaws them. These products have to be tested to ensure their compatibility with the Company C system. These resins will also be 'nicer' to work with than current resins and this may have a beneficial impact on staff moral.

Nick Haywood has been carrying out mechanical testing of current and potential resins to determine the properties of each. This will allow quantitative comparisons to be made between resins that will enable material decisions to based upon test data rather than manufactures claims. While these claims are not false, they are not related to tests that use the resin in conjunction with the materials and designs that Company C use. These tests have been carried out over a period of time and it may be possible to show that an iterative technique was used to manage the testing procedure. While other factors, such as yard activity, test facility availability, material availability and budget will have played a part, it is hoped that the iterative element will be sufficient

to enable this redesign of the materials used to be counted as a case study in manufacturing systems redesign from a technology perspective.

Process Modelling

At present there are no process models to describe the composite boat building process. The new system does not include any charting or flow analysis with the exception of defect management. There are several initiatives that are aimed at reducing the transportation of material and these may be assisted by process modelling.

There was no time available during the discussion to further pursue this option. It was felt that some modelling of the current process would be beneficial to understanding what goes on within the boat building process. There may also be links to other areas of the business that are also part of the 'Fullfil Order' process that could be improved. This will be highlighted through process modelling.

There were several areas that were felt to be outside the remit of manufacturing. The links between elements of the business could be improved and within manufacturing there appears to be considerable scope for process improvement. Several schemes are underway to improve processes within manufacturing but a process model might help to direct effort to those areas where greatest can be achieved.

Soft Systems

Within Company C there could be scope for cultural issues to be addressed. Many of these issues are related to the nature of the workforce and how they are trained. Many of the personnel involved in the fabrication of composite boats come from the surf board industry rather than the aerospace industries. They tend to be young with few financial or emotional ties to the Falmouth area.

Much of the workforce have no formal qualifications for composite materials fabrication. They are employed on the basis of experience and job references. There is, at present, no training scheme for such workers within the UK. This means that there is no professional route for employees within Company C to follow.

Within Company C itself, there are few opportunities for job advancement. The management structure has not been designed but has arisen as the business grew. This in turn has led to the management being increasingly out of touch with the work force. While there is no actual resentment of management, there are issues concerning responsibility for work and quality that need to be addressed before Company C can progress towards the kind of system that it has purchased.

Many of the issues that arise within the need to look at the social and structural elements within Company C can only be addressed over the longer term. There is no reason why they cannot be initiated now, however.

APPENDIX EIGHT – COMPANY D – CASE MATERIAL

VISIT REPORT 8/6/98

Visit to Company D to further discussions relating to the redesign of their manufacturing system. Present were John Bradford, Carolyn Ansell, Steve Osborne and Richard. The latter two being the Manufacturing Manager and Design Engineer respectively.

The visit was to revisit the grounds covered with Carolyn and Steve during the last visit and to introduce the researcher to Richard. The purpose of the research was explained to Richard together with some of the underlying theory. The basis of the research was introduced as being to assist manufacturing businesses to redesign their manufacturing systems without the effort required with 'traditional' methodologies. This was well received by Richard who agreed that in the past several 'small' things had been tried but not in an integrated or planned manner. This was because the business was fighting to manage the existing system without resources being available to redesign it.

The emphasis of the redesign was the need to achieve ISO9001 accreditation. This was rapidly becoming and Order Qualifier under procurement rules being adopted by water companies. The current system does not conform to ISO9000 and this is seen as an opportunity to design the system and achieve accreditation.

Achievements since last meeting

Since the last meeting Steve had, together with John Prynn (the Quality Manager), produced a series of Manufacturing Quality Procedures. These took the form of 16 'stages' of project management that each 'Job' would pass though between customer order and final delivery. These 'stages' were common to all work that the manufacturing function within Company D undertook.

The central requirement that these stages fulfilled was the ISO9001 requirement for documentation showing traceability and accountability. To achieve this Steve envisaged some 14 different forms being used to manage the data flow between sections of the business. The actual process described by the 16 stages follows a fairly simple, though rigorous, project management flow. There are various hand-overs and checks between functions. Each part of the project is checked before being allowed to continue to the next.

Some thought has been given to the monitoring of individual jobs on the shop floor but no 'production planning' has been developed. This is loosely included under 'Manufacturing Progress' but this is more concerned with the progress of individual jobs. The 'Design Function' is tasked with constructing a plan to complete the work but it does not look as though the whole manufacturing facility is available for planning at that point.

Adherence to PhD model

The redesign has been conducted along the lines of the model proposed within the PhD. The business has identified the issues that are most important in the redesign. These are not the 'Best Practise' issues that a text book might suggest but they are the ones that the business feels most strongly about. The risks to the business of doing something are significant in that the manufacturing system is to be redesigned in a major way. The risks of not doing anything are more severe in that business could literally dry up if ISO9000 is not achieved.

Action has been taken to develop *some* documentation to achieve the requirements of ISO9000. This is being evaluated against both the requirements of ISO and the requirements of the business for a system that it can manage and run. The feedback from this evaluation will provide the information for the next set of solutions. At that point the action will be to run the system on a manufacturing Job.

Politics

During the discussion a comment was made by Richard concerning some suggestions that had been raised by Jan Bennett and Andi Smart on a previous visit. This was to the effect that the very functional system at Company D might benefit from a more process focused approach using cross-functional co-operation. This met with some reservations from Steve.

The reservations were largely to do with the number of staff that Steve felt it would require to run the business in a flat, project team manner. This was the reason given for rejecting the idea. The idea did go against the work that Steve and John P. had put in in developing the Manufacturing Quality Procedures. Steve appeared quite keen to view manufacturing as a 'subcontracting' element within Company D. One purpose of the new procedures was to provide the manufacturing element within Company D with a modus operandi that would allow them to perform their job with minimal contact with the rest of the business.

APPENDIX NINE – AGS – SAMPLE NOTES

AGS Meeting 4th October 2000

Present: John Bradford, Katerina Williams, Tom

Duration approximately 4 hours.

The following is a transcription of field notes taken during the interview and subsequent factory tour. The principal purpose of the interview was to establish the activities that had been carried out by Tom (factory Maintenance Engineer).

Researcher – What precipitated the change programme?

Tom – The line that occupied that bay was the glazing line. This had been having major problems with quality and (we) just couldn't get it to work.

KW – This was the problem with the Swiggle.

Tom – That's right. Well we got rid of that and now we're buying in all our sealed (glazed) units. So that opened the bay and allowed us to plan moving in to that area. At first we were still planning on leaving a space for a new window line, all the costings were made on the basis for keeping some space for this new window line.

There was also the possibility of bring Cornea, the Aluminium line, down onto the shop floor. Anyway that didn't happen. The 1st move put all the machines in the one bay. Leaving the other for the new window line. The operators complained 'cause they were all cramped into a single bay and there was all this space to the side of them that we were saying they couldn't use. Then they decided they weren't going to use that space after all so we could expand the Door line into the 2nd bay. We're now using about 85% of the two bays.

Researcher – How did you go about planning the new layout and subsequent move?

Tom – Well the first thing was previous knowledge about making changes here. I put in all the services and machines. But I started with the Storeman and built the plan from there. As much as possible I use the ideas from the Leading Hands and shop floor. It's psychology, you've got to use their ideas so they accept what you're telling them. If they don't then you go right back and say well it was your idea in the first place, now you're telling me you don't want it, make up your mind 'cause I'm only trying to help you out.

Researcher – What about costing the changes?

Tom – The infrastructure costs were pretty minimal since I did all the work and all the services were there, I just had to move them about. The productivity that we'd gain would pay for everything else. There wasn't really much need for extensive costing. I just put the figures together then dropped them on Mike's (Mike Adkins – Factory Manager) desk, then get on with it.

'Cause when we first moved here they (management) employed a whole team of consultants to layout the shop floor and design everything so that we'd be able to make 1000 units a week. All nicely laid out. Before we even got in they'd decided that they need more storage space, so the Door Line got relocated throughout the shop. By the time we moved in 25-30% of the shop floor production space had been turned over to storage. Machines were fitted in where they could but the original plan was scrap. I'd put all the services in according to the original plan, came in and marked everything up. Now that all changes and half the equipment I fitted casters to so they could roll them about. And they stayed like that 'cause it was easier to move the equipment around since it didn't all fit in one place.

