An Evaluation of the Commercial and Operational Impact of Implementing Advanced Design-led Technologies within Manufacturing-based SMEs

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Within the discipline of Design

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Declaration

This dissertation is the result of my independent research. Where it is indebted to the work of others, acknowledgement has been made.

I declare that it has not been accepted for any other degree, nor is it currently being submitted in candidature for any other degree.

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Abstract

Small and medium-sized enterprises (SMEs) within the UK, particularly those in the manufacturing sector, operate in a harsh economic climate. Consequently, many UK manufacturing SMEs are making the transition from contract manufacture to design and manufacture, in order to generate a clear competitive advantage in the international market place. In order to facilitate this change companies often adopt advanced design-led technologies such as computer-aided design (CAD). A case study methodology has been successfully utilised within this research and findings from four companies reported; one longitudinal and three supporting. This work evaluates the impact of these technologies in three primary areas: project lead time; project cost; and product quality. The findings of this research show a positive impact of design-led technologies upon all three areas within the companies, the greatest impact being observed for product quality. The results led to the categorisation of the manufacturing scenarios with regard to the overall impact that the design-led technologies had upon them. Three divisions could be identified: major impact, moderate impact; and low impact. The results highlight that management combined with organisational culture within a small manufacturing company affects the success of design-led technologies, and often prevents them being fully utilised.
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1.0 Introduction

1.1 Background and Rationale

Small and medium-sized enterprises (SMEs) represent a key element in national economies around the world. They are an essential source of jobs, create entrepreneurial spirit and innovation, and are therefore crucial for fostering competitiveness and employment. In the enlarged European Union, some 23 million SMEs provide around 75 million jobs and represent 99% of all enterprises. The latest European definition (EU, 2003) of an SME is:

- Micro - employs fewer than 10 persons (and an annual turnover that does not exceed 2 million Euro).
- Small - employs fewer than 50 persons (and an annual turnover that does not exceed 10 million Euro).
- Medium-sized - employs fewer than 250 persons (and an annual turnover not exceeding 50 million Euro).

Within the UK, there are approximately four million SMEs that employ 12.5 million people and account for 54% of the private sector turnover (DTI, 2003). The SME base within Wales is particularly important to the Welsh economy. The Federation of Small Businesses state that 71% (compared with 57% in the UK) of all Welsh private sector employment and 63% of business turnover in Wales is generated by SMEs (Walters et al. 2004). Furthermore, manufacturing constitutes a significant proportion of the Welsh SME sector, in that manufacturing represents 15% of total Welsh employment (Bryan et al. 2000). This demonstrates the continued importance of manufacturing SMEs to the Welsh economy. A number of advisory services such as The Manufacturing Advisory Service, Cymru (MAS Cymru) and Design Wales
have been established specifically to support SMEs which further demonstrates the importance of SMEs to the Welsh economy.

The manufacturing-based SMEs within the UK operate in a harsh economic climate with increased low-cost competition from overseas. Government strategy advocates that companies must move up the value added chain by generating a clear competitive advantage. Patricia Hewitt, former Secretary of State for Trade and Industry, highlighted the problem:

'We cannot compete on the basis of low-cost, low-skill, low-margin goods. That means business must now more than ever rely on innovative, design-led thinking'.

One solution to this developing problem is for traditional manufacturing companies to expand into new product development, which allows them to harness product innovation and apply their core knowledge in new directions. Studies have shown that successful new product development provides higher returns than practically any other type of similar investment (Berliner and Brimson, 1988).

In order to develop this design-led thinking, companies often introduce new technologies. These technologies complement the design process and are described as advanced manufacturing technologies. The next section describes how this group can be further classified as advanced design-led technologies. This thesis evaluates the commercial and operational impact of implementing advanced design-led technologies within manufacturing SMEs.
1.2 Previous Research

1.2.1 Design-led technologies

Advanced manufacturing technologies (AMTs) have been defined by Youssef (1992) as 'a group of integrated hardware-based and software-based technologies, which if properly implemented, monitored and evaluated, will lead to improving the efficiency and effectiveness of the firm in manufacturing a product or providing a service'. Common advanced manufacturing technologies include: Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computerised Numeric Control (CNC) machine tools, industrial robots and automated control systems.

Successful implementation of advanced manufacturing technology has been associated with a number of tangible and intangible benefits by Kaplan (1986). Tangible benefits include: inventory savings, reduced floor space and improved return on equity. Intangible benefits include: enhanced competitive advantage, increased flexibility, improved product quality and enhanced reliability. Sohal et al. (1999) describe additional benefits of implementing advanced manufacturing technologies, such as obtaining a competitive advantage, countering threats from competitors, countering skill deficiencies and enhancing company image.

This study will examine a sub-set of advanced manufacturing technologies, which will be referred to as advanced design-led technologies. Design-led technologies acknowledge the importance of design within the new product development process. We can categorise design-led technology as equipment and/or processes that facilitate improvements in the design-to-manufacturing process. A prime example of a design-led technology is Computer Aided Design (CAD). Robertson and Allen (1993) describe CAD as the use of computers to speed up design and engineering
activities by rapidly capturing design intent and reducing the errors between the development stages. This joined-up design-led thinking is required for the successful development of new products. Mirman (2003) reports the advantage of three-dimensional (3D) CAD as ‘the data thread that weaves the way throughout the entire manufacturing enterprise, producing the efficiencies and agility necessary to compete successfully in a competitive global market’. Mirman (2003) also highlights the additional benefits of CAD as follows:

- Improving communication of design intent – Engineers use 3D CAD systems to capture and communicate design intent. In 2D drawing, the potential for misinterpretation is higher, and the original design intent can be lost.

- Assessing fit and tolerance problems – Fit and tolerance problems result in parts that do not fit together correctly. Often these problems go undetected when working in 2D, the advantage of 3D CAD is that engineers can assess and resolve fit and tolerance during initial design.

- Handling large, complex assemblies – CAD allows components to be assembled quickly and easily. The production of engineering drawings of a 3D part is far quicker than creating 2D drawings from scratch.

- Minimising reliance on physical prototyping – historically fit and tolerance checking may have been assisted by physical prototyping. CAD models can be assembled in a virtual space and checked without the need for expensive physical modeling.

- Creating instant production drawings - A range of different drawing views and sections can be quickly produced using modern CAD systems. It is particularly useful to be able to section parts and assemblies to ensure that they are suitable for the manufacturing process.
Reducing analysis and simulation time – Simulation techniques such as Finite Element Analysis (FEA) require the use of 3D model files. Time can be saved by using CAD systems to design parts in 3D at the outset.

Shortening manufacturing cycles – 2D Engineering/production drawings must be created repeatedly to support other processes, such as analysis, prototyping, stereolithography, manufacturing, fabrications and assembly. If a 3D finished model already exists, it is far quicker to select the views/sections required and produce these drawings, rather than having to draw them from a blank sheet. The design intent is already captured in the 3D model.

Generating precise data for downstream manufacturing – Processes such as CNC programming and tool manufacturing often require data in the form of x,y,z co-ordinates. CAD models can be used to generate this data accurately and quickly.

To enhance the interface between design and manufacturing activities, CAD systems are frequently linked with Computer Aided Manufacturing (CAM) systems (CADCAM). CAM employs the three-dimensional CAD data to define tool paths and cutting strategies for Computer Numerical Control (CNC) machine tools. Dotcheva et. al (2002) have shown that effective CAM strategies can bring tremendous benefits to manufacturers in terms of reduced production time-scales, improved quality, increased productivity (e.g. no finishing requirements), increased tool life and the ability to machine new materials. Various researchers within the precision engineering and automotive sectors have highlighted the benefits of CADCAM systems within the product development process of larger enterprises. Droge et. al (2000) demonstrate how CADCAM speeds up design and engineering activities and thereby reduces new product development lead times. Sanchez et al. (2003) have shown that the use of CADCAM can reduce the time and cost of new
product development within companies with a significant number of communication channels. Tantoush et al. (2001) indicate that CAD/CAM reduces new product development cycle time and hence can create relative advantages in market share, profit, and long-term competitiveness.

An additional application of CAD systems is the creation of geometric files for rapid prototyping (RP). RP is a process which enables the rapid generation of physical objects directly from 3D CAD data. There are a number of RP manufacturing processes currently available. Stereolithography (SLA) is an example of one of the more dominant technologies; additional technologies, such as Laminated Object Manufacturing (LOM) complement the SLA process. In each of these processes the product is created by building layers of material up from a sliced version of the CAD file. The SLA process generates a physical model by using a laser to locally cure and solidify layers of resin, in a resin bath. The focused laser spot traces the boundaries of each slice cross-section, then re-traces and solidifies the detail of the cross-section. Supports are created which act like ‘fixtures’ in conventional machining, and hold the part in position whilst preventing distortion. The slice thickness depends upon the SLA machine; however, the thinner the slice the more faithful the representation of the part and the better its surface finish. The LOM process, on the other hand, builds objects in thin layers of adhesive coated paper. The individual cross-sections are cut to the correct shape by using a special carbon dioxide laser. LOM parts are less accurate than other RP methods; this lends them to being used for the sand casting process that has tolerances that are lower than other manufacturing processes. For these reasons LOMs provide a low-cost method of rapid prototyping; they are often used for larger components where tolerance and accuracy is less essential.
A summary of the information presented above can be seen in the following table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Process description</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereolithography (SLA)</td>
<td>A physical model is generated by using a laser to locally cure &amp; solidify layers of resin in a resin bath.</td>
<td>Used for design realisation, product validation and tooling (e.g. creating silicon tooling from SLA patterns) and functional parts.</td>
</tr>
<tr>
<td>Laminated Object Manufacturing (LOM)</td>
<td>A physical model is generated by cutting layers of thin adhesive coated paper and bonding them together.</td>
<td>Lower accuracy, ideal for use as sand casting patterns. Low cost, suitable for larger builds where a lower tolerance is acceptable.</td>
</tr>
</tbody>
</table>

Table 1.1 – Summary of common RP processes.

Jacobs (1996) describes how RP contributes to reduced manufacturing costs by aiding the design for assembly and design for manufacturing processes. By approaching these issues earlier on in the new product development process design criteria can be formalised between designer, engineers, production supervisors and other team members. In addition, RP models are increasingly used for tooling. Functional RP models can be created for testing to validate a product before expensive production tooling is machined, thus saving potentially expensive tool rework. Furthermore, RP models can be used as patterns to build tooling from. For example, glass-fibre tooling is often used in preference to metal tooling due to the
cheaper construction methods. Hall (2000) reinforces the importance of being able to try and test before market entry, contributing to improved product quality and reduced time to market.

The limitations of design-led technologies have also been reviewed by other researchers. Kessler and Chakrabarti (1999) have noted that CADCAM systems can in some circumstances inhibit innovation. They found this result surprising and suggest possible explanations for this could be the inappropriate installation of the CAD systems within their case study companies (i.e. an overly long time was required for staff to learn and use them effectively). They indicate that CAD is better suited for incremental innovation (building on established concepts) rather than for true radical innovation. Tantoush et al. (2001) have compared design-led technologies within two manufacturing companies, comparing an integrated approach with a non-integrated approach. They conclude that an integrated approach to design-led technologies such as CADCAM is essential for success. They describe this approach as one in which the main barriers to change are broken down, and a change in culture is allowed to evolve. On the other hand, the company with the non-integrating approach displayed resistance to change; in particular the management team created barriers to the design-led technology, due to their own technical shortcomings. These two studies have shown that the mechanisms for implementing design-led must be carefully considered.
Chapter 1.0 - Introduction

This chapter has presented the case for introducing design-led technologies within SMEs as an important one; the use of design-led technologies is particularly important for SMEs making the transition from traditional manufacturing to product design and new product development. In fact, government strategy is largely focused on encouraging manufacturing SMEs to develop their innovation and design-led thinking. The next section will therefore discuss new product development within manufacturing SMEs.
1.2.2 New Product Development within SMEs

The majority of new product development literature focuses on the activities of large well-established companies as highlighted by Cooper (1999). He shows that although the new product development process is well understood in large enterprises, it is not necessarily well implemented. Some of the issues in large companies are a lack of skill, a faulty or mis-applied new product development process, rushing the development process, lack of leadership and running too many projects at the same time (Cooper et al. 2002). The literature on new product development in SMEs is more limited. A notable study by Woodcock et al. (2000) studied the progress of six UK companies and identified a number of concerns related to product development and innovation. The most worrying factor identified was the lack of determination to bring about change and this was attributed to the SME manager’s over-optimistic view of their performance. In addition, they report that SMEs typically avoid formal procedures, do not collect adequate data with which to monitor their product development performance, and do not involve manufacturing personnel early enough in the process. A study by Freel (2000) examines the barriers to product innovation in small UK manufacturing companies. He concludes that managers put too much emphasis on technology issues ahead of effective marketing and commercial exploitation, long-term funding needs clarification, and crucially small companies must improve their in-house technological and marketing skills base. Furthermore, Freel (2000) identifies a lack of trust within small companies to engage external design and development services. Brown et al. (1996) have also reported this issue in a study of four very small manufacturing companies. They recommend better communications, clearer product definition and the use of external agencies to overcome the prevalent small-company do-it-yourself culture.
Laugen et al. (2003) has shown there is a clear synergy between new product development and manufacturing. In an extensive study of medium and large-sized manufacturing companies, they show that programmes to speed up the new product development process lead to improvements in manufacturing performance. This was specifically shown with regard to reduced manufacturing lead times, increased customisation and improved quality. They also report that the most beneficial new product development practice for a particular company may be the one that is effectively adapted to the company’s circumstances and strategic context. These issues are also relevant to the SME sector. Barnes (2002) mirrors these findings within SMEs, by suggesting that a flexible, broad strategic model is required in order to cope with the complex mix of deliberate and emergent actions that arise within a typical small company.

Lee et al. (2000) highlights in their research the problem faced by SMEs working in particularly cost-sensitive sectors, such as the automotive sector. He describes how SMEs are often further down the manufacturing supply chain which is becoming increasingly more competitive. They have to demonstrate that they too have the technical capability to provide customised products at the lower cost and appropriate technology. It is increasingly becoming the case that large Original Equipment Manufacturers are delegating their design work to smaller SMEs, and as a direct result of this there is a requirement for such SMEs to implement advanced design-led technologies.
1.2.3 Management Culture within SMEs

The literature shows that the success of product development and realisation lies not only in the use of advanced technologies but also on managerial and organisational strategies (Bartolo et. al 2004). A significant proportion of UK SMEs are family owned and family managed, as explained by Reid et al. (2002). This leads to the situation where the owner-manager is a key player within the small company environment. Beaver and Prince (2004) consider the owner-manager as a ‘special social character’ who is autocratic, egocentric, impulsive, and strives for autonomy and independence. A review of the barriers to product development within small manufacturing companies by Millward and Lewis (2005) has shown that the dominant owner-manager can have a detrimental impact on the new product development process. They portray the dominant owner-manager as a strong-willed forceful personality, who operates in a resource-constrained environment that results in issues relating to time and cost being prioritised ahead of other key factors. In addition, senior management frequently fail to understand the importance of structured product design (Filson and Lewis, 2000), this presents difficulty in terms of integrating design activities within a long-term business strategy. In practice, SMEs have a tendency to deprioritise work on new product development when faced with other short-term pressures (Woodcock et al. 2000).

In the broad area of new product development there is a shortage of literature looking at its application within SMEs, and there appears to be no literature investigating the impact of design-led technologies. The research that has been carried out within this area shows that typically, the SME environment poses a number of problems: over-optimistic and dominant managers, a lack of formalised data collection for benchmarking progress, lack of trust, poor communications and general
organisational issues. This research will take into account these issues whilst addressing the implementation of advanced design-led technologies as part of the new product development process within SMEs.
1.3 Research Objectives

This chapter commenced by highlighting the importance of manufacturing SMEs and their requirement to add value and generate a competitive advantage. One method is to facilitate new product development through the adoption of design-led technologies. The previous research section has presented a synopsis of the current literature concerning design-led technologies, and the importance of SMEs within the new product development process of small manufacturing-based companies. It has been shown that a number of researchers have already investigated the introduction of advanced manufacturing technologies within larger enterprises and their impact. However, there appears to be a gap in the research for smaller companies. It is clear that there is a lack of data recording the impact of these technologies within small companies. Therefore, the aim of this research is to investigate the implementation of advanced design-led technologies in manufacturing-based SMEs. The research objectives are as follows:

1. Develop an appropriate methodology for the quantitative and qualitative assessment of design-led technologies within SMEs.
2. Measure and analyse the commercial and operational impact of design-led technologies within manufacturing-based SMEs.
3. Identify key success factors.
4. Disseminate findings that might inform the successful implementation of design-led technologies to initiate and maintain new product development within small manufacturing companies.
1.4 Thesis Overview

This thesis comprises the following chapters:

2.0 Methodology – The aims and objectives behind the methodology is developed and justified within this chapter.

3.0 Case Studies – The relationship between each company’s manufacturing processes and the implemented design-led technologies is outlined in detail. A flow chart is used to explore the interaction of design-led technologies with the manufacturing processes, elements of which are displayed within each company.