Researcher – So getting back to the new layout for the Door Line, how did you figure out which piece went where?

Tom – I started at the input and worked my way around. For example, we moved the glazing jigs back. Then repositioned all the storage of glass and put in a clear runway for handy access using the forklift. Before they were carrying glass all over the shop. Now there's a clear access route to bring the glass in. There was loads of time being wasted looking for pallets of glass, now its all stored next to the jigs there's no time wasted there.

Researcher – Right, and with the Door line, what order did you move the machines?

Tom – Well we started with the Saws. They're the first part since they take the profile from stores and cut it to length. The material was also moved so that it was stored next to the saws rather than on the other side of the factory with the rest of the profile. The welder was next in the flow line and then all the other machines until the assembly benches were moved, last. Before all that the services and pre-work was done.

Researcher – What sort of down time was experienced?

Tom – The move was spread out over about a week but I'd guess that less than half a day was actually lost. I tended to move the equipment when it wasn't being used or there was a lull in production. So, yeah, about half a day.

Researcher – and the re-lay out, once the new window line was no longer going to be introduced.

Tom – That was a much smaller operation since all the machines were in place. Once machine was moved about two metres back, I'll show you when we go out there. I sorted out the services and then moved the machines. 'Cause the machines were all there I just waited for a slack moment and then, woosh, moved the machine. So there was no drop in production. Again I asked all production operatives and Leading Hands which machines they wanted moving and how far. Most of the time it was obvious since they're handling six metre lengths of profile, they need to be able to cut it to length which means having at least three metres clear so you can handle the profile.

Researcher – And the glazing move?

Tom – That was about two days but we moved that jig by jig also. I discussed it with the Leading Hands and then we moved it all using temporary jigs so that there was no change in productivity. I also put in a separate QC with two big labels – 'IN' and 'OUT'. So when they've finished glazing a unit they can put it in the 'IN' rack and then when it's been QC'd it gets put in the 'OUT' rack and can move on. That way QC don't have to walk round looking for things to check and everyone knows what's been seen and what hasn't. The left-hand side is used for glazing, the right hand side is for service or repairs and the far right hand side is for the door glazing. Some of them have coloured leads so they need to be kept separate.

Then the Doors are now kept on trolleys to stop them getting damaged after being QC'd. There's now a dedicated corridor to take the finished doors to finished goods. All this was done while consulting the Shop Floor, making sure there was space for six metre profile racks, stillages etc.

(There followed an extensive discussion about storage problems, the space being taken up with remakes, service calls originating from the Swiggle problem and the number of stillages involved in storing glass. There was also a discussion concerning the original layout of the shop floor and the estimate that it would produce 1000 units a week when the most that has been achieved was 700/800 utilising 5 glaziers. The problem appeared to be a measurement one, the bottleneck operation was the glazing of individual panels, yet the measurement unit was a door or window which could have between one and several tens of glazed panels. There was no distinction. This was related to the bonus scheme and the incomprehensibility of that, which led to dissatisfaction on the shop floor.)

Researcher – Getting back to the shop floor change programme, there was the first move that was evaluated and led to the expansion into the second bay. That was evaluated to be a success and further

improvements were planned by including the glazing operation in the Door Line. Once that was done there was some training and then a roll-out of the Door Line into the rest of the factory?

Tom – Nearly, we looked at beading on the glazing line but it was too complex. In the analysis we abandoned it, the tilt tables make things much easier but we're not going to copy the Door Line to the full extent.

Researcher – Just to change tack slightly, the other idea to come out of the second Kaizen day was the reorganisation of the notice boards. How's Curley getting on with that?

Tom – That's been a great success. All the old boards have gone, with their scraps of paper and ads for cars etc. Now there's just the one board with notices about the company. Its right next to the clocking in machine so they've got to go past it. You can't do more than that, apart from putting the notices on in foot high letters! No, it's a much better use of the board. Management are also beginning to use it for putting out information, there are notices about how the company is doing and what's going on. I think that's what should be up there and its more interesting that who's trying to flog their old motor.

Researcher – Great to hear that's working so well. So what're the changes after that? What's next?

Tom – We've changed the control over sill production. You'll see when we go out, there used to be sills lying all over the place. No one knew where anything was and jobs were lying around for months. What happened is that an order would go out to the shop floor and it would get made, then the order would be cancelled and no one told the operators. So it stayed out there. Now we've got 'T' cards that are labelled with the area, customer and date. After they've been out there for four weeks, I've told them to cut up the sills. When they asked 'What if someone asks for that order after we've cut it up?' and I said to make it again. It only takes a few minutes to knock up a sill, I've no idea why they send out the orders so earlier. Well I do, its because they can't be bothered to schedule properly.

Out in the stores we've got over 500 units that have been there for several years, each time they do a stock take they put a little cross on the side and some units have loads of little x's all over them.

(There followed a discussion about stores and the problems encountered when there's too much finished goods in stores. There is also a problem with pulling orders forward and choosing orders that are still on the shop floor rather than ones that are already in stores.)

Researcher – Back to the Door Line for a moment, how was the training of the new glaziers handled? Was that done by the internal staff or were people brought in to do that?

Tom – All the training was done in-house. Its being carried out on a rotation basis. The guy doing drainage trains on the welder then he moves on to beading, then the saw and maybe fitting. They rotate when they feel like it. Its like when I was in the steel industry we had what were called Link Men who knew how to do the job of the man to either side of them.

The glazing training was carried out in a half day, now their training each other as they need it. Its great to see, they're all quite proud of being a team that makes the doors from start to finish. Its made a real difference that they've got their own area and are doing everything themselves. Derek started off on the Beader.

Researcher – He's the chap that stood up at the second Kaizen day and said he was feeling much more professional now he was part of a separate Door Line that was responsible for the whole process of making doors.

Tom – That's right, well he's now moved round practically the whole line and is on the welder now I think. I mean there always used to be resistance to change, just any change. You'd suggest something and it'd be 'No way, can't do that. It'd never work'. You go back next week and their doing it like it's the only way they've ever done that job. Try and change it back and its 'Get off what're you doing. It's much better this way!'. Now there's been a real culture change, they're beginning to get use to the idea that we're planning out changes, working them out, doing something and then going on to the next thing. They're actually asking me on the shop floor 'When's it our turn? When're you going to come and sort our area out?' which is really great.

(After some more general chat about change and the cultural shift the interview was concluded. A tour of factory then commenced looking at the changes that had been implemented and seeing the plans for future changes.)

APPENDIX TEN – HANDBOOK

- 329 -

Iterative Manufacturing Systems Redesign for SMEs
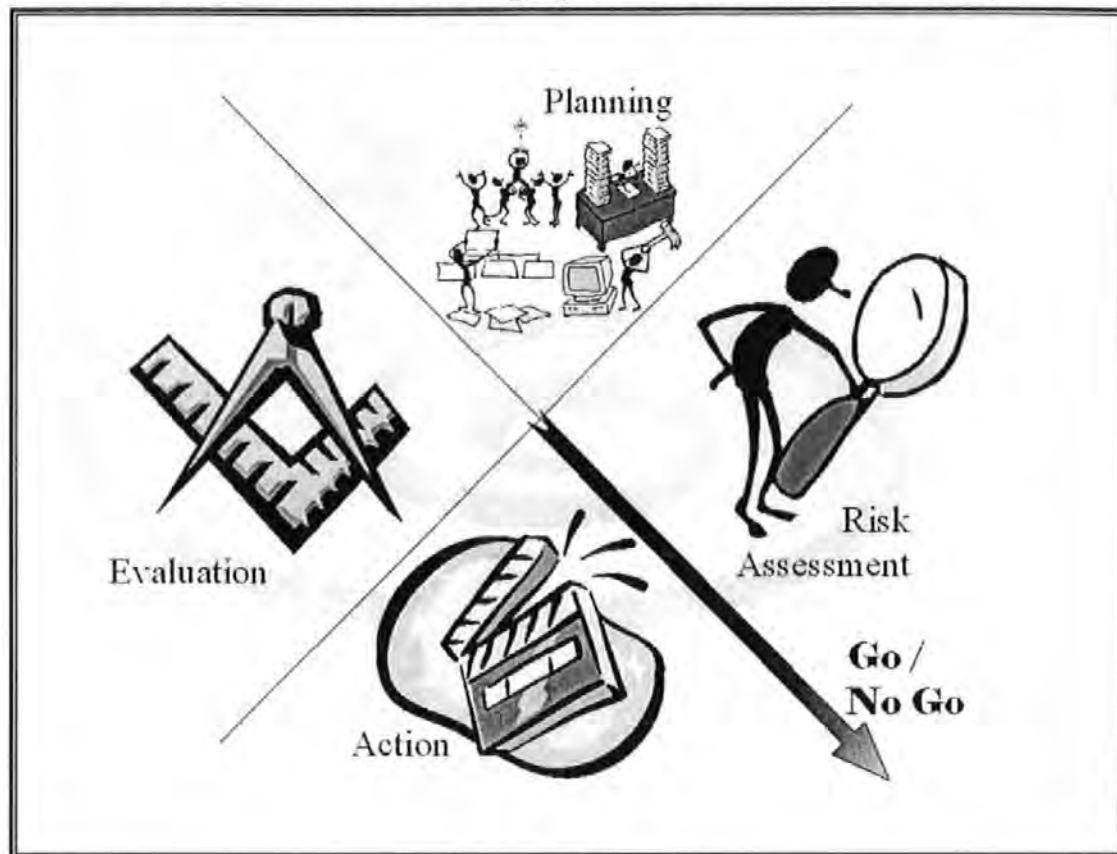
1. Overview