4.0 Results – This chapter presents the results derived from the case study companies.

5.0 Discussion – This chapter discusses the design-led technologies that have had the greatest impact on the commercial and operational factors within the case study companies. This section is sub-divided into three main areas: (1) the design-led technologies that have had the greatest impact, (2) the manufacturing scenarios that have received the main benefit; and (3) ancillary factors implicit within SMEs.

6.0 Conclusion and Future Research – This chapter presents conclusions drawn from this body of research and suggestions for future research.

7.0 References

8.0 Appendices – The findings of this research have been disseminated through the publications reproduced here.
2.0 Methodology

The previous chapter has shown how manufacturing SMEs can apply their core knowledge to develop their competitive advantage by moving into new product development. The implementation of advanced design-led technologies has been acknowledged as a beneficial part of this process and some advantages and disadvantages have been discussed. A review of literature has identified a lack of impact data for SMEs implementing advanced design-led technologies; this research aims to gather this data. Due to the idiosyncratic nature of SMEs and the lack of formal documentation processes it can be difficult for a researcher to gain access to this data. In addition to this, it often takes a long period of time (e.g. two years or more) to implement design-led technologies. The process is not instantaneous which suggests that a longitudinal research approach needs to be adopted. The longer the period over which events are studied the greater the opportunity there is to observe at first hand the relationships of events (Voss et al. 2002). The author’s position upon commencing this research was within a traditional manufacturing SME implementing advanced design-led technologies over a period of two years. During the onset of the author’s placement it became clear that a large amount of information about ‘real’ manufacturing issues within SMEs could be harnessed during these two years. As an ‘actant’ within such a traditional manufacturing company, the author was in a unique position to harness data and make valid industrial observations from within the heart of ‘real’ industry. This approach overcame problems often associated with gathering historical/retrospective data, i.e. participant may not recall important events, and even if they do their recollection may be subject to bias (Leanard-Barton, 1990).
2.1 Approach to Data Gathering

Common research strategies include experimental research, surveys, historical, analysis of archival records, audits, randomised field trials and many more. Before commencing research it was essential to decide upon the substance and form of the study (i.e. what this study is about, and whether the researcher is asking a ‘who, what, where, why or how?’ question).

The table below shows some of the common research strategies and their characteristics. In some cases, the adoption of a combination of strategies may be required.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of Research Question</th>
<th>Requires Control of Behavioural Events?</th>
<th>Focuses on Contemporary Events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>How, why?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Survey</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Archival analysis</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>History</td>
<td>How, why?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case study</td>
<td>How, why?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2.1 – Relevant situations for different research strategies - Adapted from Yin (2003).
Chapter 2.0 - Methodology

Each method has advantages and disadvantages. It is important to develop the correct research strategy in order to gain valid and useful data. Some considerations for selecting the appropriate strategy are as follows:

a) The type of question posed.

b) The extent of control the investigator has over the behavioural events.

c) Degree of focus on contemporary as opposed to historical events.

These considerations are discussed in the following text, and the methodology selected for this study is outlined.

2.1.1 Selected Research Strategy

This research investigates ‘how’ design-led technologies have impacted upon the commercial and operational aspects of manufacturing companies. Furthermore, it explores ‘why’ the findings are what they are. These type of questions deal with operational links needing to be traced over a period of time, rather than through sampling.

The investigator is presumed to have little or no control within the findings of this study. That is, the investigator is not carrying out ‘experiments’ within a laboratory environment where he or she can manipulate behaviour directly. Such an experiment would focus on one or two isolated variables and the rest could be controlled. Clearly when investigating ‘how’ and ‘why’ questions this is not the case.

Case studies differ from histories due to the fact that they deal with contemporary issues. By taking a ‘history’ research strategy an investigator deals with the ‘dead’ past. The data collected will generally be primary or secondary documents, along
with artefacts. Case studies on the other hand deal with modern-day issues, and use additional sources of evidence such as ‘direct observation’ and ‘interviews’ with persons involved in the events. In addition, case studies enable the researcher to deal with a wide range of data which includes artefacts, interviews, observations and a range of documents. Having considered points a), b) and c) from above, along with Table 2.1, it was clear that a case study approach should be adopted.

According to Robert Yin (2003), it is possible to identify some situations in which a specific strategy has a distinct advantage. For case studies this is when:

‘a how or why question is being asked about a contemporary set of events over which the investigator has little or no control’.

It is clearly seen that this is the case for this study. Case studies can be based on any mix of quantitative and qualitative evidence, and need not always include direct, detailed observations as a source of evidence.
2.1.2 Single or Multiple Case Studies?

Having decided upon case study research, the next consideration was to decide whether enough data could be harnessed from a single case study or whether a multiple case study approach should be adopted. Multiple case designs have advantages and disadvantages to single case studies. Evidence in multiple case studies has substantial analytical benefits compared to only one case study. Robert Yin (2003) states that ‘if under these varied circumstances you still can arrive at common conclusions from both cases, they will have immeasurably expanded the external generalizability of your findings, again compared to those from a single case alone’.

One of the main disadvantages of using a multiple case study approach is that due to the additional number of case studies, it can be difficult to gain access to the information. It is therefore important that every case study chosen allows the researcher to have access to data and should be chosen for a specific purpose within the overall scope of the inquiry. For this study it was decided that a multiple case study approach would be adopted. The route to selection of these case studies is now discussed.

2.1.3 Longitudinal Case Study - Use of a Knowledge Transfer Partnership

The author was employed as a Knowledge Transfer Partnership (KTP) Associate for two years within a traditional manufacturing SME. KTP Programmes are a way of introducing graduates to industry. They were created to encourage growth within the UK’s manufacturing sector. These partnerships have been in operation for approximately 30 years and are a knowledge transfer scheme that aims to strengthen the competitive and wealth creation of the UK by stimulating innovation in industrial
collaborations. The author’s KTP programme was centred on implementing design-led technologies such as CAD, CAM and RP; as such, this was an obvious choice for use as one of the case studies. The KTP Associate plays a participant-observation role (or ‘actant’) within this. Yin (2003), describes a participant-observation role as being a special mode of observation in which the researcher is not merely a passive observer, but instead may assume a variety of roles within a case study situation and may actually participate in the events being studied. As such a vast amount of data and insight can be collected from this case study. This gave the author the opportunity to carry out a longitudinal study, which could be benchmarked against a number of other research studies. The author’s company was therefore chosen to represent the main longitudinal case study.

The participant-observation role has a number of advantages: the ability to gain daily access to research data which may be inaccessible to an external researcher, the increased accuracy of first-hand or ‘real’ observation (as opposed to employee opinions/statements), and the ability to manipulate minor events such as being able to arrange meetings with key staff in order to further focus data collection. However, there are problems with this method too. There may be problems related to potential biases produced due to the participant-observer’s company role, one of the main ones being that it is harder for the investigator to remain as an impartial external observer when they have a role to fulfil within the company and may not be able to dedicate as much time as they could merely as an observer. In order to overcome any potential biases it was decided that three additional case study companies would be selected to contrast the results of the longitudinal case study with. Two of the case studies were selected from ongoing KTP programmes, and the other, specifically chosen to be a non-KTP case study. The following section describes this further.
2.1.4 Supporting Case Studies

The two additional KTP case studies were selected from a large number of programmes run by the National Centre for Product Design & Development Research (PDR). PDR is a leading research centre in the field of product development, and delivers applied research, knowledge transfer and consultancy to a wide range of national and international clients. PDR work closely with manufacturing SMEs and have found them to provide a generous supply of information as best highlighted by Lewis et al. (1998), Brown et al. (1996), and Tucker et al. (2004). In more recent years, they have employed the KTP model as an effective mechanism for partnership and collaboration with a wide range of SMEs. In many instances PDR has found that KTP companies are prime exemplars of small manufacturing companies within the UK. There were a pool of KTP programmes within PDR that can be selected from to provide a number of supporting case studies for the longitudinal case study. It is important that supporting case studies are investigated to benchmark the results of the longitudinal case study; additionally, they are used to remove any potential bias from the research. Two of these additional case studies were chosen to be current KTP programmes due to the accessibility of data and experience of PDR in providing good case study material.

The final case study chosen to benchmark the longitudinal case study against was deliberately selected to be a non-KTP company. The reason for this was to further validate results and to see if common conclusions could be arrived at across all of the case studies, thus providing more compelling evidence. This case study was called the 'validating' case study.
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The method of gathering data for the additional case studies needed consideration. In the first instance data needed to be accessible and companies willing to contribute to this research. It was decided that the author would act as an ‘observer’ using a structured interviewing method within these corroborating case studies. A combination of ‘longitudinal’ case study plus ‘supporting’ case studies gives a mix of in-depth analysis and broad coverage.

2.2 Selection Criteria for Case Studies

Having decided that three supporting case studies would be used the next stage was to create selection criteria for them to ensure that comparable results could be obtained. The selection criteria for the supporting case studies were prioritised as follows;

1. They have or are in the process of implementing advanced design-led technologies.

2. They must be a small company:
   - up to 50 employees for the two supporting case studies, because this research is primarily aimed at small companies.
   - up to a maximum of 250 employees for the validating case study, because the validating case study will preferably be a more mature company, which has undergone the implementation of advanced design-led technologies recently.

3. KTP programmes which are in progress concurrent with the research.

The non-KTP company was selected by considering companies that fall within similar criteria as above and have strong links to PDR. Having selected all of the case studies a common method of collecting data had to be considered. It was felt
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that data should be collected using a semi-structured interview approach for a number of reasons: (a) a variety of open, closed and scalar methods can be used to gather data; (b) this approach is not too restrictive and allows the interviewee to respond in greater detail and elaborate away from the direct question. This can provide the researcher with additional data that might otherwise be constrained in a highly structured interview.

2.3 Additional Information about KTP Programmes.

KTPs operate by employing a recent graduate to carry out a two-year project within a company, the majority within an SME. The projects address key elements that are central to the successful development of the specific company. The programmes are partnered with research establishments (generally universities). This provides the graduate (also known as the KTP Associate) with research at the cutting-edge of technology through to the 'harder' industrial environment.

Projects typically run for two years and have a distinct management structure with clear deliverables defined for the research body, the graduate and the SME. This plan is presented in a detailed 104 week Gantt chart form that defines the programme in order to meet the strategic needs of the company. This plan helps the company to focus on a strategic route to their technology development as opposed to the ‘ad-hoc’ style used in some companies. An additional advantage of KTPs is that they may take away some of the financial risk to a company that may otherwise inhibit the development of a project and implementation of advanced design-led technologies.

Each project is assigned an industrial and an academic supervisor. The joint contract between the company and the research centre works such that the academic
supervisor can spend up to one day per week in a company. This fosters a high level of trust and co-operation and focuses the objectives of the project with a party not directly involved in the day-to-day running of the company. Another benefit to the research organisation is that they can develop a more in-depth understanding of the strategic and operational context of the company.

KTPs are undertaken in a variety of company sectors; however, figures published looking at the programme objectives of all of the UK schemes from April 2001 to March 2002 showed that 48% of them were related to Design and 23% relating to Manufacturing (DTI, 2002). In addition to this, 62% of the Design programmes were in small companies.

Lipscomb et al. (2001) used the case study model with KTP companies to demonstrate innovative methods of technology transfer and the challenges faced when transferring research knowledge into SMEs. In common with Lipscomb et al. (2001), other researchers such as Rosser et al. (2002) have found that KTP schemes provide a rich source of case study data. The following KTP Associates (in conjunction with PDR) have published work using their KTP programmes as case studies: Goodwin et al. (2003), Humble et al. (2004) and Tucker et al. (2004). Each KTP associate has published within the context of the implementation of design-led technologies. This work represents a wide range of manufacturing scenarios ranging from boat building and high technology electronics through to design for sustainability.
2.4 Creation of Questionnaire

In order to carry out semi-structured interviews a questionnaire template was designed to provide consistency throughout each interview and a structure to follow. Interviews were then conducted with the relevant technical staff (see section 2.6). A variety of techniques were used within this questionnaire, for example open and closed questions and Visual Analogue Scales (VAS).

Open questions are used to get a more natural response from the employee without constraining or influencing their answers in any way. One of the major advantages of open questions is that the interviewee often expands upon the question asked and gives additional information that may not have been considered when creating the interview template.

According to Oakshott et al. (2001), close-ended questions are the most commonly used type of questions as they are easier to analyse and can take many forms, e.g. 'Has the technology reduced project lead times?'. As this example shows they can be easily quantified and often questions only require a simple 'yes' or 'no' answer. Clearly in this case the respondent should only give one clear answer to the question. Closed questions help to confirm the interviewee's thoughts, and validate other questions (often 'open' ones) asked.

There are a number of scalar approaches that can be used in questionnaires in order to capture quantitative data. Some of the main ones are: verbal rating scales, numerical rating scales and visual analogue scales. The disadvantage of using verbal rating scales is that they use adjectives to describe the factor in question, e.g. when quantifying the impact upon project lead times. In this case, one interviewee may
have a different view to another interviewee, and significant impact for one may be average impact for another. As a result they are less comparable. Numerical rating scales are typically boxes with numbers from 1 to 10, which the interviewee is asked to select. The advantage of these is that they are more easily used by people of a lower educational level; however, a major disadvantage is that they are an ordinal scale rather than a true interval scale, thus there is no fixed relationship between the scores, i.e. it does not follow that a score of ‘4’ is twice that of a score of ‘2’. Additionally some information can be lost, as many people are able to select more than 10 levels.

Another way of gaining quantitative data is by using Visual Analogue Scales (VAS). A Visual Analogue Scale is a visual way of asking someone to rate a question posed to them. With this type of question only two ends of the scale are provided and the respondent selects the point between the two ends that represent their views (Oakshott et al. 2001). By measuring the mark they make on the VAS quantitative data can be extracted. VAS provide the respondent with a better range to express their opinion compared to Numerical Rating Scales. If the respondent records a doubling of the score then this reflects a doubling of the change. By locating multiple VAS questions on a single page, the interviewee is able to easily compare the answers they have given to each question. An example from the finished questionnaire template follows.

Please quantify the impact on lead times, by marking a line on the following scale:

![Illustration 2.1 - An example of a VAS question used in the finished questionnaire.](image)
These techniques ensured that a mix of qualitative and quantitative data was collected. They also ensured that the questionnaires could be used to interview a range of employees at all levels within a company, from pattern-makers through to managers. The aim of the interview is to tackle people of different managerial positions within the companies, such that the results can be compared and analysed.

In order to assess the commercial and operational impact of implementing advanced design-led technologies within manufacturing SMEs a number of variables were chosen for the focus of study. These were:

- **Time** – i.e. project lead times, which are categorised as the time taken for a project to be completed, within the context of this research.

- **Cost** – i.e. project costs, which are all the commercial factors that have some bearing on the design and development process. There are obvious costs associated with the design and development process such as prototyping and testing; however, additional costs such as labour costs and administration costs will need to be considered.

- **Quality** – i.e. product quality, which are more difficult to quantify. Quality is often measured by customer and company perception; ideally these should be closely aligned.
2.5 Pilot Interviews

There were two trials of the interview and associated questionnaire, which used many ‘open’ questions allowing the respondent to answer with greater freedom. The purpose of these trials was to ensure that the best use of time and interview structure was made when gathering the actual data. One pilot interview was with a former KTP Associate within a plastics manufacturing company. The other interview was with an employee of a manufacturing support agency with experience of small manufacturing companies. Both interviewees had close links with PDR and were considered to fall within the scope of the selection criteria.

There were a number of observations made as a result of these pilots. It was highlighted that companies often have different manufacturing scenarios, e.g. they may have certain projects requiring specialist manufacturing processes or other certain projects that are volume specific. The implementation of design-led technologies has affected these project scenarios in different ways, for example, the manufacture of bespoke one-off products may be affected differently than that of mass produced products, within a manufacturing company. This would therefore result in two different scenarios for evaluation. It was therefore important to identify different project scenarios within a company and study each in turn. An example of the pilot template can be seen in the Appendix ii. Following the discovery of different project scenarios the questionnaire template was re-designed to take account of this.
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A number of additional amendments were also made following the pilot evaluation. It was felt that the questions relating to 'other techniques' such as quality systems was not required, and could confuse the interviewee with regard to the subject in hand (i.e. design-led technologies and their impact). Some additional questions relating to turnover, technology investment costs and other quantifiable data were added. To keep the interviewees thinking less constrained, 'open' questions were first asked. Then more focussed 'yes/no' questions were asked along with VAS questions, to help gain quantifiable data. This 'funnelling' technique allowed the user to be more open-minded to begin with, which often led to harnessing of peripheral data (or data otherwise not mentioned). This technique also served as a validating/triangulating technique to verify the consistency of an interviewee's answers. To complete the final template the last section entitled 'additional questions' was restructured for easier delivery. In total there were seven revisions of the questionnaire that led to the final working template. This can be seen in the Appendices.

2.6 Actual Interviews

Interviews were conducted with the staff having the greatest involvement with design-led technologies within their company. In most cases these people were the senior technical staff or managers. The nature of engineering roles such as these tends to make access to them difficult, however by utilising the strong links with PDR and the KTP companies, it was possible to gain appropriate access to their key staff. In some companies there was the added advantage of being able to gain access to a variety of staff members of various levels. This was particularly useful in companies with a number of manufacturing scenarios.
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The use of one-to-one interviews using a semi-structured approach allowed for a degree of control whilst also letting the respondent elaborate on their own views/thoughts. Each interviewee was contacted by the author explaining the purpose of the research and a date was set for the meeting. The interviews were then carried out with the interviewer asking questions and making written notes using the questionnaire template. Where VAS were used the candidate was asked to mark a line according to their response. Each interview was kept to approximately one hour. At the beginning of each interview it was made clear that the results would be anonymous and not communicated to anyone else within the company. Interviewees were made aware that the anonymous data would form the basis of research papers and this MPhil thesis. It was felt that this would give employees the freedom to answer questions without worrying that their senior managers might read their responses. After each interview the researcher was able to spend time reviewing the notes taken and adding to them whilst the information was still fresh.

2.7 Summary

This section has defined the case-study methodology, demonstrated how KTP programmes suit the case-study approach, and described the structured interview and questionnaire design employed to gather an effective set of data. Once all of the data had been collected from each case study it was then reviewed and documented. Results were grouped using a spreadsheet and relevant tables created to compare results.
3.0 Case Studies

The previous chapter described the selection and justification for the chosen research methodology of this work. The author was directly involved with implementing these new technologies which included CAD, CAM and the creation of an in-house design facility. The supporting case studies were chosen to benchmark this longitudinal company against. As such, they were of a similar traditional manufacturing background and were in the process of implementing similar design-led technologies. This chapter describes each case study with particular regard to the background of the company, its product base and the technologies implemented. The longitudinal case study is described in greater detail. The following table summaries the four selected case studies:

<table>
<thead>
<tr>
<th>Company</th>
<th>Form of case study</th>
<th>Relationship to PDR</th>
<th>Design-led technology</th>
<th>Company size</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Longitudinal - Researched as actant</td>
<td>KTP &amp; commercial activity</td>
<td>Currently implementing</td>
<td>&lt;50</td>
</tr>
<tr>
<td>B</td>
<td>Supporting - Observer</td>
<td>KTP &amp; commercial activity</td>
<td>Currently implementing</td>
<td>&lt;50</td>
</tr>
<tr>
<td>C</td>
<td>Validating - Observer</td>
<td>Non-KTP, but commercial links</td>
<td>Successfully implemented</td>
<td>50-250</td>
</tr>
<tr>
<td>D</td>
<td>Supporting - Observer</td>
<td>KTP</td>
<td>Currently implementing</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

Table 3.1 – Summary of Case Study Companies
3.1 Case Study A

This is the longitudinal case study company. Company A is a traditional manufacturing company with 48 employees. It was established in 1987. This company was originally founded as an aluminium casting foundry by a time-served patternmaker. The business grew quickly and serves a large number of business sectors, including: the automotive, mass transport and architectural castings industries. Due to the declining sales of aluminium castings, the company has diversified into the production of polyurethane mouldings and phenolic mouldings. The impact of design-led technologies was investigated in relation to these manufacturing scenarios. Descriptions of these areas follow along with details of the design-led technologies and their realisation within each of these areas.

3.1.1 Aluminium Castings

The roots of the company are in manufacturing precision aluminium castings. The company founder was a skilled patternmaker and used these skills to start the business, which grew quickly and serves a large number of business sectors. The casting process is a highly manual process, with the only significant automation being used to re-cycle the sand and pour it out of the large hoppers. The nature of the sand casting process lends itself to larger batch runs of simple components or smaller batch runs of more complex components. The most skilful part of the sand-casting process is the manufacture of the patterns to create the sand moulds (assuming that the part to be cast has been designed to suit the sand-casting process). Traditionally this has been a manual process.
This company introduced design-led technologies with the aim of reducing pattern-making times and improving design for manufacture (i.e. by communicating the core manufacturing requirements to clients during their design process).

Batch sizes can vary, but generally aluminium sand casting is ideally suited to small batch sizes due to the labour required to make each product. Mass production would be carried out using permanent aluminium die-cast tooling.

3.1.2 Polyurethane Moulding

Company A observed that orders had been in gradual decline for aluminium castings over the last few years. One of the main observations for this being that competition from overseas casting companies (e.g. China) has greatly increased (partly due to much cheaper labour costs). The Managing Director (MD) therefore took the opportunity to diversify their products when the sale of a PU moulding factory arose. This facility was bought and taken in house to introduce the company to plastics moulding technology. The additional skills of the patternmakers that were transferred across to company A from the original Polyurethane (PU) company improved in-house capacity.

Company A generally retained the existing customers from before the take-over, and did not put a large amount of effort into marketing the resource. This meant that the work tended to come in intermittently. The implementation of design-led technology promised increased customer communication through the use of electronic CAD data, in the same format as the customers. The direct effect of this was to achieve an increase in work from design consultants, who use the latest CAD technologies and formats.
About 60% of the processing time of a PU moulding was due to hand finishing which included rubbing down, filling and spray painting. This resulted in a very small profit margin, if any, for the PU business aspect of the company. Also priority for any tooling work was always given to the aluminium components or new phenolic components, creating lags in delivery time for PU components, resulting in unsatisfied customers. The PU mouldings offered small batch runs of products ideal for prototype plastic products.

3.1.3 Phenolic Mouldings

The toolmaking facilities and expertise gained by company A as a result of the acquisition of the PU moulding department helped pave the way for the next business development. The senior managers, having worked with the rail industry for many years, believed that there was an opportunity to manufacture phenolics to a higher standard than that available from existing manufacturers. A consultant was contracted to investigate this market, and the conclusion made that it was a viable area to pursue. Subsequently, with the help of grant funding, a phenolics factory was built. This new phenolics factory was specifically designed to automate the traditional manual moulding process by using new closed moulding technologies along with state of the art CNC profiling techniques. This had the potential to greatly enhance the product quality and consistency.

In addition to the new factory, investments were also made in purchasing of resin transfer machines and pumps, the installation of a curing oven and a 5-axis CNC trimming machine. The phenolics factory was aimed mainly at the mass transport industry, and in particular one key supplier to this industry. The company engaged with the design-led technologies to enhance their communication, and increase the
services that they offer to original equipment manufactures (OEMs) / larger customers.

3.1.4 Technology Implemented in Case Study A

The following technologies were implemented within this company:

1. Closed mould phenolic tooling
2. 5-axis milling machine
3. Computer Aided Design software (CAD)
4. Computer Aided Manufacture software (CAM)

These technologies are displayed graphically in Figure 3.1. The interfaces highlighted in Figure 3.1 are also representative of some of the technology interactions that will be covered in the supporting and validating case studies.

Technologies 1 and 2 were implemented as part of the new phenolics moulding factory. The reasons for this new venture have been discussed above. Technologies 3 and 4 were a direct result of implementing a new design-led facility as part of its two year KTP programme. There were a number of driving forces for this; the first being a lack of knowledge base within the company to disseminate the manufacturing knowledge out to the clients. The term ‘knowledge base’ refers to the creation of an ‘intelligent’ in-house manufacturing resource, which can interact with the client design process at an early stage to ensure optimum product characteristics, shortened lead times and efficient use of manufacturing processes. By using the skills of a graduate design engineer to carry out a structured two-year programme this core of design knowledge could be created. The creation of this in-house design resource also allowed the company to undertake design work in its own right. This new
facility permitted the company to tender for larger ‘design-and-manufacture’ contracts.
**Figure 3.1 - Customer Interface & Design Resource**

- **Simple**
  - Create manufacturing drawings (machining details etc.)
  - Patternmakers create tooling.
  - Cast Parts

- **Complex**
  - Alter CAD data for RP model
  - Patternmakers create tooling.
  - Cast Parts

- **Aluminium**
  - RP models used as patterns, to increase capacity of patternmakers. Manufacture quick samples.

- **Resin Tooling**
  - Print up as necessary
  - Add any loose pieces
  - Moulded parts

- **Moulded Parts**
  - Create toolpaths for CNC machine using CAM

- **3D CAD Models**
  - 2D CAD Drawings (Customer & In-house)

- **Phenolic**
  - Alter CAD data for RP model (add resin channels etc.)
  - Patternmakers create tooling.
  - Mould parts
  - Cure parts in oven
  - CNC trim parts

- **PU**
  - Patternmakers create tooling.
  - Parts 'printed up' to remove undercuts and parting line created to suit geometry.

- **Reference CAD Data**
  - Create toolpaths for CNC machine using CAM
3.2 Case Study B

This is one of the supporting case study companies. Company B is a traditional patternmaking and toolmaking shop. This company is a specialist supplier of moulding tools and patterns to the automotive industry. The description of these processes follows.

3.2.1 Patternmaking

This company has traditionally manufactured patterns using manual methods. Once created, these patterns are used in a sand casting process to make tools for expanded polystyrene products. Simple programmable CNC machines have also been part of this manufacturing process where required. They are programmed using a programming language called G-code. G-code is essentially a list of commands telling the tool to go to various x, y, z co-ordinates. Within this code feed rates and spindle speed commands are also applied. Complex products require highly skilled CNC programmers and involve a lot of time for calculation of the required toolpath co-ordinates.

3.2.2 Toolmaking

Once again traditional manufacturing techniques were used as in the patternmaking scenario. Tools are either manufactured by directly machining them from metal or by fabricating them out of wood. Where castings are made from patterns then these are brought back in-house and finished off ready for the expanded polystyrene manufacturing machines.
3.2.3 Technology Implemented in Case Study B

The following technologies were implemented within this company:

1. CAD
2. CAM
3. A new CNC machine

The CAD & CAM technology was initially bought by this company on the advice of one of their customers. The software was installed but used unproductively. Subsequently the software was only used as a viewing package for customer files (3D models and 2D engineering drawings).

The managing director believed that in order to remain competitive and become market leaders they needed to offer their clients an ‘intelligent’ CAD resource. The vehicle for achieving this change was a KTP programme.

During the first few months of the KTP programme, the associate used the existing software and linked it up to the 3-axis milling machines. He found that the software originally purchased by Company B was not powerful enough. Therefore, one of the first major tasks was to evaluate existing CAD/CAM packages and select the most appropriate system for this company. The company opted for a more powerful system that facilitated complex machining with an easier user interface (which would make future staff training easier). The next step was to then purchase another machine to offer additional capacity and reduce lead times further. The newer machine also enabled more complex products to be manufactured. The above three technologies were successfully implemented during this structured two-year programme.
3.3 Case Study C

This company is the validating case study. Company C is a thermoplastic moulding company for the automotive industry. They specialise in precision mouldings and metal overmoulding (i.e. forming plastic parts with embedded metal components). These manufacturing processes particularly lend themselves to their core business of automotive assemblies and sub-assemblies. They also supply individual parts and sub-assemblies for domestic appliances, electrical products and the communications industry.

The company has 120 employees and is part of a global group. For the purposes of this research, it acts as a validating case study as it is representative of a non-KTP small company. The use of a non-KTP company has been discussed in the previous chapter. Within this case study the impact of design-led technologies was investigated upon the following manufacturing scenarios present within the company.

3.3.1 High Variety Mass Customisation

Company C manufactures products for the automotive industry. This industry is extremely competitive and as such component manufacturers have their costs ‘squeezed’ continuously. One way that this company has managed to keep costs down is by creating products which can be customised easily in order to provide components which can be used across a range of vehicles. This has kept tooling costs down and increased competitiveness.
3.3.2 High Volume Mass Production

The other main manufacturing within this company is that of high volume mass production. This describes the more traditional manufacturing scenario where projects are condensed as much as possible due to very competitive market constraints. This is typical of the automotive industry. The company must operate at the limits of time and cost in order to remain within this type of market. In order to be successful in high volume and mass production, companies must have carefully controlled processes, and measures to ensure consistent quality.

3.3.3 Technology Implemented in Case Study C

The following technologies were implemented within this company:

1. CAD/CAM.
2. Statistical Process Control (SPC). This was used primarily to aid the production of injection moulded components.
3. Rapid Prototyping. SLA models were employed for validation of parts. The technology used was sub-contracted out, using a local trusted supplier.

The owner’s philosophy and understanding of the market (i.e., customers driving suppliers along this route) were the key drivers to implementing the above technologies.

The CAD systems were used for design and development work along with CAM programming and machining. Company C has been using CAD systems since they first became available in order to increase productivity and retain their strong market position. The other major advantage of CAD has been the ability to communicate data to the other European plants, which make up the global group.
The Statistical Process Control technology allows the company to monitor performance and collate key process parameters, analyse them and then use the results to run the machines more efficiently.

The Rapid Prototyping technology was explored using the design and development research facilities offered by PDR. This enabled the company to use state-of-the-art rapid prototyping processes to validate their products before fully committing themselves to permanent tooling. The ability of this company to develop close working relationships with the local research centre meant that they could utilise external equipment and expertise without purchasing highly expensive rapid prototyping machines themselves.
3.4 Case Study D

This is the other supporting case study company. Company D manufacture and distribute safety, medical, survival and camping equipment to governmental and non-governmental groups and individuals all over the world. A high percentage of its products are exported. It has 49 employees and has been established for just over twenty years. The managing director realised that in order to expand the business they could use their own in depth knowledge of the market to design and manufacture their own products.

As in case studies A and B, they chose to utilise a KTP programme to bring a graduate product designer into the company, with the support of a local university. The primary goal of this programme was new product development, from concept through to production. The secondary goal of this programme was product improvement; including, re-design, aesthetics and design for assembly. The graduate designer established a design department capable of taking a product from initial concept through to production. As part of this process the graduate developed structured product development procedures for the company. The KTP programme focused on a single design-led technology for the company, and this is described below.
3.4.1 Technology Implemented in Case Study D

1. CAD modelling software

The CAD software was an integral part of the new product development process implemented by the Associate. The Associate created an interactive CD programme that enabled staff to learn about the importance of a robust design process (which was often an oversight within this company). CAD was primarily introduced to enable products to be designed, developed and interrogated in a virtual environment before investing in tooling. The management perception was that the introduction of CAD would enable more products to be designed, however they chose to ignore the importance of using a structured product development process in order to achieve this. The marketing department saw CAD along with the Associate’s desktop publishing skills, as a way of marketing new products and of producing graphic designs, instead of using the CAD software as a tool to develop the technical aspects of products.

CAD was however used as a vital communication tool when obtaining quotes for tooling and rapid prototyping. The university partner’s rapid prototyping facilities were utilised to produce full-scale models that could be used to present product concepts to clients.
3.5 Summary

This chapter has presented four case studies: one longitudinal, two supporting and one validating case study. The longitudinal case study is described in the greatest detail due to the novel position of the author being a participant-actant within the company. Figure 3.1 displays the relationships between this company’s manufacturing processes and the implemented design-led technologies. For example, the introduction of CAD allowed the company to view client data and use it to manufacture products in a choice of aluminium, polyurethane or phenolics. The detailed interaction of the technology with the manufacturing process is shown by use of a flow chart working from left to right.

Elements of this flow chart can be seen for the CADCAM technology introduced in case studies B and C. Case study B used CAD software to alter client data and create models of tools; these CAD models were then imported into the CAM software and toolpaths created. These toolpaths were then simulated and refined in the virtual CAM simulation environment before being sent to the CNC machine, to cut tools directly from aluminium billet. Case study C used 3D CAD models to manufacture rapid prototypes for use as functional prototypes. In this case, the rapid prototypes enabled full product testing before having to commit to expensive production tooling. Case study D focussed on 3D CAD implementation, and this was not linked with manufacturing technology. The supporting and validating case studies have focussed upon the adopted technologies, along with the company background and manufactured products. The next chapter presents the results of this research and begins to explore the impact of introducing advanced design-led technologies into these manufacturing-based companies.
4.0 Results

In order to assess the commercial and operational impact of implementing advanced design-led technologies within manufacturing SMEs a number of factors were chosen to concentrate upon. These factors were time, cost and quality.

A semi-structured interviewing approach was chosen to gather the results. These results are a mixture of qualitative and quantitative data. The beginning of this chapter will report the key details and quotes from each interview (this is mainly qualitative). The quantitative data is then tabulated and observations begin to be drawn from the information within this section.