This approach cycles through four phases of Planning, Risk/Benefit Assessment, Action and Evaluation. After the Evaluation phase you begin Planning the next cycle and so forth. This allows for the rapid translation of plans into action and completes the feedback loop for the next planning phase. Within the Planning phase there are four perspectives to help focus the planning effort, these relate to Structure, People, Technology and Process. This is an iterative approach so don't try and change the whole system in one go.

2. Planning

All change involves a degree of planning, whether a vague idea that the business should be moving in a certain direction, the sketch on the back of a beer-mat, or a stack of Gantt charts and responsibility matrixes. Iterative change is no different. You should consider who will have the authority for initiating change and who the change team will involve. A good way of rapidly developing a plan is to devise some SMART objectives: Specific; Measurable; Achievable; Required; Time bound.

To help begin the planning it is advised that you view your manufacturing system from four different perspectives: 1) Structure; 2) People; 3) Technology; 4) Process. Changes that you introduce will tend to adopt a particular perspective and this is useful in planning and implementing your change but remember to think about the other perspectives at each planning phase to make sure that you aren't missing something in your changes.

2.1   Structure

The structural perspective considers the organisation of the business. Responsibilities, authority and power structures are part of the main features of a structural perspective. It is also the perspective that considers the business culture, whether the organisation has a powerful central leader, strong functional roles, dynamic matrix for project solving or disparate cluster of people working towards a largely common goal. These are represented as diagrams in Figure 1 below. Organi-graphs may be developed to map the different groups within organisations and their interactions, these differ from organisational charts since they map interactions and information flow rather than rigid reporting structures.

| Power Culture | Role Culture | Task Culture | People Culture |

After Charles Handy, 1993
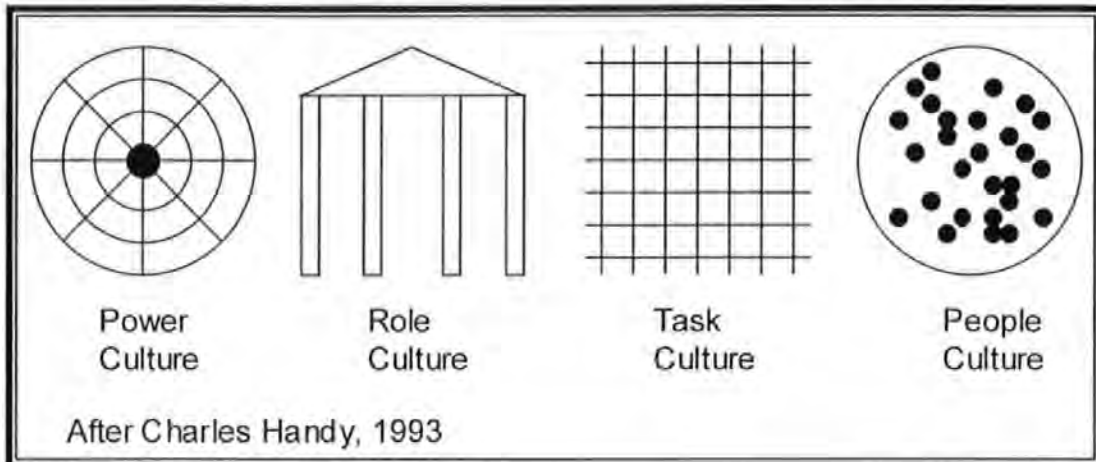
Figure 1 – Cultural types in organisations

2.2   People

A key feature in considering manufacturing systems redesign are the skills and competencies that the people within the system have or will need. It is also important to realise that changing people's behaviour can be much harder than changing their working environment or procedures. Communication is vital and its important to listen to concerns voiced and act upon them. Change introduces uncertainty and a perceived lack of control, discussions will reduce this perception and may reveal possibilities that were previously unknown.

2.3   Technology

The use of technology and control in a system is vital to ensure that objectives are met. New information technology can provide unprecedented levels of data analysis and control. Data flow diagrams can be used to identify and chart the route of data within the system. This can lead to better analysis and more future looking information.

2.4   Process

Within the manufacturing system there will be many activities that are required to transform inputs (such as orders and raw materials), into outputs (such as orders for materials and finished goods). These activities can be grouped together into processes and analysed using tried and tested techniques. The layout of the shop floor and machinery used are also process issues for consideration. Great improvements can be made by moving machinery around so that material has less distance to travel or so that one area can carry out the production of a whole part or product.