4.1 Summary of Interviews with Company A

4.1.1 Technical Manager (TMC)

The Technical Manager (castings) is responsible for liaising directly with customers in the first instance and then following the technical details through from signing-off some of the manufacturing drawings to first article inspections. The nature of this role has meant that he has seen the industry develop along with customer requirements, ‘Five years ago [company A] solely worked from 2D drawings. Their main source of work was from design consultancies, they moved to 3D, which required us to move to 3D’. It is clear in this case that the customers were a large driver for this company to move away from 2D paper drawings to electronic drawings and models. This manager felt that the new technology was fundamental to keeping their existing business and to hopefully increasing their market share. A number of time savings were reported. Firstly the interviewee saved time by reducing site-meetings to discuss products. The new technology made it possible to discuss a
client’s model in ‘real-time’ whilst making a conference call. This time saving was
directly reflected in the reduction of product lead times. In addition, the interviewee
commented that using rapid prototype models for tooling made further reductions in
project times. When asked about any “unexpected outcomes” that the design-led
technologies brought with them, his response was ‘it makes other projects
manufacturable in our process that weren’t achievable previously, e.g. [components
with] constant wall thicknesses are achievable along with complex curvature’. The
complex geometry of some parts was far quicker to replicate using RP models than
traditional pattern-making techniques. However, one disadvantage was the increased
cost of purchasing sub-contracted RP parts. Conversely the saving of the labour costs
were reported to ‘be up to 40 per cent on some jobs’.

When questioned on quality, TMC said that the resin used in the rapid prototype
models gives a better surface finish. The resin is very stable, more uniform and
harder wearing than the traditional pattern-making materials used by the company
such as hardwoods. In discussing the effect upon the company’s markets, TMC said,
‘yes market shares have increased. Lots of competitors have scaled down whereas we
have expanded our workforce’.

Company A has ‘increased their niche in the market place as we can offer a service
that can assist the customer’. In TMC’s opinion, the Managing Director saw the
future of the technology as essential and proposed that metal flow technology should
be investigated in the future. This would be used to aid analysis of metal flow into
and out of the moulds to increase the quality of castings.
4.1.2 Operations Manager, Mouldings (OMM)

The Operations Manager (mouldings) within company A felt that the design-led technologies were implemented to keep the company ahead of its competitors, increase product quality, and improve accuracy and repeatability of the product. His primary role was the implementation of the new phenolics plant. He was also responsible for the PU moulding side of the business. In consequence, his comments mainly reflect these aspects of the business. Along with TMCs comments – the operations manager found that the speed of toolmaking was dependant upon the speed of the operator. His feedback also cited cost advantages of using SLAs for tooling. OMM gave a higher figure for the amount of work that is sub-contracted. This is indicative of the costs associated with buying large rapid prototype (RP) patterns for the phenolic and PU mouldings – along with the metal brackets that they require.

OMM also found considerable time savings in the reduction of site visits and meetings from initial quotation right through to manufacturing products. He explained how the new design resource had ‘improved the customer interface’. When asked about project lead times, OMM said ‘if things had been done another way it would have taken a lot longer’. OMM saw the new design-led facility (and associated technologies) as ‘advantageous to the company’. The new phenolics products produced by company A were reported as ‘consistent, highly repeatable and accurate’ because of the implemented CADCAM design-led technologies. The interviewee even went so far as to say that this technology introduction was ‘a significant achievement over competitors’, and that ‘there would be no phenolics business without the implemented technology’.
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The Operations Manager (mouldings) observed that one unexpected outcome of the CAD technology was the ability to use integral CAM software for accurate part machining. With regard to the impact that the technology has had upon the company markets, OMM suggested that it had enabled the company to make in-roads into large rail original equipment manufacturers.

4.1.3 Senior Patternmaker (SP)

The senior patternmaker was also interviewed. It was felt that his perspective on the new design-led technology would provide a useful comparison with that of the management. He is the individual who creates the actual tools that are used to make the company’s products. The senior patternmaker (SP) is responsible for making production tools and patterns from which components are manufactured.

SP felt that the technology was chosen to keep pace with competitors and reduce time to market of products. Historically, the patternmakers measured any ‘missing’ product dimensions from scaled drawings supplied by the customers. If further information was required then customers were telephoned/faxed which was time consuming. SP reported that there were often times when work had to stop on a project and await confirmation of design intent from the clients. After the implementation of the new design resource, SP described the CAD as a ‘fantastic system with regard to querying drawings for shapes, sizes and features such as draft angles and undercuts’. SP also said how it was very useful to print out hard copies of 1:1 templates (or ‘footprints’) which saved the patternmakers a large amount of time in marking up drawings or re-creating them. The senior patternmaker felt that the current design-led technologies were more than adequate, however he recommended the introduction of basic patternmaking CNC machines that could be used to make
repetitive parts that require multiple copies, e.g. runners/risers/flow channels, or simple parts with straightforward geometry.

The introduction of RP models used for tooling combined with quick-cast resin allows the patternmakers to make multiple patterns from one mould. This highlights how tooling costs are reduced along with project lead times. Increased communication between patternmakers, designers and project engineers, were described as an effective way to communicate appropriate ‘design for manufacture’ to the customers, i.e. a better designed product by the customer for the intended manufacturing process.

SP concluded that the introduction of design-led technologies had saved money and reduced lead times in certain instances (i.e. communication / use of RPs for complex components / clarifications of dimensions and design intent). However, SP identified there were issues with over-allocation of work due to poor project scheduling by the managers. SP stated that this was mainly due to managers ordering a large number of RP models assuming, wrongly, that they did not need a lot of work done on them to create tooling. Unfortunately SP reported that they forgot the additional work required to ‘print-up’ the patterns, remove undercuts and fill any holes etc. Printing-up a model refers to the process of adding material to patterns in such a way that when the tooling is created using glass fibre, the undercuts are removed and the product can be moulded. Managers not wanting to turn away business due to the harsh economic climate – however failed to realise that repeat business was unlikely if delivery deadlines were missed etc.
4.2 Summary of Interview with Company B

4.2.1 Knowledge Transfer Partnership Associate 1 (AB)

The KTP Associate championed the introduction of design-led technologies within company B. He was responsible for selecting and commissioning appropriate CADCAM software along with any appropriate machining centres. The KTP Associate will be referred to as AB.

AB reported that the technologies were introduced to keep pace with competitors and improve profit margins. The software selected was mainly biased toward the potential support that the university would offer.

The amount of work sub-contracted by company B was described as being greatly reduced due to the ability of the new technology (and skills) to manufacture patterns in-house and manipulate CAD data. AB described the technology as having moved on from traditional CNC patternmaking/toolmaking techniques from hard copy drawings, to the use of a simple CAD viewer package, right through to the current integrated CADCAM system.

AB highlighted the additional purchase of a new 3-axis CNC milling machine as very beneficial with regard to achieving more complex tool geometry.

It was reported that project lead times reduced as a result of the implemented advanced design-led technologies. Reasons given for this included: removal of sub-contractors (i.e. LOMs no longer required for patterns), lower tool production time
(complex toolpaths calculated using computers) and the fact that tools were taken off the machines requiring no additional finishing.

The major cost reductions achieved were highlighted by AB as the removal of subcontractors (CAD manipulation in-house and the direct cutting of patterns and tools in house requiring no LOMs or cast tools).

The use of optimised CAM generated toolpaths, produced more accurate tools with better surface finish and therefore higher quality mouldings. This, in turn with the ability to machine more complex geometries, appealed to new customers and increased company B’s market share for specialist i.e. complex tooling.

In conclusion, AB reported that the CADCAM technology had a major impact upon product lead times, costs and quality. As such, customers were reported as being ‘very happy, [the] tools have succeeded their expectations and cost. Good value for money’. However, AB also added to this that the work was being undercharged for due to the management failing to ‘realise the extra added-value within the new product by the customer’. AB suggested that a higher mark up should be included to reflect the improved products.

Additionally, AB found that ‘the technology was over-allocated. Sometimes wrong jobs were allocated to the new technology (which could be better spent doing something else)’. This was a reflection of poor project scheduling by senior managers. AB explained that the ‘fire fighting’ approach adopted by management often resulted in the machines being prioritised for simple, low profit-making jobs, when they could have been used for more complex, high-profit making jobs.
4.3 Summary of Interview with Company C

4.3.1 Project Manager (PM)

A project engineering manager (PM) was interviewed from the validating case study. PM described the design-based technologies within company C as quite pro-active. They were quick to implement 3D CADCAM in its early days. The company used statistical process control (SPC) to enable efficient use of its moulding machines. These technologies were reported to be driven by the market, i.e. this company manufactures products for the automotive market, which has high technical requirements. PM described one of the most recent examples of technology as work carried out with prototype tooling and ‘over-moulding’ of metal. This utilised the latest in advanced design-led technologies.

PM highlighted the company preference to keep the use of sub-contractors to a minimum for standard manufacturing work (this is due to the high accuracy required by its automotive customers). However, to further explore tooling and over-moulding they implemented advanced prototyping technologies from a local university (PDR, UWIC). This enabled them to utilise the latest in advanced design-led technologies.

According to PM the technology ‘will continue according to the requirements of the market…clients seek shorter lead times and higher levels of variety, this will be the main driver of the adoption of new technology’. It was highlighted that the industry within which company C operates (i.e. large automotive Tier 1 manufacturers), expect design-led technologies as standard practise, due to their high quality requirements.
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‘For traditional projects the cost benefits of getting it right first time, have made the enormous impact on projects’, was reported by PM. ‘For example, 35% of tooling costs are due to commissioning the tool, getting it up and running, and tweaking etc. With the RP tooling and prototyping route, half of this percentage is saved’.

A major impact upon quality was also recorded by PM. The ability to get it right first time - as mentioned above - was one of the contributory factors for this, along with the use of data gathering tools such as statistical process control. The combination of these approaches helped to reduce failure rates of parts produced and therefore removed waste from the manufacturing process.

PM summarised that the new design-led technologies had ‘improved sustainability of the company by being able to access higher end niche markets, enabling the company to maintain profitability and sustain its position’. The implementation of design-led technologies reinforced the company’s continued drive for improvement, which also helped them to remain competitive.
4.4 Summary of Interviews with Company D

4.4.1 Knowledge Transfer Partnership Associate 2 (AD)

The KTP Associate was employed to introduce design-led technologies as part of an in-house design facility within company D. He was responsible for selecting a suitable CAD system that would be used to increase the company’s product range by developing their own survival products.

AD described the traditional approach to design within company D: ‘Historically, design was undertaken within the company on an ad-hoc basis with no formal procedures or dedicated department. The role of product development was undertaken often by the managing director or sales people, none of whom had experience or qualifications in product/industrial design’. Hence the need for the introduction of a structured design department was recognised and a KTP programme was used as a vehicle to achieve this. AD estimated the amount of products manufactured by other suppliers for company D as 90%. The company has traditionally been a sales and supply company. It was considered too early to estimate the percentage of sub-contracting for new products as many were still in the developmental stages. As such, the in-house technology was described as limited due to the sourcing of products from the Far East. The manufacturing technologies utilised by the company consists mainly of very old equipment.

When asked how the use of new technology within company D is likely to continue, AD suggested that the 3D CAD technologies should be reviewed, further developing the company’s ability to liaise with advanced manufacturing suppliers.
AD explained that due to the embryonic nature of the NPD process within company D it is difficult to estimate the impact that the technology has had upon project completion times, however ‘it has allowed design concepts and prototypes to be evaluated in a much shorter timescale. There was however no benchmark for previous activities’.

The quality was reported to have been improved (subjectively speaking) due to the application of 3D CAD and the ability to spot design flaws earlier in the new product development process. On the commercial impact of the design-led technologies, the advantage of being able to produce concepts for market evaluation and presentation to clients greatly helped the company’s image with regard to response rates.

AD highlighted that with the introduction of his skills and the new design resource, he was ‘swamped with new ideas and old ones… this meant that the resources were overstretched at times, but this could [have been] due to poor planning and lack of company focus’.

Existing staff were said to be interested in the new technology (particularly the marketing department), and were keen to see the results. However they were not interested in learning the technology.
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4.4.2 Knowledge Transfer Partnership Supervisor (KS)

The KTP supervisor is an example of a senior university employee who oversees the knowledge transfer partnership (company D in this case). KTP supervisors are employed to ensure that the host company, graduate and university receive the support and help required to achieve the programme goal. They were in the unique position to have observed the effects of implementing (in this case) the advanced design-led technologies within a company, whilst keeping an unbiased viewpoint. The KTP supervisor for company D will be know as KS.

A new product development department was implemented within company D. A suitable CAD system was also introduced as part of this in-house design facility. Sub-contracting was reported as being part of the development process.

The technology development over the last 5 years was described as ‘having transformed the company from a paper-run company to a software based management system company’.

KS felt that, regarding manufacture, ‘the company was starting from scratch’. It was therefore highlighted that due to this embryonic nature of the company there was little if any impact upon product time, cost and quality.

Commercial benefits were reported as the ‘ability to communicate with potential clients (marketing tools, presentation of concepts etc)...With established client and customers it enhanced their perceived design for manufacture capabilities’.
KS highlighted one unexpected outcome as being ‘the lack of knowledge amongst the successful company management. The MD was not prepared for the effort required to develop a product successfully. A short-term view was apparent instead of a strategic long-term view’.

In conclusion, KS described a situation where the potential to exploit a new market with new product development was not fully utilised by harnessing the full benefits of the implemented advanced design-led technologies.

4.5 Quantitative Results

The main operational areas chosen to concentrate on were lead times, project costs and product quality. Lead times and project costs are an effective metric, as they are quantifiable. The use of these as indicators has been discussed in previous literature by Droge et al. (2000) and Sanchez et al. (2003). Product quality is less tangible because it covers a number of customer and company perceptions, but is an important area of consideration. Customer perception of product quality ranges from branding and aesthetic issues to durability and extended functionality; whereas company perception is the control of dimensions/tolerances, reduced rework and lower failure rates. Having described the qualitative data recorded from the interviews, a summary of the quantitative data gathered follows in Table 4.1. The manufacturing scenarios that each interviewee discussed and the ensuing data have been segregated for clarity. A graphical representation of the average impact factors, across all scenarios, for time, cost and quality is shown in Figure 4.1.
Table 4.1 Manufacturing scenarios and associated impact of design-led technologies upon lead times, project costs & product quality

<table>
<thead>
<tr>
<th>Company</th>
<th>Manufacturing Scenario</th>
<th>Quantified Impact</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lead Times</td>
</tr>
<tr>
<td>A</td>
<td>A1-Phenolics moulding process</td>
<td>(Y), 0.75</td>
</tr>
<tr>
<td></td>
<td>A2-Polyurethane RIM casting</td>
<td>(Y), 0.59</td>
</tr>
<tr>
<td></td>
<td>A3-Casting, low to medium volume, simple jobs</td>
<td>(Y), 0.20</td>
</tr>
<tr>
<td></td>
<td>A4-Casting, low to medium volume, complex jobs</td>
<td>(Y), 0.48</td>
</tr>
<tr>
<td></td>
<td>A5-General patternmaking</td>
<td>(Y), 0.44</td>
</tr>
<tr>
<td></td>
<td>Averages for company A</td>
<td>0.49</td>
</tr>
<tr>
<td>B</td>
<td>B1-Toolmaking</td>
<td>(Y), 0.78</td>
</tr>
<tr>
<td></td>
<td>B2-Patterns</td>
<td>(Y), 0.74</td>
</tr>
<tr>
<td></td>
<td>Averages for company B</td>
<td>0.76</td>
</tr>
<tr>
<td>C</td>
<td>C1-high variety mass customisation</td>
<td>(Y), 0.75</td>
</tr>
<tr>
<td></td>
<td>C2-high volume &amp; mass production</td>
<td>(Y), 0.28</td>
</tr>
<tr>
<td></td>
<td>Averages for company C</td>
<td>0.52</td>
</tr>
<tr>
<td>D</td>
<td>D1-New designs</td>
<td>too early*</td>
</tr>
<tr>
<td></td>
<td>Combined averages</td>
<td>0.56</td>
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<tr>
<td></td>
<td>Standard Deviation</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Notes:

( ) Is the Yes/No answer to the question 'have design-led technologies reduced times or reduced costs or improved quality?' The figures which follow are the scores from the VAS.

* it was too early to obtain a value for this company scenario due to a lack of completed new product development projects – reasons for this are discussed later.
Figure 4.1 Average VAS impact factors of lead-time, project cost & product quality
It is useful to highlight some of the results from Table 4.1 before analysing them as a whole. Looking at this table the key results are that 28 out of 30 possible answers show that design-led technologies have had a positive impact upon time, cost and quality. There were only two exceptions to this where the results were too early to report. These are discussed later. The highest score was given for product quality in scenario A1. This reflected the high quality and accuracy achieved using the new moulding, trimming and CADCAM technologies.

Figure 4.1 displays the average VAS impact factors of lead times, project costs and product quality. The height of each bar represents the average score for each measured metric. The error bar shows the lowest and highest recorded score for each metric and the length is an indicator of the range. When asking the interviewee whether the technology had reduced project lead times, project costs or increased product quality they were able to rate the impact from no impact (zero) to the best possible (a score of one). Figure 4.1 shows that the calculated average impact for time, cost and quality is over 0.5 in each case, clearly showing the benefits of introducing design-led technologies. Additionally, benefits in terms of lead times and project costs appear to be similar. There does not appear to be a great deal of difference between the two - in terms of scores and variability or span of scores - this indicates closer agreement of the data between manufacturing scenarios. Across the manufacturing scenarios, the mean VAS scores for the positive impact on lead times, project costs and product quality were 0.56, 0.51 and 0.77 respectively. It is interesting to note that the mean VAS score for the increase in product quality is greater than the mean scores for reduction in lead times and project costs. Product quality can be difficult to assess in comparison to time and cost as there is not a
defined metric to provide a measurement of product quality. The scores for product quality had a lower standard deviation of 0.12. This shows decreased variability than the corresponding scores for lead times and project costs, which are almost twice this with a value of 0.22 each. The following sections analyse the results as a whole with respect to each of the operational areas of time, cost and quality.

4.6 Lead Times

In case studies A, B and C, there was unanimous agreement by respondents that lead times have been reduced with the introduction of the new technologies. Within Company A, four different scenarios were investigated. Scenario A1 shows a particularly high score in comparison to the others. The reason for this is that this scenario concerns the company's new phenolics moulding plant, which needed to produce its first products in a very short time, in order to win business. The production manager said, 'There would be no [phenolic] business without the new technologies'. He was referring to the fact that all the implemented technologies, i.e. phenolic moulding, CAD and CAM were integral to producing the finished article. Scenarios A2 to A5 all showed decreases in lead times, although less dramatic than for case A1. The reasons for these reductions, even though they refer to different processes, were primarily due to the use of rapid prototype models in making the tooling. The ability to interrogate 3D model files and make them suitable for RP models, which can then be used for tooling, greatly reduced product lead times. Scenario A3 also showed reductions for similar reasons, however as the products are simple ones, the impact was less as they could be made by more traditional pattern making techniques. In scenario A5 it was reported that the interaction between the patternmakers and the clients/designers technical specifications was greatly enhanced
with the introduction of CAD and an in-house design resource. The main reason for this was that the patternmakers could ask the company’s design engineer to interrogate CAD files in real time with them, in order to get the exact dimensions or data required. If this was not possible, then the design engineer could spend time pursuing the information whilst the patternmakers could focus on making tooling. A natural part of this process was the ability for the patternmakers to pass on inherent process information to the clients, enabling them to design products for the company’s manufacturing processes from the onset. In addition, the patternmakers worked closely with the in-house design department. This allowed rapid prototype models to be modified taking into consideration the requirements of the patternmaking process. For example any through-holes would be removed from the model and replaced with ‘dimples’ (i.e. centre marks), to mark the position of the holes for drilling after casting.

The capacity of design-led technologies to reduce lead times in both scenarios of case study B was very high. The ability to work with 3D data and a CAD modelling system was beneficial to both project situations. By having the ability to view client parts using CAD, these parts could be interrogated and converted into 3D tool models, prior to cutting metal. Production times could then be simulated using the CADCAM modelling software. The ability to use CAM technology to process complex paths for the machine tools to follow (i.e. toolpaths) made the greatest impact on project lead times. Previously toolpaths would have been programmed manually, and complex machining could have taken days. Some of the companies’ new projects would have been far too complex to programme manually.
In case study C, for the high volume and mass production scenario (C2), the relatively low impact on lead times is typical of this scenario, due to the fact that the projects have already been compressed as much as possible. These projects are within a very competitive market, in which a company has to be operating at the limits of cost and time in order to enter it. However in C1, lead times were greatly reduced due to the ability to use rapid prototyping, in order to run tools quicker, and create first-off samples much faster for testing. In case study D, the projects were still in the development phase, no new products had reached manufacturing, and therefore no assessment of lead times could be made.

4.7 Project Costs

All companies had reported that the implementation of advanced engineering design-led technologies reduced project costs.

Looking at case study A, it is seen that Scenario A1 witnessed the largest overall reduction in project costs. This was partly due to the reduction in labour during the moulding process and regulation of material used. CAD had been used to create patterns for tooling purposes, but this had not had a great impact on cost. Scenario A2 showed that a score of 0.42 had been reported for reducing costs (see Table 4.1). The main contributory factor for this is the ability to communicate the design-for-manufacture process to the customer by viewing and adapting their concept CAD model files. Expenditure on travelling time and labour time is greatly reduced with the ability to hold conference telephone calls whilst viewing CAD models and making design decisions. Additionally, management would carry out customer visits, and were unable to drive the CAD software used by the clients, and therefore the
information given to them would have to be re-iterated to the in-house designer on returning so that any relevant changes could be made. Scenarios A3 and A4 both showed a reduction in project costs, but not as significant. In the case of casting complex jobs, cost reductions were nearly twice as much as simple jobs. Again, this was due to the ability of being able to use in-house CAD facilities to generate files for rapid prototyping of patterns. By using RP models as patterns, more complex jobs such as those with complex curvature, or non-uniform walls, were much quicker to produce than when made manually. This in turn reduced costs. The senior patternmaker highlighted a far greater impact on the reduction of project costs. In comparison the Project Manager would have been assessing the cost of labour time and raw material costs whereas the Technical Manager (castings) was additionally responsible for administrative project costs. This would suggest that the impact was far greater at the actual ‘material cutting’ end of the process, but not as extreme when considering the whole manufacturing administration costs.

Case study B showed one of the largest perceived reductions in project costs. The introduction of CAM software had enabled toolpaths to be created more quickly than could manually be programmed. Also, the ability to simulate programmes before running them gave the engineer the confidence to run machines overnight, thus maximising machine running time and further reducing cost. This applied to both project scenarios. It is interesting to note that the cost reductions in situation B2 refers to pattern making, as reported in Scenarios A3 and A4 for case study A. In A3 and A4 the quality and speed of rapid prototyping patterns was shown to be less labour intensive and more cost effective than using manual methods. The inverse situation arose in scenario B2; the CADCAM systems implemented enabled the company to
reduce its reliance upon externally produced LOMs which were used as patterns to cast tools from. They were then able to cut product geometry directly from billets of aluminium. In this case the removal of two sub-contractors (i.e. LOM and casting companies) was removed from the manufacturing process and associated cost savings made.

Across all case studies and all manufacturing scenarios, the greatest impact on cost saving was made in the case of the high-variety, mass-customisation project in company C. It was the ability to use the CADCAM technologies to produce rapid tooling alongside permanent tooling that made the most significant impact on these projects. For example, permanent high volume tooling costs many thousands of pounds and takes months to make. Therefore, once permanent tooling production has begun, rapid tooling and sample products can be manufactured in a matter of weeks. These can then be tested and checked, and any changes can be made to the permanent tooling at an early, less costly stage. For high volume mass production projects, cost savings were also made as a result of the use of specialist monitoring technologies, which measured key process parameters. The data from this was used for statistical process control, which enabled process optimisation and a further reduction in costs.

For case study D, project costs were shown to have a rating of 0.53, which is marginally above the calculated average value of 0.51. Perhaps a contributing factor for this was the ability to communicate with manufacturers using CAD, and discussions of product designs as early as the concept stage. However, there was a lack of data to draw upon which further supported this due to the very limited number of projects completed by the company; further data would be needed to see if there is
any significance to the rating given. The use of RP models were important for presenting new products to clients, however the costs associated with RP models were described by AD as a surprise to the company; the company felt that the costs were too high and AD described a very cost constrained environment in which he had to work. He suggested that the management did not appreciate the overall benefits that could be achieved with the initial investments. An interview in the future may give more insight into the impact that the new technology has had on project costs.

4.8 Product Quality

The interviewees were asked to consider product quality as a measure of customer perception and company perception, which ideally should be reasonably closely aligned. Examples of a company perception of quality might be the observed rejects and waste in a process; examples of customer perception might be receiving products on time, complete, and to the required product specification and/or drawing.

Eight out of the nine company scenarios reported an increase in product quality as a result of the application of these technologies. It is interesting to note that case study A contains the scenario with the highest perceived increase in product quality, as well as a scenario whereby it was too early to rate the quality (A1 and A2 respectively). In the first scenario for example, the product was being manufactured using a bespoke tooling process and trimmed using 5-axis CAM technology, which enabled difficult toolpaths to be created quickly and accurately. This method gave the customer products which were more accurate and repeatable than competitors could achieve. The first product that was manufactured in scenario A1 using the new design-led technologies was a large electrical housing unit for use within a train cabin. The
respondent used this example as an illustration of how he arrived at his VAS score for quality. Within the large phenolic moulding a number of brackets were bonded or mechanically fastened. Monitors and additional electrical components were then bonded or fastened to this bracketry. During the first article inspection (i.e. assembly and fit in-situ) of the product, the Operations Manager (mouldings) reported how the clients could not believe the accuracy and alignment of the product with cabin fixings. The phenolics products that they received from other phenolics suppliers were typically inaccurate and out of alignment. The fact that they had never received a phenolic moulding that fitted first time before meant that the customer was so pleased they took the company managers out for a champagne lunch.

The impact of the design-led technologies on quality within scenario A2 (polyurethane mouldings) was observed to be far less than for A1 (phenolics mouldings). The Operations Manager (mouldings) said that he could not answer yes or no when asked ‘had the technology implemented increased product quality?’ Thus he could not provide a VAS rating accordingly. There are a number of possible reasons for this: originally the polyurethane business was bought to gain knowledge of plastic moulding technology, with a strategic view of developing the company knowledge of plastic moulding. With this in mind it was highlighted that little time and money was re-invested in developing the quality of polyurethane mouldings. As a result of the lack of investment, the products required a large amount of finishing by hand, thus the quality can vary. The emphasis of the design-led technologies was focussed upon new company ventures (i.e. the new phenolics business and main casting business). For the above reasons, the quality of the polyurethane mouldings were influenced less. However, the Technical Manager (castings) described how one
particular new product was developed with a design consultancy which resulted in the company's most complex polyurethane moulding. He explained how this would not have been achieved without the customer-focussed approach adopted with the new CAD systems and RP patterns. This suggests that quality was influenced; a reason for the Operations Manager's (mouldings) negative comments may be related to his bias towards the phenolics business, which was his main responsibility, and he was seconded to manage the polyurethane business reluctantly.

For scenarios A3 and A4, considerably higher ratings for product quality were given than for lead times and project costs. The reasons for this were given by the Technical Manager (castings), as the use of 'modern methods which provide far superior patterns'. The company use resin models which are more accurate than traditional wood materials, and have no wood grain, and produce a better finish. The Senior Patternmaker supported this and suggested that an additional reason was due to the increased communication with the in-house designer and clients. That is, products were being designed to better suit the company processes, and therefore higher quality products could be cast/moulded.

Case study B reported high scores for the effect that technology has had on its production quality for both its pattern making and tool making projects. One of the major contributing factors for this was the ability to create more complex toolpaths and to vary the range of parameters. Such parameters as cut type and feed rate may not have been easily altered before or were very time consuming, or impossible to do manually.
Both scenarios in case study C have the same high rating of 0.83 for product quality. This is due to the very low failure rate; the number of products which fail are in single figures in terms of parts per million made. A large contributory factor to this is the complex process control systems of the company’s moulding machines as mentioned previously. Case study D reported that the ability to communicate concepts with manufacturers and customers enabled the high increase in product quality. The use of 3D CAD modelling and 2D drafting enabled the designer to get feedback on designs, and if necessary, adjust them according to the most suitable method for manufacture. The ability to use rendered 3D models in conjunction with other graphics packages allowed the designer to produce presentation visuals for customers very quickly.

4.9 Summary

Within this section the quantitative and qualitative results have been brought together from the structured interviews and the ten manufacturing scenarios that have been highlighted. The key result from Table 4.1 is that 28 out of 30 possible answers show that design-led technologies have had a positive impact upon time, cost and quality. The design-led technologies appear to have influenced product quality more than lead times and project costs. Additionally the results for product quality across the scenarios display a lower deviation and therefore show greater agreement than the combined results for lead times and project costs. The next chapter will explore whether the manufacturing scenarios can be refined or regrouped with regard to the overall impact of design-led technologies. In addition, other factors that appear to influence the success of these technologies will be discussed.
Chapter 5.0 - Discussion

5.0 Discussion

This research study evaluates the commercial and operational impact of implementing advanced design-led technologies within manufacturing SMEs. Although a relatively small number of case studies have been observed, the importance that design-led technologies have played in the process of taking new products from concept through to manufacture has been observed within these companies. A case study approach was selected to gather data in four manufacturing SMEs, and a methodology for this presented. Results have been taken across the observed manufacturing scenarios within these companies and are presented in chapter 4. The key result from Table 4.1 is that 28 out of the 30 cases (of which some respondents covered several) commented that design-led technologies have had a positive impact upon lead time, project cost and product quality. Furthermore, product quality displayed the greatest impact as a result of the implementation of the advanced design-led technologies, and displayed less variability than the results for lead times and project costs. A limited range of technical and manufacturing scenarios of companies have been investigated during this research; however, it is clear that this research lays the foundation for a more robust study of the commercial and operational impact of implementing advanced design-led technologies within manufacturing-based SMEs. Chapter 1 has shown that there is limited research within these topics relating to SMEs. This work has contributed to bridging the gap in the research by addressing the interaction between design-led technologies and various manufacturing scenarios within small manufacturing companies. Importantly the management and cultural issues that impact on the technology have also been covered.
This chapter discusses the design-led technologies that have had the greatest impact upon the commercial and operational factors within the case study companies. An important factor to consider is the difficulty in gaining some quantitative results for the commercial factors because the interviewees did not have this information, and often it is not well recorded in SMEs. For example, the time taken to create a CAD model or CAM toolpath is unlikely to be recorded within an SME due to a lack of formal documentation, and the high demands placed on employees, reducing the time they have to capture such data. In this example of measuring project lead times, the research methodology enabled the respondent to quantify the overall impact of design-led technologies by using VAS. This removed the requirement for project specific data. The operational and commercial factors may be so closely bound within SMEs that the following issues will touch on both. The design-led technologies observed to have the greatest impact upon the SMEs are CAD, CAM and Rapid Prototyping.

This chapter will discuss the results in relation to three main areas: (1) the design-led technologies that have had the greatest impact (CAD, CAM and Rapid Prototyping), (2) the manufacturing scenarios that have received the most benefit; and (3) ancillary factors implicit within SMEs.

5.1 Effective Design-Led Technologies

5.1.1 Computer Aided Design

The results from this research support findings that CAD and CAM software speed up design and engineering activities. Robertson et al. (1993) report that one of the main contributory factors for this was the enhanced level of communication reported
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throughout all stages of the product development process. For example, the ability of a designer to discuss the manufacturability of a concept at an early stage saved additional development work at the manufacturing stage. This greatly enhanced communication was clearly observed to be one of the major advantages of implementing CAD as an advanced design-led technology within companies A, B and D. The levels to which CAD was used within each case study varied, however in its most simple function - as a way to communicate and understand design intent of components/parts between manufacturer and customer - it meant that small companies could converse directly in the same electronic manner as their much larger customers (often OEMs). For company A this technical advantage meant that they successfully won work from competitors who were not able to offer the modern design-led technologies that they could offer their OEM customer. Additionally, company A reported that by having conference calls whilst viewing computer models with clients, a large amount of management time was saved avoiding unnecessary site visits and that such time could be focussed more effectively on projects at work.

Company B was able to prepare quotes more quickly by viewing client files on screen, rather than necessitating visits to clients. Within case study D, even though at the embryonic stage of new product development, concepts could be sent to external manufacturers for quotations and comments on design for manufacture. These findings build on the research of Hall (2000), who describes this process as collaborative engineering; he explains how the advances in internet technology has enabled engineering teams to work on one 3D CAD model, replacing the historical methods of travelling for meetings, or using the postal service to communicate ideas.

In addition to this, the KTP Associate (Company A) prepared detailed views, screen shots and other hard copy information for the technical managers, pattern-makers and quality engineers to refer to. The combined effect of the increased levels of
effectiveness of communication meant that decisions were made quickly, which has a positive impact on project lead times. This is illustrated in Figure 3.1 (see ‘reference CAD data’ box). The use of an in-house design resource meant that data was more accessible within the manufacturing process, and less time was spent waiting for clients to confirm details, such as dimensions, over the telephone. Templates could also be printed out and used as footprints (where the base of the product meets the mould joint), saving marking up time and providing a quick reference tool.

Some additional benefits of introducing CAD across the range of manufacturing scenarios were:

- **Client presentation** - The ability to present rendered models of concepts to clients for the tendering of contracts and professional display material.

- **Clash analysis of parts** - Where components fit together, CAD software can calculate where parts may interfere with each other. This prevents mistakes being made early on in the production process, and allows for virtual assembly.