A particularly useful method for drawing processes is to identify general activities, such as 'Get Order', 'Fulfil Order', 'Develop Product' and 'Support Product' and then identify the sub-activities that go to make up these larger activities. Examples are shown in Figures 2 and 3. There is a general flow from top-left to bottom right with inputs flowing from left to right through the activity boxes. Activities are triggered and controlled by the information and data coming in from above and the mechanisms that enable the activity to occur are shown supporting from below. More detail can be shown by investigating each activity until it no longer makes sense to decompose further. In general between 3 and 6 activities per diagram is sufficient.
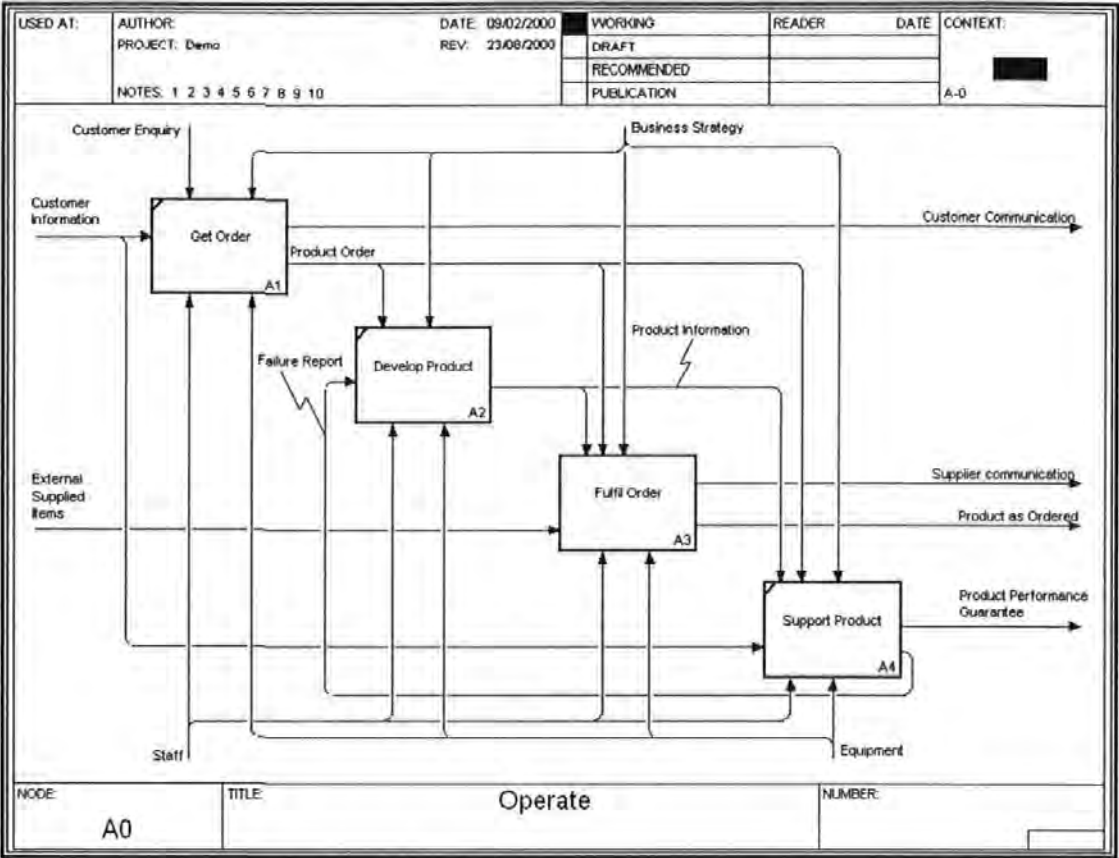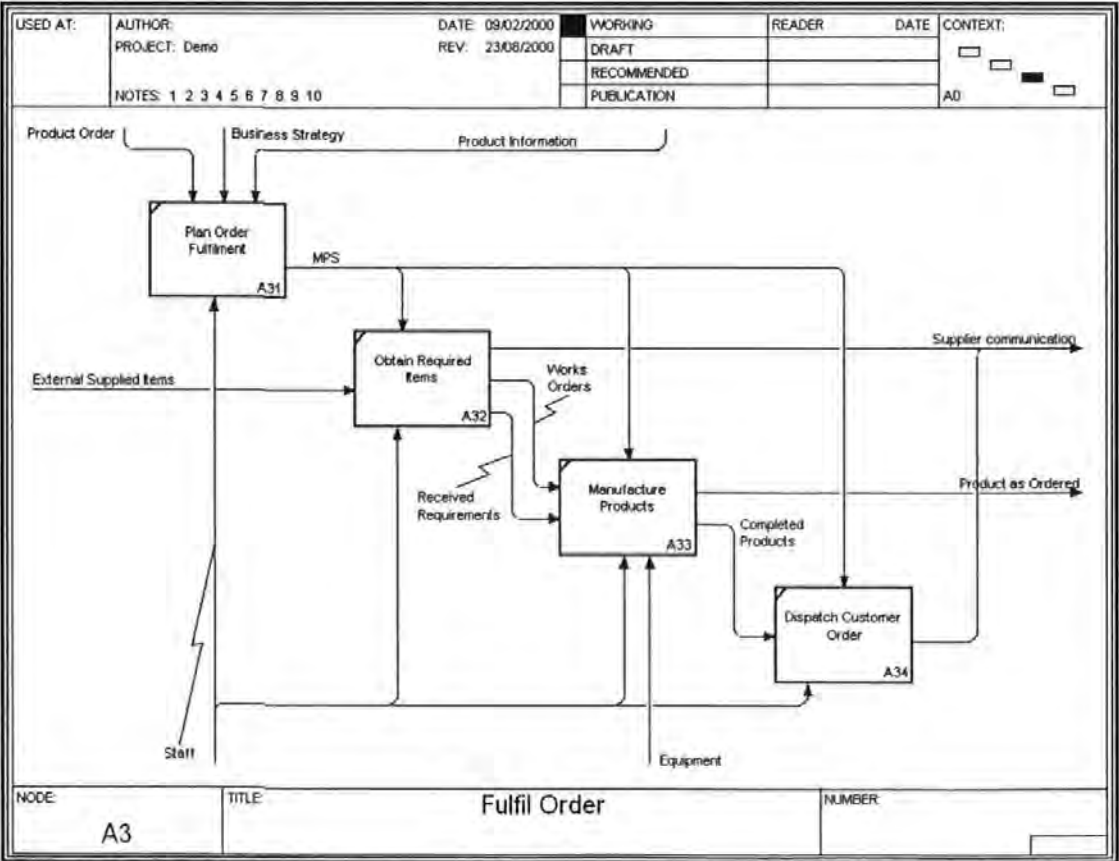
Figure 2 – Simplified Operate process

Figure 3 – Detail within the Fulfil Order Process

3. Risk/Benefit Analysis

All change involves risks and benefits, the aim is to gain benefits that outweigh the risks or costs of change. The simplest analysis is to estimate the benefits to the business in financial terms and set these against any costs that are likely to be incurred. Cumulative savings will provide a payback duration that can be used to offset larger capital investment. Most changes can be implemented with minimal financial investment. If you've been working on a problem for some time then Pareto analysis may be useful (Figure 4).
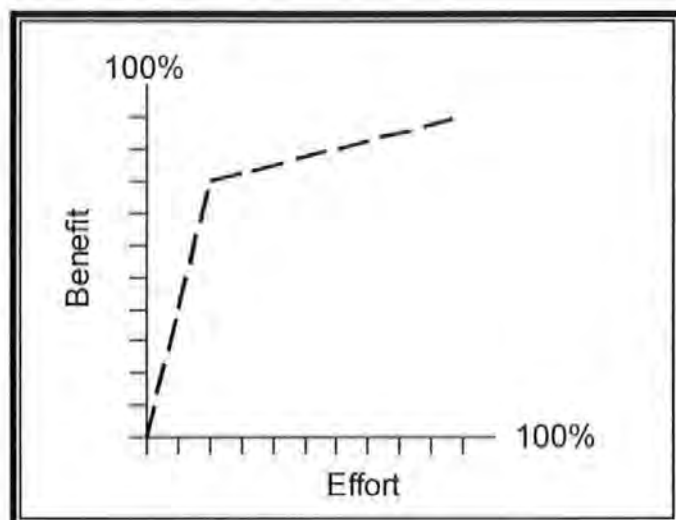
Pareto was an economist at the turn of the 19th Century who found 80-20 divisions wherever he looked. The analysis suggests that 80% of the benefits of a change programme will be achieved by the first 20% of the changes or effort. If change is getting bogged down in details or momentum appears to be flagging it may be worth adopting a different perspective to tackle the same issue or attacking a different issue. Remember that there are four perspectives to choose from, what may appear to be insurmountable in one perspective may appear simple in another.

Figure 4 – Pareto Analysis

4. Action

Just do it. There's a time for consideration and a time for action, this is the time for action. Bare in mind that this is an iterative approach so you don't need to change the entire manufacturing system in one 'big bang'. Its actually better to change in a series of small increments since you can learn about the impact that your changes are having as you make them. This allows you to re-evaluate your plans and ideas about what the business needs. Remember also the Pareto analysis in Figure 4, once you reach that 80% level it may be better to switch perspective and consider another feature of the manufacturing system. You can always return to the current change later once other parts of the system have been improved.

5. Evaluation

If you developed SMART objectives you should have some measures by which you can evaluate your changes. This is important as you don't want to be battling for the last 20% of benefits if you can switch tack and gain another 80% somewhere else. It's also important to reflect on the change to see what can be learnt about the business's reaction to change. A good format is to consider what you'd do again and what should be done differently next time. Then go on to the next planning phase and repeat!

APPENDIX ELEVEN – SAMPLE EMAIL

Hope this gets to you.

Trust you had a great holiday! I've attached a Word7 doc that I hope
illustrates the format for recording your change programme.

If there's anything that's unclear, please contact me and we can sort
it out.

cheers...

Attachments:
 D:\mydocu ~ 1\thesis\agscas ~ 1\method ~ 1i.doc

PROJECT RECORD

This document is to record the redesign of the Manufacturing System at AGS. Each new Project should be titled using Heading One. This style has been used for the heading of this section. An introduction to the redesign target should be explained, e.g. 'Improvement in Al section profitability'

Planning

The phases should be identified using Heading Two titles as here.

Organisation

Within the subsections, further breakdown is available using Heading Three titles. This structure will enable you to keep track of different ideas and the development of change programmes. An example iteration follows.

Performance Measures

Any further subdivisions can be made using Heading Four titles. An example of how these would be used follows.

IMPROVE AL EFFICIENCY

The project is to improve the efficiency of the aluminium section. This is in line with the longer term plans that AGS has. Before other changes can be made the general efficiency needs improvement.

Planning

Before efficiency improvements can be made there needs to be a base line from which improvements can be measured. At present there is no measurement of efficiency. There need to be some measures implemented.

Organisation

The first iteration will adopt an organisational focus. This is to develop performance measures that will enable future iterations to be measured against a base line. These measures will also be used to justify future actions.

Performance Measures

The performance measures put in place are:... Analysis of something showed that these measures would provide the information required.

Risk / Benefit Analysis

The costs of implementing the performance measures are minimal. There will be some down time attributable to recording the measures as the operators will be self-reporting. This time can, itself, be captured. The risks are that the employees will feel under scrutiny and suspicion. It is important, therefore, that the reason for measuring is explained and their buy-in sought.

The Benefits are that we will know the current efficiency of the Al section and where the greatest inefficiencies lie. This will inform future decisions.

Decision
Performance Measures are worth pursuing and should be implemented.

Action

The measures were put in place on 1/5/99 and have been in use since then. The operators have agreed to the use of the measures and are diligent in recording the data. There is no evidence that they are failing in this activity. The record sheets run on a weekly basis.

Other Stuff

There may be some other notes on how the action is progressing, collection of data. Inputting of data etc.

Data collection
Lots of Data Collection

Evaluation

The data collected has been evaluated in Excel and efficiency has been found to be 65%.

Planning

More detailed analysis would enable us to identify specific areas where efficiency is <65%. To do this a longer period of measurement is required to ensure reliable measurement. In addition more data is required.

A new set of measures have been developed as follows....

Risk/Benefit Analysis

While the knowledge of where the efficiency is lacking would be useful, it is more important to improve efficiency. The business has a good idea where these deficiencies are. The longer analysis phase will set back plans to improve the efficiency of the area.

Decision

No increase in analysis detail. Current measures to be continued.

Planning

Much of the lack in efficiency stems from time spent moving material around the shop floor. Therefore we could make a significant improvement through shop-floor layout changes.

Task

By redesigning the task layout, savings will be made. The current efficiency is 65%, the estimate is that over half the loss comes from layout problems. This relates to £20k p.a. in overhead and handling costs.

The current layout is according to machinery, a layout according to flow would provide this saving. Drawings attached (I haven't done drawings but you might have to). Those involved in the change have been involved in the redesign. This was achieved through 3 workshops at which the situation was explained, suggestions sought, designs considered and feedback provided. Reports of these meetings are attached.

The planned expenditure is also attached in the Excel spreadsheet. From this it can be seen that payback is in 6 months. This is together with the reduced throughput times.

A workplan has been draw up that shows the activities involved in the change. The planned change period is 2 months from start to finish. Not all the moves will be made at once with machinery being moved in a phased plan. This will reduce both the impact of the changes and the disruption.

Risk benefit analysis

There is always some risk associated with making changes. The move from machine to flow layout will carry some risk with the workforce. The workforce has been involved in the data collection that identified efficiency as being lacking. They have recognised the need for change and contributed to the designs proposed.

The expenditure is minimal and payback within company guidelines.

Decision

To go ahead with the planned layout changes.

Action

Record of changes made and other related information, staff impressions, problems that were overcome, adherence to schedule and budget.

Evaluation

Comparison between current efficiency and previous efficiency to show massive savings. :o)

Planning

Other changes, technical, organisational, task or people focussed.

HI Kat,

Just thought I'd drop you a quick note... not sure if you're about to
leave for Cyprus or just getting back.

I've emailed Kevin Rowley about a web designer, just waiting for him
to get back to me. Have you had any more thoughts about the IT audit
for Module 4?

Has AutoSketch been delivered yet?

Has there been any movement on the Kaizen work? The beading
machines and the new noticeboard regime?

cheers
John

We've moved glazing, to squeeze the process together, get the glass
in, make it safer for pedestrians, make sure the glazers aren't
distured by passes by, use the 10 window trolley, closer to the exit
and closer to beading - which we hope to move later.

cheers, Kat :)

APPENDIX TWELVE – SUMMARY OF PREVIOUS KAIZEN

Summary of Previous Kaizen projects at AGS

The projects are summarised below. What can be deduced from them is that the changes are all focused on the production activities. This is only to be expected since the Kaizen programme was not intended to look at wider systems problems. What is also clear, and less expected, is that there is no pattern to the improvements. There is no indication that, having made one improvement, further developments were sought. There is no systematic consideration of the design problem and subsequent formulation of solutions.

19th November 1997

Modification to Sash Line. Six elements to the proposal, estimation of 5 hours labour time. No other costs to be incurred.
No indication of project status or follow on activity.

28th November 1997

A single system for monitoring and reviewing rework levels during manufacturing process. Each team to have their own book and to maintain graphs of daily production and rework together with a weekly costing for rework. Costing to be based upon a simple cost per weld, metre of profile or m^2 of unit. Sample chart included.
No indication of project status or follow on activity.

19th December 1997

To rearrange welding area to eliminate storage problems, cut down movement between machines, stop operators criss-crossing the welding area and achieve better welds through an air supply upgrade. Total costs estimated at £230 together with 50 man hours of labour for the Factory Maintenance Engineer and 4 hours for the shop floor. Diagram of shop floor area included but it is unclear whether this is the current or to-be layout.
No indication of project status or follow on activity.

19th December 1997

To rack all in-house glass units so that the float and toughened units end up on the same trolley in their respective runs. No associated costs but an estimate of 3 extra windows per day from the glazing line.
No indication of project status or follow on activity.

22 December 1997

To make drainage of 1848 sash easier and less time consuming. Achieved by re-designing the support blocks to allow drainage to occur inside and outside where this is currently carried out in two operations. Estimated saving of 15 seconds per sash with no associated costs other than labour.
No indication of project status or follow on activity.

1st February 1998

To reduce walking time, increase productivity and efficiency. This will be achieved through changing the location of benches and machinery to lessen the handling of sashes. Also suggested to bring in material in bulk to prevent carrying by hand. No associated costs other than labour. A diagram of the proposed layout is attached.
No indication of project status or follow on activity.

12th June 1998

To redesign the benches in metal with extra shelves, vices and tool boxes attached to the bench. The aim being to tied up the working area, four benches are suggested. The project is costed at £50 per bench, £15 per vice, steel from current stock and tool boxes from plywood off-cuts plus labour. Sketch of bench design included.
No indication of project status or follow on activity.

9ᵗʰ February 1999

To redesign the beading blocks. This is to reduce the number of block sets from two to one. Changing over takes approximately 6 minutes and may occur 10 to 15 times a day. The project was costed at £20 to modify one set of blocks and approximately £250 for a set to supply the other saw. A 3ʳᵈ angle drawing is included of the new block design.

No indication of project status or follow on activity.