- **Enhanced company profile** - In Company A, the design resource was regularly used as a show-piece for visiting clients, and the technology demonstrated. This service enhanced their perception of what was a traditional casting company. The UK Government continues to push the ‘high-technology’, ‘high-innovation’ requirements of manufacturing SMEs to remain competitive. This research suggests that the implementation of advanced design-led technologies have the additional effect of selling the technical capability of a company. Customers were seen to positively view the implemented design-led technologies within all four case studies. In case study A it led to a large OEM committing orders to them, in case study B clients were realising the additional complexity the technologies
brought to their products, and were impressed by the high quality of product, giving repeat business in a competitive tooling market. Case study C had already established a high profile, and was part of a globally recognised group. The image of case study D, however, was enhanced with the additional presentation of concepts to clients, however the lack of actual products manufactured reduced the impact.

The implementation of CAD affected costs, time and quality in a positive way; however, the author observed a number of projects in which speed of information sharing could create problems in keeping track of concept revisions. Often management wanted the CAD systems and therefore had them installed, but did not want to spend time and resources to update document control systems to complement the software. This meant that errors could occur, e.g. in one case study company a manager gave the clearance to have an RP model built without checking its revision status, subsequently the wrong revision was built and a few thousand pounds squandered. Feltham et al. (2005) describe these 'sub-optimal' decisions as dangerous, and suggest that they are due to a lack of delegation by owner managers. These decisions can act as 'barriers' to the successful implementation of design-led technologies, as was observed particularly in the case of Company D. According to the KTP Associate, the owner manager continually swamped the design capability with new ideas, making it hard to pursue any of them to final production. Further research with a larger data set of companies would be able to build on the initial findings of the four companies within this body of research, and strategies for dealing with these 'barriers' could be outlined.
5.1.2 Computer Aided Manufacture

The positive effect of introducing CAM into three of the manufacturing scenarios was observed as follows:

- Increased complexity of products (i.e. the ability to produce more complex toolpaths and finishing paths).
- Reduction in manual programming.
- ‘Lights out’ machining, i.e. having the confidence to simulate toolpaths during the day and then run them on the machine without an operator overnight.
- Increased accuracy of cuts and parts made within tighter tolerance bands.
- Increased quality of parts – the software had the ability to adjust machining parameters quickly and easily, resulting in a smoother surface finish, for example the way in which a tool enters a workpiece can affect the surface quality, but with CAM this parameter is easily adjusted for optimum performance. Manually, this type of programming would take a long time.

Perhaps the most important of these effects was the speed with which complex toolpaths for CNC machining could be programmed; this was demonstrated within case study A where primary toolpaths were generated in two hours using CAM software. This compares with the two or three days that would have been required for manual programming. In case study B, the CAM software enabled particularly complex 3D toolpaths to be created very rapidly. One such example was for the machining of a hemisphere shaped product, cut from a solid aluminium block. Manual programming of such a complex job would have taken far longer and less factors could have been so closely controlled. However, it was also noted in case studies A and B that training and development time for staff is essential if they are to use the CAM equipment effectively. The conflicting views of senior management in
case study A restricted development of pattern/tool making using the company’s CNC machines. This was mainly due to friction amongst senior managers, i.e. Manager X would restrict use of the machine because Manager Y wanted to carry out development work on it, and so on. This was also combined with the ineptitude of the CNC Technician, who was directly related to the MD, and could consequently be considered beyond reproach (as witnessed by the KTP Associate). In contrast to this, case study B’s associate made sure that a number of staff were trained to use the CAD/CAM software. Slight resistance surfaced from one or two employees who were not computer literate, however with time they became competent users of the CAM software. Although the CAM technology was well utilised within case study B, the KTP Associate reported that management often allocated simple jobs to the new machines that had the capacity for more complex and higher revenue generating work. In addition to the lack of project management, customers were often promised finished parts within an unrealistic timescale. This caused frustration and meant that customers would often be left waiting for their products.
5.1.3 Rapid Prototyping

In each of the reported manufacturing scenarios RP technology was harnessed for a variety of design-led applications. Two different RP processes were used: Stereolithography (SLA) and Laminated Object Manufacture (LOM). SLA models are manufactured from a vat of resin that is cured layer by layer to produce a 3D model. LOM models are manufactured from layers of paper that are cut and bonded together to form a 3D model. SLA models were used by case studies A, C and D, whereas LOM models where used in case study B. The main uses for RP models observed in the case study companies can be described as follows: (1) facsimile models, (2) patterns and (3) functional models.

Facsimile models are physical models created to give the designers, clients and users a real ‘feel’ for a product concept. They allow people to interact with the product and test features such as ergonomics and comfort. Facsimile models were used in case study D for these reasons.

A pattern - in general moulding terms - is an exact replica of the part to be made, which can be used to create tooling from. In the cases of companies A and B, patterns were used to create permanent patterns that sand moulds of the required part or tool were made from. Sand moulds are produced around a pattern which is withdrawn to leave a cavity. Molten metal is poured into the mould and solidifies; the mould is then broken up to retrieve the casting. Company A manufactured components using this process and company B manufactured tools which were then used in the expanded polystyrene moulding process to create products such as car bumper inserts. These tools could then be used for plastics moulding to create the required parts. Case study B had used LOMs for a number of years prior to the
implemented CADCAM technology observed in this piece of research. Having successfully implemented the CADCAM systems along with a new 3-axis machining centre, the enhanced machining ability meant that tools could be cut directly from billets of aluminium, removing the need to buy LOMs and subsequently cast tools from them. This had a major impact upon product lead times, costs and quality.

Additionally, in case study A, the above principle of using RP models to create permanent tooling was used for plastic and phenolic moulding; instead of using sand to create the cavity a permanent glass fibre mould is created around the pattern which is withdrawn and plastic injected into the cavity. The plastic then solidifies, and when the mould is parted the product can be retrieved (the phenolic process is more complex, but the principle remains the same). Within all of the above processes, the part model must be scaled appropriately to take into account the shrinkage requirements of the material upon solidifying.

Rapid prototype modelling services were sub-contracted out in all of the manufacturing scenarios. The main reason for this was intimated to be that RP machines are highly expensive and in order to make the money back on the investment the machines would need to be running continuously. In the case study companies, the requirements for RP models were on a project by project basis, and therefore sub-contracting was more-cost effective.

In case study A there were some disadvantages of using RP models. It was observed that incorrect lead times were promised to customers due to poor project planning and the absence of production meetings, which meant that managers would often over-allocate work to the pattern-making department. Case study A also tried to
divorce itself from responsibility by assuming that RP models created directly from client CAD data required no additional dimensional checks, and would be exactly the same as the initial customer model files. Unfortunately, management failed to understand that RP is just one element in the development process, and critical dimensional checks must still be observed for externally created patterns. One observed problem with using SLA models for tooling was that due to the scale and shape of a product, warping could occur; without critical dimensional checking of the parts upon delivery, the error could be noticed halfway through tooling production, and time lost remedying the situation.

Functional prototyping was used in case study C. The product to be developed was an electronic assembly for use in the automotive sector. The assembly relied on over-moulding metallic and polymeric parts at the final production process. Over-moulding requires complex injection-moulding tooling; therefore this product could not be prototyped to test its functionality as the conventional tooling and manufacturing processes were too expensive and time-consuming. Committing to production tooling without having any test data to 'prove' the design was an unacceptable risk. Therefore, case study C decided to experiment with the stereolithography process in order to combine the two materials within a single assembled unit. Once this had been shown to be an applicable process, a fully functional rapid prototype that allowed the verification and validation of the design prior to making the expensive commitment to permanent tooling was created. The validation process included visualisation tests and extensive functional testing. The metal insert stereolithography process provided company C with an economical route to prototype parts with the desired physical properties in the required volume.
The description of how RP techniques have been used in case studies A to D has been described in this sub-section.

So far this chapter has discussed the results in relation to the design-led technologies that have had the greatest impact upon the case study companies: CAD, CAM and Rapid Prototyping. The following table summarises the advantages and disadvantages of design-led technologies observed through the case study research.

<table>
<thead>
<tr>
<th>Design-led technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| CAD                   | - Speeds up design and engineering practises.  
- Enhanced communication with clients.  
- Enhanced company profile and presentation graphics.  
- Clash analysis and virtual prototyping. | - Concept revisions need to be carefully managed. |
| CAM                   | - Increased complexity of products.  
- Reduction in manual programming.  
- ‘Lights out’ machining.  
- Increased accuracy.  
- Increased quality (tighter control over process parameters). | - Training and development time deprioritised.  
- Failure to exploit full capabilities (tying up machine time with simple, low profit-making jobs). |
| RP                    | - Accurate reproduction of customer models from their raw/supplied data.  
- Use as patterns, reduced lead times and increased surface finish.  
- Accurate reproduction of complex patterns and parts.  
- Creation of fully functional rapid prototypes for design validation.  
- Reduced tooling costs. | - Dimensional checking of RP models often ignored (assumption of accuracy due to high-tech RP process).  
- Poor project planning (not taking into account set-up time for using RP models as patterns). |

Table 5.1 – Summary of the advantages and disadvantages of the design-led technologies displaying the greatest impact upon the case studies.
5.2 Categorising the Manufacturing Scenarios

As part of the methodology pilot interviews were carried out. During these interviews it became apparent that it was important to distinguish between the different manufacturing scenarios within a company.

Having gathered all of the data and extracted the key results from the case studies, it is now possible to review all of the scenarios based on a number of factors. For instance, the VAS scores can be used for guidance and therefore assess which scenarios have benefited most from the design-led technologies, and see if they can be categorised.

Having reviewed Table 4.1 and re-organised this in such a way that the manufacturing scenarios can be categorised with regard to their overall impact, it is shown that three divisions can be identified: major impact, moderate impact and low impact. Table 5.1 is shown on the following page and illustrates the three divisions proposed.
<table>
<thead>
<tr>
<th>Manufacturing Scenario</th>
<th>Representative VAS Result</th>
<th>Comments</th>
<th>Impact category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 - Phenolics moulding process</td>
<td>Product Quality = 1.0</td>
<td>Highest observed impact upon quality. This was a result of the combination of the design-led technologies introduced within company A.</td>
<td></td>
</tr>
<tr>
<td>A2 - Polyurethane RIM casting</td>
<td>Lead times = 0.59</td>
<td>Liaising with design consultants to speed up design for manufacture.</td>
<td></td>
</tr>
<tr>
<td>A4 - Casting, complex jobs</td>
<td>Project Quality = 0.65</td>
<td>Ability to cast complex parts, increase quality of products, increasing the complexity of products to enable high quality castings</td>
<td></td>
</tr>
<tr>
<td>A5 - General patternmaking</td>
<td>Project Costs = 0.68</td>
<td>Reduced labour costs of patternmaker (by using RP models)</td>
<td>MAJOR Impact - Transition from manual techniques to automated low volume production.</td>
</tr>
<tr>
<td>B1 - Toolmaking</td>
<td>Lead Times = 0.78</td>
<td>Cut out RP/LOMs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Product Quality = 0.78</td>
<td>Cut out casting, direct cut into aluminium billet</td>
<td></td>
</tr>
<tr>
<td>B2 - Patterns</td>
<td>Lead times = 0.74</td>
<td>Cut out RP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Machine directly into polystyrene</td>
<td></td>
</tr>
<tr>
<td>C1 - High variety mass customisation</td>
<td>Lead times = 0.75</td>
<td>The use of functional prototyping technologies allowed for validation and approval of designs prior to the procurement of expensive permanent tooling</td>
<td></td>
</tr>
<tr>
<td>A3 - Casting, simple jobs</td>
<td>Project Costs = 0.16</td>
<td>Simple jobs are just as quick for the pattern-makers to manufacture manually, and likely to be less expensive than RP patterns. The manual quality may not be as high as RP; however, if the job is simple, this probably will not be as important.</td>
<td>MODERATE Impact - Simple high volume production which is cost sensitive.</td>
</tr>
<tr>
<td>C2 - High volume &amp; mass production</td>
<td>Project Costs = 0.28</td>
<td>Quality is still very high, however, the impact upon project costs has been affected less due to the tight operating envelope that the Tier 1 automotive suppliers must work within.</td>
<td></td>
</tr>
<tr>
<td>D1 - New designs</td>
<td>Lead times = Too early</td>
<td>No new products altered from concept through to manufacture.</td>
<td>LOW Impact - failure to successfully link the design to manufacture process resulting in no finished products.</td>
</tr>
</tbody>
</table>

Table 5.2 - Categorising the manufacturing scenarios in terms of impact of design-led technologies
5.2.1 Major Impact

A major impact has been observed within the companies that have made the transition from predominantly manual manufacturing to automated low volume production. The phenolics moulding scenario observed in company A is a typical example of this. In fact, the combination of design-led technologies implemented within this scenario displayed the highest impact upon product quality than any of the others. Another example of a scenario in which a major impact was experienced was scenario B1 (toolmaking). The ability to machine patterns and tools in-house removed the need to use sub-contractors, making a considerable impact upon lead times. In addition, the use of the complex CAM software enabled greater control of cutting parameters, such that a far superior quality of finish was achieved; the reduction in additional finishing time was also reduced or removed as a result of this. The scenario observed in company C - high variety mass customisation – demonstrated the importance of using design-led technologies to validate and approve designs before committing to highly expensive tooling; lead times were greatly reduced having removed the work often required to alter tooling during a project. Other examples are given in Table 5.1.

5.2.2 Moderate Impact

The impact of design-led technologies upon scenarios A3 and C2 has been classed as moderate. Moderate describes a situation where the factors of time and cost are constrained such that it is difficult to have a significant impact on these areas. For example, in A3 the use of CAD and RP technologies only gave marginal benefits for product that can be made quickly using the traditional materials and processes. In C2, the impact of the design-led technologies is less because this scenario is already operating within tight operating conditions (i.e. high volume and mass production
within a Tier 1 automotive supplier), and the interviewed Project Manager explained that the use of design-led technologies is unlikely to make a significant difference in these situations.

5.2.3 Low Impact

The final category – low impact – refers to scenarios that have implemented new design-led technologies which have failed to fully link the design and manufacturing processes. D1 was observed to be the only scenario to fit into this category. The results observed during this study have shown that case study D did not make it past the initial CAD stage, illustrated in Figure 3.1. The implemented CAD was only used for front-end design work and there was no clear link established between the design and manufacturing stages of their new product development process. This KTP programme was described by its KTP Supervisor as one of the most unsuccessful schemes run by PDR, primarily because of the poor management of the company and its obsession with saving money.

Table 5.1 shows how 7 out of 10 of the manufacturing scenarios observed have been categorised as having demonstrated a major impact from the implemented design-led technologies.
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5.3 SME Managerial Barriers

This research has shown that the general impact of design-led technologies upon the manufacturing scenarios has been to deliver a major impact in terms of lead times, project costs and product quality; however, when we analyse the individual case study company’s abilities to fully deliver the maximum impact of the new design-led technologies, the findings are less positive and highlight a number of barriers that need to be addressed.

Due to the size of SMEs it is assumed that there are simple, direct communication channels in place, but this is not always the case (Friedman, 2004). This was observed in case study A; work was prioritised for larger customers often leaving smaller customers waiting for the delivery of their products. One example of this was when the CNC technician was on annual leave and management had forgotten that prototype castings had to be machined that week. Subsequently, the KTP Associate was able to use his limited knowledge of the 3-axis CNC machine and do two weeks of ten hour days in order to get the parts out on time. The clear lack of production scheduling and production meetings led to this situation.

As a direct result of the dominant owner/manager in companies A, B and D, product development lead times were often hampered from the outset by unrealistic expectations. In the case of company D, the management had no understanding of the importance of adequate development time, and as such the KTP Associate was expected to simply ‘draw a product – make it – sell it’. When this approach failed, the managing director would quickly switch attention to another new idea. The
interviewee described a situation within which it was difficult to complete projects due to the managerial cost constraints, and as such no projects were fully realised. Technical meetings within company D focussed just on sales and profit-margins, such that product development was absurdly cost-sensitive. The result was that senior management were willing to sacrifice quality in order to reduce costs. The net effect of the twin obsessions of time and cost was to produce situations in companies A, B and D where product design, development and manufacturing proceeded in a highly constrained manner, as observed by Woodcock et al. (2000). Long-term product development was further suppressed within Company A by their willingness to nurture a ‘quick fix’ reputation with their key multinational customer.