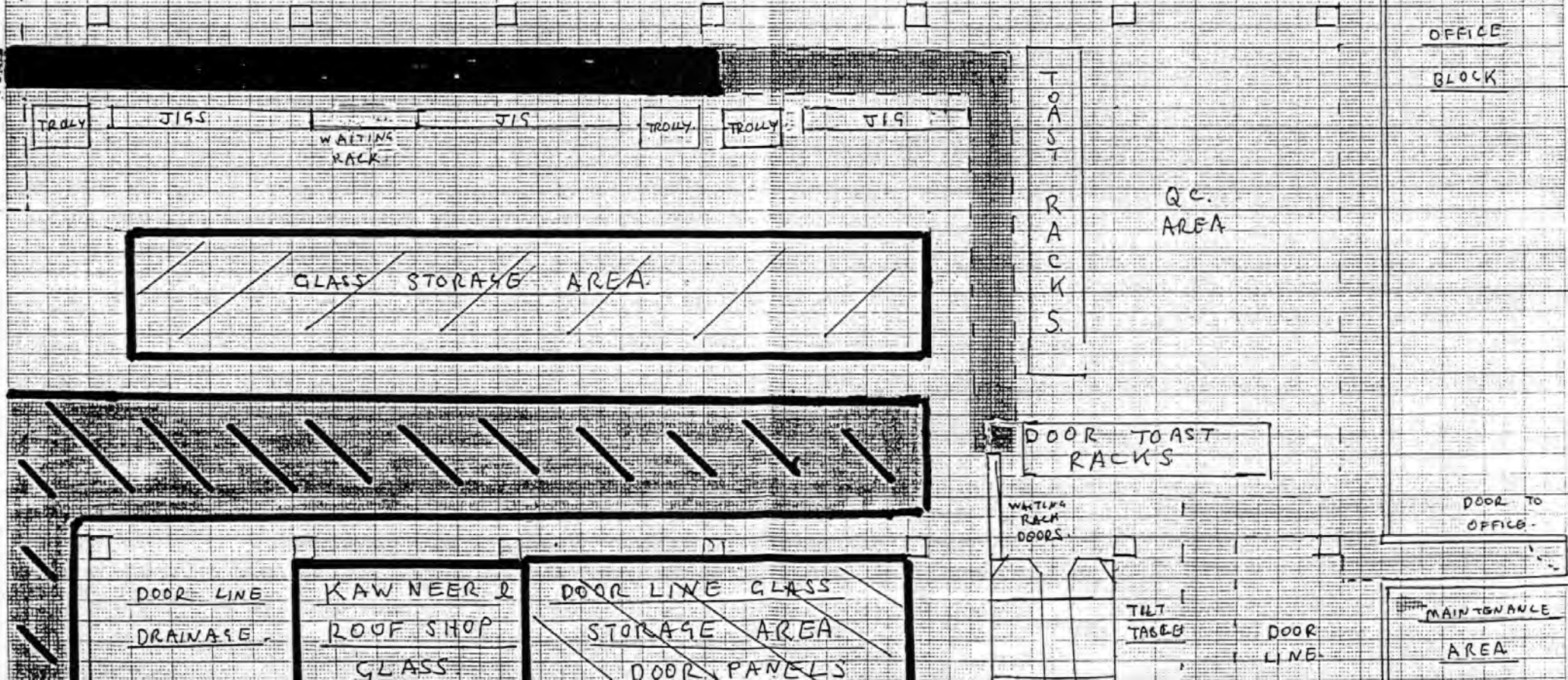# APPENDIX THIRTEEN – LAYOUT DIAGRAM

-343-

PEDESTRIAN WALKWAYS.

COMPLETED UNITS TO STORE CORRIDOR.

DEDICATED FORK LIFT CORRIDOR.

GLASS RACKS & STORAGE AREAS

OFFICE

BLOCK

TROLY JIGS WAITING RACK JIG TROLY TROLY JIG

T
O
A
S
T

R
A
C
K
S.

Q.C.
AREA

GLASS STORAGE AREA

DOOR TO AST
RACKS

WAITING
RACK
DOORS.

DOOR TO
OFFICE.

DOOR LINE KAW NEER & DOOR LINE GLASS
DRAINAGE. ROOF SHOP STORAGE AREA
GLASS DOOR PANELS

TILT
TABLE DOOR
LINE

MAINTENANCE
AREA

PUBLICATIONS

THE RE-DESIGN OF MANUFACTURING SYSTEMS WITHIN SMEs – AN ALTERNATIVE APPROACH

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KEYWORDS

ABSTRACT

Much work has been carried out on the redesign of manufacturing systems. This work has tended to focus upon systems found in larger organisations where there are the resources for large scale change programmes. The problems of the SME have largely been ignored. This article reports on an iterative approach that allows SMEs to conduct systemic and systematic redesign of their manufacturing systems.

The work has been developed from experiences gained working in an SME. These experiences have been combined with techniques from literature to provide a methodology for redesigning manufacturing systems within SMEs. The methodology has been used in an SME with encouraging results. The methodology has been found to be effective and ongoing work will provide further support from other cases.

PURPOSE OF PAPER

This paper aims to disseminate research that has been conducted into the re-design of manufacturing systems within UK manufacturing SMEs. The paper will set out the research method employed and then consider a definition of the phenomenon under investigation. This will lead to a discussion on design methodologies which will provide the basis for the proposed solution to the issues of manufacturing systems redesign in SMEs.

Within the current British manufacturing environment, SMEs, (businesses with less than 250 employees), account for 99.8% of UK businesses, 56.5% of employment and 54.5% of total business turnover (DTI, 1997). For this reason alone they are vital to the health of the United Kingdom economy. The government has frequently suggested that smaller businesses need to improve the way they do business.

Recent work has highlighted the need for SMEs to develop their ability to manage growth (Yarrow et al, 1999). Other work in this area was commented upon the lack of systematic approaches being adopted by SMEs (Voss et al, 1998).

These and other authors have also tended to focus on technical solutions (Bennett, 1986, Gallagher & Knight, 1986, Parish, 1990, Harrington, 1991, Wu, 1992, O'Sullivan, 1994). The investment that is required for some technical solutions is beyond most SMEs (Joyce et al, 1990). In addition, Welsh & White (1981) clearly identify that a small business is not a little big business (see also Westhead & Storey, 1996) and thus, the methods for manufacturing system re-design that are applicable for large organisations may not be applicable for smaller ones. This is the hypothesis that will be used to develop a redesign methodology that is applicable for smaller businesses.

RESEARCH METHOD

The research is adopting an action research approach (Eden & Huxham 1996). The reason for this approach is both historical and epistemological. The need for work in this area was highlighted during two years the principal author spent as a production engineer in a manufacturing company. During this time several projects were undertaken to modify the manufacturing system through the introduction of automation. While classical design methodologies were adopted, the realities of life in an SME made these approaches highly problematical. The greatest limitation was resource poverty (Welsh & White, 1981) and the lack of systemic approaches being employed by the SME under study. This provided valuable case material that will be used to support and inform the methodology development. The case design was carried out using the principles that Yin (1989) describes. These multiple, embedded cases looked at several units of analysis. These ranged from continuous improvements to the whole manufacturing system through to elements of production equipment on the shop floor. This provided a wide and rich experiential data set that has formed the understanding that has

shaped the development of the proposed manufacturing systems redesign methodology.

The epistemological reason for adopting an action research approach is that while observation and understanding are valid reasons for conducting research, there is a requirement to feed that understanding back into the system under investigation. The initial research showed a general lack of systemic and systematic redesign approaches being used in SMEs. To address this issue the research has to produce a method that SMEs can use to undertake systemic and systematic redesign. Merely increasing academic understanding of the phenomenon under discussion will not assist those SMEs being studied.

To achieve a method that SMEs can use, it is proposed that small businesses should be involved in the development of that mthod. These requirements for co-operative work with the subject to produce change closely match Eden & Huxham's assertion that research should be practical (1996). Assuming that there is a concrete reality about which we can converse, the knowledge gained through this research can, and should, be used to improve the lot of SMEs.

This mutually agreed framework for change is one of the principal ideas behind Eden & Huxham's contentions on action research. It should also be noted that the redesign methodology is an action focused one, there is considerable emphasis placed on getting results on to the shop floor early. While this will lead to action being taken before all the relevant analysis has been carried out, there is a question of motivation that will be addressed later in this paper.

In his 1988 paper, Reisman describes seven strategies that can be applied to research in management and social sciences. He claims that the most common approach to research in this field is that of 'ripple' research. This is where the corpus of knowledge is incrementally increased from a known, or assumed, starting position. Much of the work being carried out in this research is building upon that of others. It is being moved forward through modification to be useful to those in smaller organisations. Reisman also describes an approach that he terms 'transfer of technology' (1988). In this mode of research, a technique or technology from one discipline is used in another. He differentiates this from a bridging research strategy in that there is typically no impact on the source discipline.

Cyclic design methods from Deming and Shewhart, (1984, 1939) software design methods from Pressman (1982) and systems thinking from Checkland (1991) are being applied to manufacturing systems re-design. No effort is being made to address the fields of software design or systems thinking. These cyclic design methods are successful in their own fields and this paper contends that the field of manufacturing systems exhibits many characteristics of those fields. Where applicable, these methods are then being extended to be applicable to the area of manufacturing systems re-design. Some work is required to combine relevant elements from the disparate fields so that the result is applicable to manufacturing systems.

INITIAL CASE STUDIES

The initial work showed that the linear approaches adopted by most design theoreticians since the early 1970's do not translate well for the smaller business. In his 1970 book on design methods, Jones contends that the purpose of research into design was to eliminate the iterative and unpredictable element in design. This is very much in keeping with the mood of the era when computers where being developed and there was a great feeling that 'scientific' solutions would prove the salvation to many of mankind's problems. This was reflected in the perceived need for a scientific design process that was repeatable and systematic. This approach found great favour in the technical design activities that were being developed. Design techniques have developed considerably since those early days but the underlying concept of trying to constrain design to a linear, repeatable format remains.

As design projects grew there was an increasing requirement for control over the design process. Structured Systems Analysis and Design Methodology (SSADM, Longworth 1992, Ashworth & Goodland 1990) and similar approaches were aimed at developing very complex information systems. These were based upon the linear approaches espoused by Jones in 1970 and developed over the intervening years. When systems thinking was introduced by Checkland and others they were faced with using these linear techniques to solve problems that were outside the problem domain for which they were suitable. Soft Systems Methodology (SSM) was developed by Checkland (1991) to overcome the limitations of traditional design techniques. Checkland was concerned with developing solutions to problems that were not expressed in tangible terms. These are similar to those that are experienced by small businesses. There is still a long lead time between identifying the problem situation and developing a solution. What is needed is an approach that allows action to take place much earlier in the design process.

The initial cases cover three change episodes in an SME. These looked at developing new manufacturing practices and technologies. The first two cases used redesign methodologies that were in line with best practice as suggested by the literature. This was to cover feasibility, preliminary design, detailed design and planning, (see Figure 1). Jones (1970) further describes the planning stage as evaluating and altering the design concept to suit the requirements of production, distribution, consumption and product retirement. The third case used a more iterative approach.
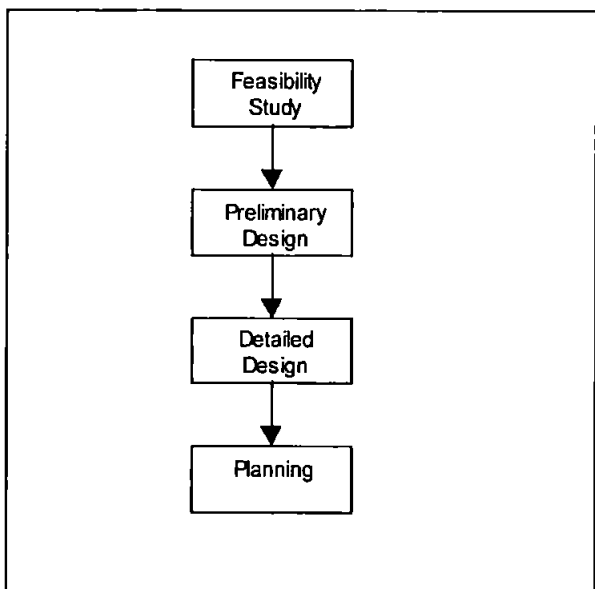
Feasibility
Study

Preliminary
Design

Detailed
Design

Planning

Figure 1 Four Phases of design (Jones 1970)

The first case was to develop a new encapsulation process for small electronic devices. These were placed in a jig which was over-filled with resin and then placed in a vacuum chamber to remove the air. This process resulted in 60% wastage through spilt and overfilled resin. The process was very messy and unpleasant for operators and represented a perceived bottleneck in production. While the vacuum chambers could be stopped in mid-cycle this was rarely done as it was difficult to ensure that components would then be fully evacuated. The design brief was to develop an automated system that would accept components and fill, evacuate and cure in one process.

The initial designs were completed by both external contractors and internal design teams. These were costed to determine which would be the chosen solution. The investment was likely to be considerable, in excess of £20,000 and there was concern within the business that the contractors were not fully aware of the material considerations involved. It was suggested

that more trials be carried out to determine the technical feasibility of the project. These trials showed that the encapsulation material was more viscous than had been allowed for. This led to difficulties in ensuring complete replacement of air with resin. It was suggested that the encapsulation resin be changed. This led the project in to an iterative development phase that ended with a modification to existing practise but not the significant change that had been promised at the outset of the project.

The second project was to develop automated processing equipment to improve the quality and repeatability of a key stage in the manufacturing process. This would also have a major impact on the skills requirement of the workforce. The process was currently carried out manually using intuitive measurement to ascertain the degree of processing that had been carried out. The new system would accept raw components and release conditioned parts. There would be very little interaction on the part of the operator and this change to the manufacturing system was not included as part of the system consideration.

The initial design involved experimentation to ensure that the process itself was understood and sufficiently well bounded to be automated. The knowledge gained during this time proved useful in solving other production problems. The design was carried out and work contracted out. Once the work was returned assembly began. While the initial design was adhered to, modifications were made to improve the operational effectiveness. This iterative process was carried out between the mechanical components and control software. The final equipment was released to the shop floor but has continued to undergo modification. There was no mechanism to effectively finish the project once it began iterative development.

The difficulties experienced with the first two projects resulted largely from the linear approach taken. For the third project an iterative approach was adopted in line with the work carried out by Pressman (1992, Figure 2). The third project was to develop an automated component welding system. The components were small sub-assemblies that were later used in evacuating sealed glass tubes. The assemble was very simple, a short strip welded on to the end of a tube. The scale of the components was the greatest challenge (the tube was 0.7mm OD, 0.5mm ID, the strip 1.0mm x 0.2mm). Based upon the previous experience of making changes it was decided to use an iterative approach to the systems design.
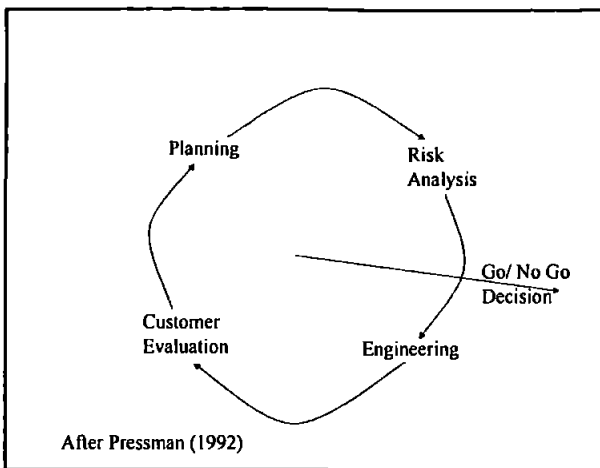
After Pressman (1992)

Figure 2 Cyclic design showing four phases and decision break point (Pressman 1992)

The first stage was to plan out what changes to the current production could be made. There was little scope for changing the organisation of work as the process was technologically constrained. This implied that the first change would have to be technology led. It was recognised that the proposed change would lead to a change in the production management system as the process times would alter and the scope for more responsive manufacture would place the focus on other areas of production. The new equipment would also release operators to carry out other, value-adding tasks.

The first task was to conduct a study of the existing production. This provide initial cost analysis that would enable future risk/benefit analysis to be carried out. The evaluation of this initial work showed that there was a financial as well as quality and capacity benefit to the proposed change. The next iteration was to plan some trials to ensure that the technology was capable of achieving the performance required. This involved several trials each of which was evaluated upon the risk of failure to the project against the increase in certainty that the project would succeed.

Trials were carried out on different welding positions and techniques. This was very important as the weld performance was fundamental to the technical performance of the final product. The cost of these trials was very low as they were carried out in-house and the potential cost to the business through component failure was much greater. These trials proved that the welding technology could produce viable welds under test conditions. It was left to contractors to determine that they could replicate the results under production conditions.

There was some concern on the effect that a different weld would have on post-process operations. Trials were carried out that showed that there were limitations on what could be done before other processes in the manufacturing system would be adversely affected. This involved a study evaluating the point at which a decrease in one process would outweigh the increase in welding efficiency. This provided data that allowed the design to be further refined.

Finally, the proposed components were manually constructed and built into a finished product. This was then subjected to the full range of tests that the production product would be expected to pass. Having successfully passed these tests the process change was deemed to be viable. Contractors had been involved at all stages of the iterative process and were also happy with what was being asked of them, although it would stretch their capabilities to the limit.

When developing the equipment that would produce the welded parts, advice was sought from the shop floor. This was to ensure that the people using the equipment would have a sense of ownership. This was identified as an important element of systems design that was not always considered.

At this point a business situation arose and the project was put on hold. It did, however, demonstrate that an iterative change programme was viable and controllable. It provided an opportunity to examine the proposed change from different vantage points and to assess changes frequently with quick response to new data. While this change did not occur, the process of change management that was used worked well and would be applicable to other manufacturing systems redesigns.

These three cases have shown how linear redesign approaches have been inappropriate for SMEs. The emphasis on the initial designs caused problems where the problem was not tightly defined, as was often the case. The third project demonstrated that an iterative approach could be used successfully within redesign. The approach described by Pressman (1992) requires some modification as the customer is internal and the engineering phase would be better labelled as 'action'. The Pressman model does not provide the user with a systemic approach as it is designed for software development. There is a requirement to enable the SME to carry out an iterative redesign exercise that encompasses a systemic axiom.