Owner-managers often do not have experience or knowledge of implementing design-led technologies successfully; they attempt to cultivate knowledge ‘through osmosis’, rather than through formal training (Formosa and Kroeter, 2002). Their domineering personalities result in them making a disproportionately high number of key design and development decisions. In effect, they act as sole design authority, even though they do not possess the knowledge to make informed judgements on prototyping, tooling and other key product development elements. Rather than taking a longer term strategic and management role, they seek to control all design and manufacturing activities (Lewis and Filson, 2000). Furthermore, such owner/managers often tend to resist delegating responsibility to employees with greater expertise, which can lead to poor decision-making, (Feltham et al. 2005). This situation is exacerbated by the often ineffective management structures observed within case studies A, B and D. In case study A, the Managing Director would often join in with manual operations on the shop floor, instead of taking a step back and using his time to develop the long-term
company strategies and policy deployment (i.e. high level management). In case study B, the KTP Associate described a situation where the Managing Director would spend his management time delivering products to customers, when he should have been carrying out his managerial responsibilities. These examples show how Managing Directors often find it hard to relinquish control and trust their employees to carry out the tasks that they are employed for. This may also be a reflection of managers who have worked up their way to managing their own companies from apprenticeship/shop-floor positions. It is interesting to note that company C is not a family-run company and has expanded to have small operational branches in a number of countries. Due to this increased development they have probably worked through the anguish of the organisational/management change faced by companies A, B and D. This is also reflected in their mature approach to new product development.
5.4 Evaluation of Research Objectives

The methodology chosen for this research split the data gathering into qualitative and quantitative data within different manufacturing areas. The use of VAS within a structured interview approach enabled quantitative data to be successfully generated. In addition to this, VAS also enable the more qualitative data to be ranked and compared which is often hard to achieve in practice. Other PDR-based research has also recently used the VAS technique, for example Walters et al. (2005). This methodology has worked well, and is developing into an approach that is useful for future PDR research. Figure 3.1 has displayed the impact that design-led technologies have had within the longitudinal case study, Company A. The rest of the case studies all fit into this figure, with varying levels of impact. The findings from the KTP and non-KTP company are consistent. In fact the non-KTP company was a key driver in highlighting the impact on different manufacturing scenarios.

Four case studies have been used within this body of research and the effects of implementing design led technologies have been successfully observed with particular detail given to the longitudinal case study. If more resources were available in the future it would be interesting to investigate further case studies, and collect additional data to analyse and gain some statistically significant results. A recommended total number of case studies would between eight and twelve. No significance testing has been carried out with the current data set, as a larger data set is required for this. It would be extremely interesting to further analyse how additional companies fit with Table 5.1 to further validate this categorisation method. More case-study material is needed to assess the ‘moderate impact’ and ‘low impact’ categories.
It would have been beneficial to have captured key data on profits/turnover, but this information was not communicated to the interviewees. The systems for recording and disseminating this type of information to key staff (e.g. meetings, information boards etc.) appears to be inadequate in the SMEs researched. This may or may not be indicative of other manufacturing-based SMEs. Within this body of research the before and after effect of implementing advanced design-led technologies has been measured. However, it is difficult to obtain the figures showing the change in profits/sales/turnover which are due solely to the introduction of design-led technologies.
6.0 Conclusions and Future Work

The use of KTP programmes as a vehicle for data gathering is shown to be a valid methodology for carrying out research within SMEs. A longitudinal case study, where the researcher took a participant-observation role, has provided a wealth and depth of information. The use of two supporting case studies and one validating case study produced results across a range of manufacturing scenarios that complemented the longitudinal case study.

The use of structured interviews, questions and interviewee observations constituted the bulk of the data gathering. Quantitative data was collected by employing a VAS scoring system, and qualitative data from structured interviews. The data gathering techniques were well received by the interviewees and were a very informative method of collecting data.

The implementation of design-led technologies has had a positive impact in 28 out of 30 assessments. These were made up of ten manufacturing scenarios evaluated in terms of lead times, project cost and product quality. Across the various manufacturing scenarios, the mean VAS scores for the positive impact on lead times, project costs and product quality were 0.56, 0.51 and 0.77, respectively. This initial study showed the mean VAS scores for the increase in product quality were greater than the scores for reduction in lead times and project costs. The scores for product quality showed decreased variability than the corresponding scores for lead times and project costs.
Chapter 6.0 - Conclusions and Future Work

The most effective design-led technologies were CAD, CAM and RP. CAD was pivotal within all four case studies and was the vital link between design and manufacturing that enabled products to be fully developed. The CAD data facilitated the downstream technologies CAM and RP.

The preliminary findings indicate that the manufacturing scenarios investigated can be categorised according to the level of impact of the design-led technologies: major impact, moderate impact and low impact. The major impact category is associated with transition from manual techniques to automated low-volume production. The moderate impact category is associated with simple high-volume production that is cost sensitive. The low impact category is associated with a scenario that displayed an inadequate link between the design and manufacturing activities.

This research and its application is not only directed at manufacturing-based SMEs, but can be linked with business support agencies such as Design Wales and MAS Cymru. These support agencies can then ensure that the relevant help and advice that they give addresses the challenges and barriers faced when manufacturing SMEs adopt advanced design-led technologies.

Future work could investigate whether the proposed system of categorisation is valid for additional SMEs falling within the scope of this research work. It is suggested that an additional eight case studies be researched to provide a greater sample of data that could be analysed to give statistically significant data. This would be extended to include companies throughout Europe. Additionally, the use of larger multi-national companies instead of a medium-sized company for the validating case study would provide useful comparisons with SMEs.
7.0 References


Appendices
# Appendix i

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SME</td>
<td>Small and medium-sized enterprises</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>DTI</td>
<td>Department of Trade and Industry (now known as the Department of Productivity, Energy and Industry)</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numeric Control</td>
</tr>
<tr>
<td>3D</td>
<td>Three-dimensional</td>
</tr>
<tr>
<td>2D</td>
<td>Two-dimensional</td>
</tr>
<tr>
<td>FEA</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>CADCAM</td>
<td>Linking of CAD systems with CAM systems for automated manufacturing</td>
</tr>
<tr>
<td>SLA</td>
<td>Stereolithography</td>
</tr>
<tr>
<td>RP</td>
<td>Rapid Prototyping</td>
</tr>
<tr>
<td>LOM</td>
<td>Laminated Object Manufacture</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>KTP</td>
<td>Knowledge Transfer Partnership</td>
</tr>
<tr>
<td>PDR</td>
<td>The National Centre for Product Design &amp; Development Research</td>
</tr>
<tr>
<td>UWIC</td>
<td>The University of Wales Institute, Cardiff</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual Analogue Scale</td>
</tr>
<tr>
<td>MD</td>
<td>Managing Director</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>SPC</td>
<td>Statistical Process Control</td>
</tr>
<tr>
<td>TMC</td>
<td>Technical Manager (company A)</td>
</tr>
<tr>
<td>OMM</td>
<td>Operations manager, mouldings (company A)</td>
</tr>
<tr>
<td>SP</td>
<td>Senior Patternmaker (SP)</td>
</tr>
<tr>
<td>AB</td>
<td>Knowledge Transfer Partnership Associate 1</td>
</tr>
<tr>
<td>PM</td>
<td>Project Manager</td>
</tr>
<tr>
<td>AD</td>
<td>Knowledge Transfer Partnership Associate 2</td>
</tr>
<tr>
<td>KS</td>
<td>Knowledge Transfer Partnership Supervisor</td>
</tr>
<tr>
<td>AMT</td>
<td>Advanced Manufacturing Technologies</td>
</tr>
</tbody>
</table>
Appendix ii

Development of Interview Templates

Data was collected for each manufacturing scenario by conducting a series of semi-structured interviews. Two trial interviews were carried out with key employees in companies who have recently implemented advanced design-led technologies. These exploratory/pilot interviews used a questionnaire template with a large number of 'open' questions allowing the respondent to answer with a great deal of freedom, and remove any element of interviewer bias. The results from these interviews were used to refine the actual research template. It was highlighted that companies often have different manufacturing scenarios, which meant that it was important to alter the template to identify different project scenarios within a company in turn. The pilot and final template designs now follow (blank copies are included to allow the case study companies to remain anonymous).
Introduction: This study is being undertaken to measure and analyse the impact of implementing design-led technologies and techniques within manufacturing SME's.

Objective: To review current technologies/techniques used for design purposes within manufacturing SME's, and highlight any resulting changes in the company's operational and commercial performance.

Scope: This study is aimed mainly at manufacturing companies that design their own products or add value to their customers products by redesigning them for a specific manufacturing process.

Confidentiality: All case study material will be treated as confidential. Case study material will only be published following prior approval from the company. The case study company will, in all cases, remain anonymous.
PDR RESEARCH QUESTIONNAIRE

Work your way through each page of this document, and fill in the answers most appropriate to your company.

Light blue boxes indicate spaces for responses to questions. Where a choice of answers has been given, please type an "x" in the box next to the most appropriate answer.
PDR RESEARCH QUESTIONNAIRE

Can you start by telling me a little bit about your company:

<table>
<thead>
<tr>
<th>Type of business</th>
<th>Pilot company number 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date established</td>
<td></td>
</tr>
<tr>
<td>Number of employees</td>
<td></td>
</tr>
</tbody>
</table>

*Please continue with the next section on "Technology & Techniques"*
Identify your company's *current* in-house design, engineering and manufacturing technology:

Examples might be Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacture (CAM) & Rapid Prototyping (RP). Please give additional information, for example, if you have CAD you may include the software used, the number of seats, any add-on packages etc.

Identify your company's *current* design, engineering and manufacturing techniques:
(e.g. QFD, Failure Modes and Effects Analysis (FMEA), SixSigma, design control,SOP's, qualit)

Are these mature systems? Or perhaps they are still being introduced?
Using the most recent technology or technique from above as the example, please select why it was chosen for use within your company:

<table>
<thead>
<tr>
<th>a need to keep pace with competitors</th>
<th>a requirement to increase process efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>the need to add value to your services/products</td>
<td>a way of reducing time to market of your products</td>
</tr>
<tr>
<td>to increase the ways of communicating product data with customers</td>
<td>to improve profit margin</td>
</tr>
</tbody>
</table>

**Any other comments on this technology choice:**

---

How was it selected? For example, were external consultants used, or perhaps market research indicated the need its introduction?
Do you sub-contract to enable you to use any other key technologies?

Generally speaking, how has the technology within your company evolved over the last five years?

How do you expect the use of new technology within your company to continue?

*Please continue with the next section on "Commercial Impact"*
OPERATIONAL IMPACT
How has the current technology contributed to project completion times:

Appendix ii - Example of Pilot Interview Template.
Has the technology reduced project times?  

Yes  

No

How would you quantify the impact on project completion times:

No impact  

Best possible

(e.g. all projects)

How has the current technology and techniques contributed to project costs:
How would you estimate their impact on project costs (scalar 0 to 10)

worst possible

(negative impact)

(Massive reduction in project costs)

How has the implementation of new technology affected employment?

Please continue with the next section on "Operational Impact"
COMMERCIAL IMPACT
How has the current technology and techniques contributed to product quality:

How would you estimate their impact on product quality (please mark line):

worst

(best
(negative
impact)

(Zero rejects)
What other commercial benefits have the current technology and techniques brought to the company?

If possible, can you please provide the following information:

Annual turnover prior to this technology investment

Annual turnover after this technology investment

Total cost of investment
Has this technology affected the markets that you aim your products at?
Perhaps you now sell to markets that you previously could not.
Has your market share increased?

Thank you for taking the time to complete this questionnaire
PDR RESEARCH QUESTIONNAIRE

ADDITIONAL QUESTIONS

Did the introduction of this technology throw up issues of resourcing within your company?

For example, is the technology over-allocated due to it exceeding initial expectations?

Are staff/were they excited with the introduction of new technology and the chance to increase their skills base?

Has the introduction of this technology revealed things that you did not expect?

What do your customers think about what you have done?

Has it helped to communicate ideas with them?

Thank you for taking the time to read this through.
**PDR RESEARCH QUESTIONNAIRE**

<table>
<thead>
<tr>
<th>Introduction:</th>
<th>This study is being undertaken to measure and analyse the impact of implementing design-led technologies and techniques within manufacturing SME's.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective:</td>
<td>To review current technologies used for design purposes within manufacturing SME's, and highlight any resulting changes in the company's operational and commercial performance.</td>
</tr>
<tr>
<td>Scope:</td>
<td>This study is aimed mainly at manufacturing companies that design their own products or add value to their customers products by re-designing them for a specific manufacturing process.</td>
</tr>
<tr>
<td>Confidentiality:</td>
<td>All case study material will be treated as confidential. Case study material will only be published following prior approval from the company. The case study company will, in all cases, remain anonymous.</td>
</tr>
</tbody>
</table>

**Appendix ii - Example of Completed Interview Template.**
Can you start by telling me a little bit about your company:

Type of business

Date established

Number of employees

Your name

Your position
Identify your company's current in-house design, engineering and manufacturing technology:

Examples might be Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacture (CAM) & Rapid Prototyping (RP). Please give additional information, for example, if you have CAD you may include the software used, the number of seats, any add-on packages etc.
Using the most recent technology from above as the example, please select why it was chosen for use within your company:

- a need to keep pace with competitors
- a requirement to increase process efficiency
- the need to add value to your services/products
- a way of reducing time to market of your products
- to increase the ways of communicating product data with customers
- to improve profit margin

*Any other comments on this technology choice (are there any other examples?):*

---

How was it selected? For example, were external consultants used, or perhaps market research indicated the need its introduction?
Do you sub-contract to enable you to use any other key technologies?  

Can you estimate the amount of work that is subcontracted each year, as a percentage?  

Has this amount reduced as the result of your new technology?  

Generally speaking, how has the technology within your company evolved over the last five years?  

How do you expect the use of new technology within your company to continue?
OPERATIONAL IMPACT
How has the current technology contributed to project completion times:

How has the current technology contributed to project costs:

How has the current technology contributed to product quality:
There may be more than one type of standard project within your company, therefore I will ask you the following questions for each project scenario that you can identify:

**Project Scenario**

Has the technology reduced project lead times?  
- yes  
- no

If so, please quantify the impact on lead times, by marking a line on the following scale:

- no impact
- best possible
  (e.g. all projects completed ahead of schedule)

Has the technology reduced project costs?  
- yes  
- no

Please quantify the impact of the technology on project costs:

- no impact
- best possible
  (massive reduction in project costs)

Has the current technology increased product quality?  
- yes  
- no

Please quantify the impact of the technology on product quality:

- no impact
- best possible
  (zero rejects)
What other commercial benefits have the current technology and techniques brought to the company?

If possible, can you please provide the following information:

Annual turnover prior to this technology investment

Annual turnover after this technology investment

Total cost of investment
What percentage of annual turnover is re-invested in technology?

Can you comment on the above values? What do they indicate to you?

Has this technology affected the markets that you aim your products at? Perhaps you now sell to markets that you previously could not. Has your market share increased?
PDR RESEARCH QUESTIONNAIRE

ADDITIONAL QUESTIONS
Did the introduction of this technology throw up issues of resourcing within your company?
For example, is the technology over-allocated due to it exceeding initial expectations?

Are staff were they excited with the introduction of new technology and the chance to increase their skills base?
Did you have to employ staff with new skills to compliment the new technology, or new staff as a result of increase business?
Has the introduction of this technology revealed things that you did not expect?