DEVELOPMENT OF PROPOSED METHODOLOGY

The requirements of SMEs are fundamentally different to those of larger businesses. Welsh and White (1981) put forward the economic argument that a small business has to be particularly careful during times of growth as well as decline. They point out that rapid and fundamental growth can have dramatic, and fatal, consequences to the financial health of the business. This is one result of what they term resource poverty. This resource poverty makes iterative change more appealing for smaller businesses as it does not pose the risk to their financial health that a more traditional approach might. During the initial cases and subsequent research with SMEs, it was found that radical change was looked upon as a source of risk and uncertainty, though no manager was able to translate this in to a financial risk assessment.

There is a need, as identified earlier, to encourage SMEs to consider more than just a technical solution. Indeed there is a need to consider the manufacturing system itself more widely in keeping with systemic thinking. The majority of linear redesign approaches stem from the scientific approach espoused by Jones (1970) and this has led to a technical bias in their approach to solving the problems that they are used to tackle.

As early as 1939, Shewhart had described the need to move from the 'old' way of manufacturing with a linear progression through specification, production and inspection to the 'new' way with a cyclic process. By 1984 Deming had described the cyclic design methodology as being better than the linear model. Deming saw the linear model as having no direct feedback from consumers to the design effort. These methodologies have proven invaluable in continuous improvement and Kaizen but have not been applied to larger scale systems development. There is a requirement in large organisations for a degree of planning that mitigates against iterative methodologies because of the uncertainty beyond the next visible iteration.

The iterative approach is, however, the one that is used in smaller businesses. This has been found in the cases conducted in the initial phase of this research and through experience with other small businesses. One such iterative approach which lends itself to such modification is provided by Pressman (1992, Figure 2).

Pressman developed this model in the world of software engineering where prototyping is widely used for product development. Having established that there is a problem to be solved the risk analysis is used to determine the probable costs/benefits of action. The business can then proceed with some engineering or activity and a review of that action to see if the problem has been alleviated. If there is still a problem then the planning phase can consider the next iteration. When the risk outweighs the benefit the process terminates. The iterative approach alone does not offer a systemic approach that would make it suitable for systems redesign.

To ensure that the SME evaluates the manufacturing system as a whole, there needs to be a facility within the methodology that prompts the SME into considering the wider system. The work of organisational psychologist Leavitt (1972) considered how managers could be helped to view businesses in a wider context. He proposed that four views, or considerations should be used when discussing organisational issues. Leavitt named these – Structure, People, Task and Technology. Considering these views at the planning stage allows a systemic approach to be applied through iterative implementation.

The combination of the iterative approach of Pressman and the four views of Leavitt results in a new methodology for manufacturing systems redesign (Figure 3). This methodology allows a systemic philosophy to be combined with an iterative implementation to provide the SME with an approach which enables them to use the available resources without placing undue demand upon them.
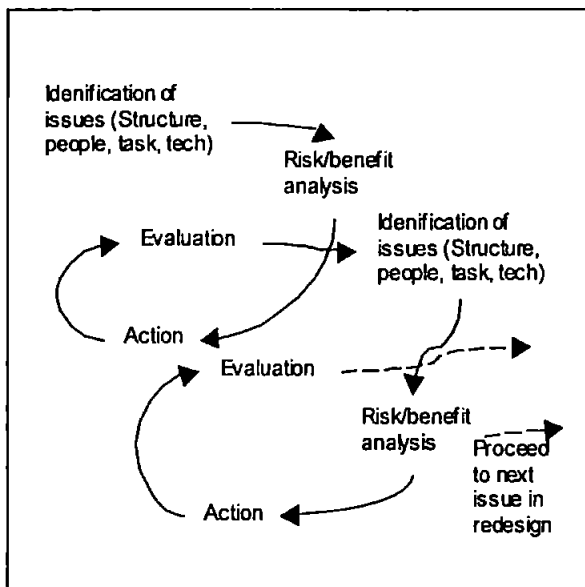
Figure 3 Proposed iterative redesign approach

Westhead and Storey (1996) discuss the effect that uncertainty has on smaller companies. They contend that the impact of external uncertainty is a prime consideration for smaller companies. While this might be viewed as a reactive position to adopt, Westhead and Storey argue that in CEOs smaller businesses can be more certain that their plans are being carried out as they envisaged as the management chain is shorter. This leads to less internal uncertainty. The introduction of a relatively large change programme is likely to introduce internal uncertainty. Iterative change programmes are less likely to produce large uncertainty as the management can remain in close contact with the programme at all times.

FINDINGS

The model (Fig. 3) has been used in ongoing work with a manufacturing of machine tools. The views allowed the Works Director to frame his concerns with the business in to problems that could be tackled. What was previously a huge, all-encompassing problem was reduced into 'bite-sized' portions that retained their systemicity because the problem was viewed from a systemic perspective. The four views were ones that the Works Director could relate to in his daily activities and he was able to see how changes to the tasks that people carried out would have an impact on the people involved and would require new technology to be fully implemented. The complete systems redesign was something that had been under consideration for several years but was too large to be tackled. The use of the four views to break the problem

down and the iterative approach to carrying out the redesign allowed the Director to begin formulating a change programme.

One difficulty was gaining momentum for the change process. The iterative nature of the methodology can make it difficult for users to determine quite where the current iteration will lead. While there are clear objectives for each iteration, until the work has been carried out and analysed by the user the next phase remains uncertain. What did work well was the risk analysis feature that allowed the business to monitor the risks against the potential benefits and to terminate projects that had either achieved their aims or were not going to. This is a strength of the methodology that does not exist in other methodologies. While this might be seen as a weakness, that the modelling had not been completed before moving on, the business did not have time to allow more in depth analysis to be carried out. Their concern was to use the knowledge that had been generated to fuel the next iteration.

The proposed methodology has been shown to be effective in a small business environment. When the proposed methodology has been used in smaller businesses there is evidence that they have been able to reconcile differing views of the business and develop solutions that address the root cause of problems. From experiential research an iterative approach was felt to be a viable alternative to the linear model found at the heart of most contemporary approaches. This has a precedent in the work of Jones (1970) where he describes six design strategies. These cover linear, cyclic, branching, adaptive, incremental and random. Historical precedence has favoured the linear approach and this research is addressing the imbalance through the use of cyclic re-design for smaller businesses.

CONCLUSIONS

It was not considered sufficient to provide a cyclic problem solving tool for manufacturing style issues as these have been well covered in the literature, significantly by Deming (1984) and his successors. There was a requirement to enable the business to adopt a systemic approach to the re-design. This could only be achieved by adopting a systemic approach to the consideration of the problem. In this instance the manufacturing system is more than just an information technology issue, or a human resources issue, or an organisational issue. The manufacturing system is a socio-technical system which includes elements of human activity systems and designed physical systems.

The methodology that guides the re-design must, therefore, be capable of resolving these issues. In doing so it must provide the SME with an opportunity to look beyond the view that has been adopted of the manufacturing system to date and to encourage different perspectives. The proposed methodology does this while allowing SMEs to pursue their own re-design. The methodology has been particularly successful in encouraging SMEs to experiment with solutions that are not from the same viewpoint as the perceived problem. That is to say that if the business has identified a problem with the procedures that govern the business, a human focussed solution might be more applicable than more procedures (a task focussed problem with a people focussed solution).

The experience gained in applying the methodology shows that small businesses are capable of carrying out systemic re-design but that they cannot devote the resources to this activity that a large organisation might. This means that the manager who is driving the change programme is likely to be carrying out several operational roles in addition to the change initiator role. This limits the scale of the change that can be attempted and this in turn tends to lead to an iterative approach. It is not that SMEs are timid or afraid of change, merely that they do not have the resources to tackle a larger programme.

FUTURE WORK

From the research it is clear that much remains to be done in this area. The methodology described is unlikely to benefit all business sizes and there will be a point at which the change programme becomes too large for such a relatively informal, iterative method. This research has not attempted to define this transition point.

Having established that linear methodologies are not the best for smaller businesses, are there other approaches that might be equally, or more, effective? Do different manufacturing sectors respond to different re-design approaches? Are manufacturing SMEs unique in their requirements for systemic change, can this approach be adapted for other business environments? How does this new approach to manufacturing system re-design affect other business functions such as strategy development, product design, marketing and personnel management?

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