What do your customers think about what you have done?
Has it helped to communicate ideas with them?
Appendix iii

Summary of Interviews

To help with the process of analysis the interviews were summarised in a table format. This can be seen on the following pages.
<p>| <strong>Pattern maker</strong> | <strong>Keep pace with competitors, reduce time to market of products.</strong>&lt;br&gt;<strong>10% increased sub-contracting for increased numbers of SLA patterns. In-house design facility reduced sub-contracting.</strong>&lt;br&gt;<strong>Historically dimensions measured off of 1:1 drawings or via conversations directly with customer – time consuming.</strong>&lt;br&gt;<strong>The CAD’s a fantastic system with regard to querying drawings etc. for shapes and sizes.</strong>&lt;br&gt;<strong>‘Depends upon the co-operation with new personnel’.</strong>&lt;br&gt;<strong>The current CAD system is more than adequate. Recommended that CNC’s do the more complicated parts while the patternmakers carries on with the other parts. Maybe introduce a basic programmable patternmakers CNC machine.</strong>&lt;br&gt;<strong>Sped them up.</strong>&lt;br&gt;<strong>Time taken previously to check drawings, develop 1:1 shapes, sizes and templates were replaced by quicker CAD access.</strong>&lt;br&gt;<strong>-Rapid prototypes are quicker for the majority of complex shapes.</strong>&lt;br&gt;<strong>-In certain instances money is saved using SLAs for complex components.</strong>&lt;br&gt;<strong>-Far less down-time in chasing customers (e.g. sometimes the departmental manager is off-site for ½ a day, and they were the only one with the information).</strong>&lt;br&gt;<strong>-Use of quick-cast resin, only taking 30 mins to set.</strong>&lt;br&gt;<strong>This allows for quicker working in the whole day.</strong>&lt;br&gt;<strong>-The ability to manipulate CAD data to confirm draught angles etc.</strong>&lt;br&gt;<strong>-Removal of tooling.</strong>&lt;br&gt;<strong>-Complex forms cut directly out of billet.</strong>&lt;br&gt;<strong>-RPR models not really made a difference, as patternmakers have pride in their work so creates a great finished product anyway.</strong>&lt;br&gt;<strong>-New patterns product good moulds.</strong>&lt;br&gt;<strong>-Communications, easy access to CAD data to confirm draught angles etc.</strong>&lt;br&gt;<strong>More interest from outside companies with the addition of the new technologies, introduction of CAD technologies (Internet).</strong>&lt;br&gt;<strong>Enquiries generated.</strong>&lt;br&gt;<strong>Estimated at 5% – No investment for patternmakers.</strong>&lt;br&gt;<strong>No planning decisions shared with patternmakers from senior managers.</strong>&lt;br&gt;<strong>Wild market. New jobs have been created.</strong>&lt;br&gt;<strong>Some over-allocation of work.</strong>&lt;br&gt;<strong>Bad planning of inward jobs, causing there to be too much work in progress in the pattern shop (an example would be when too many SLA models are ordered, and the work to print them up and prepare them has not been accounted for).</strong>&lt;br&gt;<strong>Surprised depth of information and speed from CAD files.</strong>&lt;br&gt;<strong>The development of the design department and the liaison of the designer with the patternmakers has transferred the knowledge of the patternmakers out to the clients. Clients then design products which suit the company processes better.</strong>&lt;br&gt;<strong>Employment – jobs in phenolics and continued role for a CAD draughtsman.</strong>&lt;br&gt;<strong>Additional patternmaker employed.</strong>&lt;br&gt;<strong>Project Engineer, KTP Associate</strong> | <strong>CAD – Version 0 1 idea. CAM – integrated with the CAD package.</strong>&lt;br&gt;<strong>-Technology implemented to keep pace with competitors and improve profit margin.</strong>&lt;br&gt;<strong>-System selected due to support from university.</strong>&lt;br&gt;<strong>Sub-contracting reduced with new technology.</strong>&lt;br&gt;<strong>-Used to purchase LOMs for patterns which were used to cast off or make resin tooling. Since the technology was introduced patterns were machined in house.</strong>&lt;br&gt;<strong>-8 years ago no CAD/CAM, all traditional pattern making (any customer CAD files were sent to PDR for manufacture of LOMs).</strong>&lt;br&gt;<strong>-3.5 years ago a CAD viewer was installed to help with quoting work (PSR still required to do any further work on files).</strong>&lt;br&gt;<strong>-A CAD system was bought (Visicad) and easy files were imported and 2D engineering drawings created this was bought on customer recommendation – and included a CAM system).</strong>&lt;br&gt;<strong>-KTP programme enabled better use of existing package, and then more appropriate CAD/CAM system installed.</strong>&lt;br&gt;<strong>-Tool design will continue to be carried out using the 3D CAD/CAM systems (i.e. generate tool paths etc.).</strong>&lt;br&gt;<strong>-Investment in new CNC equipment (e.g. a CNC router for manufacture of sample).</strong>&lt;br&gt;<strong>-Reduced project times; quicker project start to finish times.</strong>&lt;br&gt;<strong>-Removal of sub-contractors.</strong>&lt;br&gt;<strong>-Tool production time lower (optimised computer generated toolpaths etc.).</strong>&lt;br&gt;<strong>-Tools finished when they come off the machine. No additional finishing.</strong>&lt;br&gt;<strong>-Project costs reduced. Ability to manipulate CAD data removed cost of sub-contracting this work.</strong>&lt;br&gt;<strong>-Also removal of sub-contracting work out to an aluminium casting foundry because the whole tool can be cut on the machine.</strong>&lt;br&gt;<strong>-Therefore two sub-contractors removed from the process.</strong>&lt;br&gt;<strong>-Product quality is bettered.</strong>&lt;br&gt;<strong>-Tools are more accurate (in tool tolerance/ work first time/ accuracy and form in 1 ⅛ &amp; 3D planes/better surface finish, surface quality, better mouldings).</strong>&lt;br&gt;<strong>New customers because of the new capabilities.</strong>&lt;br&gt;<strong>-Complex forms cut directly out of billet.</strong>&lt;br&gt;<strong>-With the product (Company X) is producing the investment isn’t realising its full potential because there is no realisation of the extra added value within the new products by the customer’.</strong>&lt;br&gt;<strong>-2% The market share for complex specialist CAM tooling has increased.</strong>&lt;br&gt;<strong>-Yes, the technology was over-allocated. Sometimes wrong jobs were allocated to the new technology (which could be better spent doing something else).</strong>&lt;br&gt;<strong>-The ability to machine from Polyurethane foam directly for samples.</strong>&lt;br&gt;<strong>-Staff – internal staff were interested in new technology.</strong>&lt;br&gt;<strong>-‘Organisational problems hindered this. Generally [interest] was to be as expected. Some resistance.’</strong>&lt;br&gt;<strong>-Colleagues trained in CAD/CAM use.</strong> |</p>
<table>
<thead>
<tr>
<th><strong>KTP Supervisor (KS)</strong></th>
<th><strong>Engineer / Manager</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAO, external experts, suppliers.</strong> Technology chosen as a cost effective, low cost entry into the market. Use the technology as a building to move into bigger things. Design Engineer made technology decisions. Important to future proof the technology (purchase of product and software that can be used to build on for future work).</td>
<td><strong>Tech choice</strong> Design-based technologies located in central plant. 3D CAO, GerMach (CAM). Moulding machines are in the local plants. They are monitored using statistical process control. All technologies customer driven. One recent example of a new technology is overmoulding and metal for motor products. Company places emphasis on using new technologies.</td>
</tr>
<tr>
<td><strong>Yes to sub-contracting. Manufacturing of PU parts &amp; sub-contracting of bolt-on products.</strong> Sub-contracting less than 3%.</td>
<td><strong>Sub-contract</strong> Used as little as possible. Automotive industry very competitive, Company 'doesn't want to give away any secrets or ideas'. Additionally very high accuracy required and by keeping this in-house there is confidence in achieving it. Prototyping work was sub-contracted out to PDR. This reduced time to market of products and proved designs before committing to permanent tooling.</td>
</tr>
<tr>
<td><strong>Gone from a purely paper-written company to a software based management system company.</strong></td>
<td><strong>Tech develop</strong> Company very receptive to using new technologies. Originally the technology was selected due to the owner's own philosophy / insight. The was driven by engineering challenges. Polymer technology and materials have changed. Customers tend to shop around for a variety of technologies now, therefore not reliant upon one method or supplier.</td>
</tr>
<tr>
<td><strong>Regarding manufacturing, the company was starting from scratch. Too early.</strong></td>
<td><strong>Tech future</strong> Refer to additional notes.</td>
</tr>
<tr>
<td><strong>Ability to communicate with potential clients (marketing tool, presenting of concepts etc.).</strong></td>
<td><strong>Time</strong></td>
</tr>
<tr>
<td><strong>6% - Lack of awareness of NPD for ongoing benefits to the company.</strong></td>
<td><strong>Cost</strong></td>
</tr>
<tr>
<td><strong>No, technology has not affected the markets the products were aimed at. This is purely because the MD didn't launch the new products properly.</strong></td>
<td><strong>Quality</strong></td>
</tr>
<tr>
<td><strong>Yes, in a negative way. The new technology would have been essential to communicating with subcontractor tool makers, however the MD felt that they were too expensive and 20 drawings were posted to cheaper manufacturers. Predictably the tooling wasn't up to an adequate quality.</strong></td>
<td><strong>Other commercial benefit</strong> Improved sustainability of the company by being able to access higher end 'niche' markets. Have allowed the company to maintain profitability &amp; sustain position.</td>
</tr>
<tr>
<td><strong>The general feedback was positive. The new technology enabled the company to evolve into its current markets, which have very difficult entry barriers to overcome (automotive market).</strong></td>
<td><strong>Reinvestment</strong> 3% - Continued investment has enabled the company to evolve into its current markets, which have very difficult entry barriers to overcome (automotive market).</td>
</tr>
<tr>
<td><strong>The implementation of design-led technologies didn't affect employment. It may have if products had been launched. The e-marketing had greater short-term effect - MD didn't realise the future costs; e.g. prototyping, gaining marketing skills... He (MD) didn't see the long-term. Staff were interested in this new technology but it wasn't seen to be of any relevance to them.</strong></td>
<td><strong>Markets</strong> The market is a safety critical market - customers buy these products for this reason.</td>
</tr>
<tr>
<td><strong>Unexpected</strong> Some problems with obtaining staff with required level of skill. The internal management of the large volume of files etc. is difficult.</td>
<td><strong>Customer Feedback</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Additional Notes</strong> Variants on products - i.e. smaller production runs are at the low prices that are normally typical of the mass produced processes. Prototype tooling, e.g. sintered tooling is used to achieve these lower prices, with the reduced batch sizes. This is mass customisation. Market unusual as it has high investments and high overheads. 'Once a company is set up in this manner, it is difficult to transfer this infrastructure to a new market. Market growth is approximately 5% per year'.</td>
</tr>
</tbody>
</table>
Appendix iv
List of Author’s Published Papers


Note: Papers follow in the above order.
Product design education in practise: Evaluating the key transition from undergraduate degree to initial industrial position

D. EGGBEER, J. REES, P. DORRINGTON, H. MILLWARD AND A. LEWIS
The National Centre for Product Design and Development Research (PDR), University of Wales Institute Cardiff (UWIC), Western Avenue, CARDIFF CF5 2YB, UK

ABSTRACT

This paper assesses the educational and training needs of recent product design graduates by evaluating their progress from undergraduate degree through to their first two years in industry. A case study approach is used to track three graduates from UWIC’s Product Design degree course through to employment within TCS (formerly known as the Teaching Company Scheme) programmes operating in small and medium-sized enterprises (SMEs). The undergraduate education and the structured TCS-based training are reviewed, and the challenges associated with working with SMEs are highlighted. Generic educational and training issues are identified, with particular emphasis on design-for-manufacture and ethical design.

1. INTRODUCTION

Product design is a key component in the new product development cycle, and hence an essential component within the wealth-creation process and the economy in general. In order to maximise the effectiveness of the product designer within industry, consideration needs to be given to two key areas: (a) education received at university degree level; and (b) vocational training received in the industrial sector. Novice product designers entering the workplace rely on a solid undergraduate education to prepare them for the challenges of industry, and a number of approaches have been postulated for promoting industry-relevant skills (1). Within the work-place environment, there is a wide variety of literature focused on developing and refining product design techniques, such as systematic design and stage-gate processes (2). However, the majority of product design education studies report industrial collaborations with large well-established companies (3). There has been limited attention paid to analysing the needs of young product designers as they undertake the key transition from undergraduate degree to initial industrial position within small companies, specifically small manufacturing companies who often lack a clear understanding of design.

SMEs represent an important element in national economies around the world, and they play a significant role in the design, development and manufacture of new products. In the EU an SME is categorised as a company employing fewer than 250 people. In fact, more than 95% of the three million businesses in the UK employ fewer than 20 people (4). The majority of the PDR-based TCS programmes have focused on introducing design technology and
techniques into 'traditional' manufacturing SMEs. Advanced design technologies, such as computer aided design (CAD) software, can bring significant benefits to SMEs (5). However, the idiosyncratic nature of small companies means that this can be a culture shock for young product designers. A number of research studies have highlighted the difficulties of implementing new product development activities within SMEs (6). Furthermore, senior management within SMEs seldom have the education or training relevant in product design activities. Within the manufacturing industry, there is a tendency for management to attempt to cultivate design literacy 'through osmosis' rather than through formal targeted training (7), and this has an impact on training standards for subordinate staff.

This paper will assess the educational and training needs of recent product design graduates by evaluating how they coped with the transition from undergraduate degree through to their two-year TCS programme within a manufacturing SME. The SME environment is not necessarily conducive to ethical design but the TCS programmes are structured and closely monitored, and aim to develop both the technical and personal competencies of the graduates. Therefore this research, based on a series of case studies, will provide a unique insight into the particular challenges encountered by product designers working within SMEs. The aim is to highlight key degree course elements that support their transition into industry, and also to identify work-based training requirements. In addition, the case study material will be used to show the extent to which the TCS programmes prepare the graduates for education at the research degree level.

2. TCS MODEL

PDR have employed the TCS model as an effective mechanism for partnership and collaboration with a wide range of SMEs. TCS has been in operation for over 20 years, and is a government-backed knowledge transfer scheme. The aim of the scheme is to strengthen the competitiveness and wealth creation of the UK by stimulating innovation in industry through structured collaborations with universities and research organisations. The programmes are usually two years duration and provide employment for a well-qualified graduate TCS Associate for the duration of the programme.

All the PDR-based TCS programmes are focused on product design, and the numbers reflect the UK trend in that the majority have been based in small companies. PDR have successfully completed nine TCS programmes since 1995, and there are ten PDR-based TCS programmes currently ongoing. In line with other researchers (8), PDR have found that the TCS model is an ideal vehicle through which to evaluate the training needs of product design graduates, and assess the application of these skills within new product development activities.

The well-defined management and structure of the TCS process promotes a detailed analysis of both the TCS Associate and the company from the university partner’s perspective. PDR is based within UWIC, and have found that the BSc Product Design course at UWIC provides a good foundation for a TCS Associate. Once an appointment has been made, the Associate is assigned at least two PDR-based supervisors. Regular contact with the TCS Associate and company fosters a level of trust and co-operation that generates an in-depth understanding of the subtle issues and problems inherent in any small company. TCS programmes are characterised by a commitment to disciplined effective project management through mandatory monthly and quarterly meetings. The monthly meetings between the supervisors
and the Associate focus on the technical issues within the programme, as well as addressing training and personal development requirements. As part of the TCS programme, each Associate attends four separate one-week training modules, and it is estimated that 10% of their time is spend on training-related activities.

This research study has selected three anonymous TCS Associate case studies to illustrate a range of product design education and training issues, specifically within the distinctive working environment of a manufacturing SME. The selection criteria for the case studies were as follows:

a) Good honours graduate from UWIC’s BSc Product Design course;
b) Completed or undertaking a PDR-based TCS programme with a small company, of between 10 and 50 employees;
c) Employed within the ‘traditional’ manufacturing sector, with a commitment from within the company to enhance its design capability.

3. UWIC’s PRODUCT DESIGN COURSE

The undergraduate course is a three-year full-time course, providing a BSc Honours degree accreditation. The course runs live projects with industry, but does not include formal work placements. However, each of the three TCS Associates selected for this research study completed periods of relevant work experience during the degree course. The course aims to combine the traditional attributes of product design and mechanical engineering, with particular emphasis on the design engineering skills required during the development of a new product. A summary of the three-year course is given below.

<table>
<thead>
<tr>
<th>Year 1 Modules (100% taught)</th>
<th>Year 2 Modules (100% taught)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Marketing &amp; Design Interface</td>
<td>Marketing Influences on Design</td>
</tr>
<tr>
<td>Design Models &amp; Methods</td>
<td>Information Ergonomics</td>
</tr>
<tr>
<td>Ergonomics in Design</td>
<td>Concept Generation &amp; Development</td>
</tr>
<tr>
<td>Effective Communication of Design Concepts</td>
<td>Design for Manufacture &amp; Assembly</td>
</tr>
<tr>
<td>Workshop Practice &amp; Model Making</td>
<td>Manufacturing Analysis &amp; Reverse Engineering</td>
</tr>
<tr>
<td>Materials &amp; Manufacturing Process Selection</td>
<td>Integrated Design &amp; Concurrent Engineering</td>
</tr>
<tr>
<td>Technical Specifications</td>
<td>System Control &amp; Instrumentation</td>
</tr>
<tr>
<td>Engineering Science for Product Designers</td>
<td>Mathematics 2</td>
</tr>
<tr>
<td>Electronics for Product Designers</td>
<td>Mechanical Engineering Studies A</td>
</tr>
<tr>
<td>Mathematics 1</td>
<td>Mechanical Engineering Studies B</td>
</tr>
<tr>
<td>History of Design &amp; Technology</td>
<td>CAD Software Training: I-DEAS</td>
</tr>
<tr>
<td>Computer &amp; IT Studies</td>
<td>Computer Aided Mechanical Engineering</td>
</tr>
</tbody>
</table>

**Year 3 Modules (15% taught, 85% project-based)**

- Business Management & Professional Practice
- Project Management & Product Development
- Advanced Design Option: self-directed, research-based product/technology project
- Major Project: self-directed design project

The Year 3 major project was an important element within the course, whereby the students developed a design principle from initial concept through to final working prototype. This element brought together their 3D CAD, rapid prototyping and model-making skills. It should be noted that the opportunities to develop these skills varied between students. For example,
one Associate was only introduced to basic CAD solid-modelling, whereas another chose to make extra use of 3D CAD and was effectively self-taught.

4. TCS ASSOCIATE CASE STUDIES

4.1 TCS Associate A: Safety equipment manufacturer

Associate A was employed in a small family-run company that specialised in the manufacture of safety and survival equipment for the outdoor and military markets. The company were active in identifying new market opportunities, but required a structured development process to bring their new products to market. The TCS programme was configured to address this need. However, the company was sales-orientated; it lacked adequate market research and initially resisted the concept of structured innovation. Therefore, the challenge for Associate A was to introduce new working practices that could be understood and applied by a range of different staff.

Product designs were brought to realisation through the use of a 3D CAD workstation employing I-DEAS software. New product designs were successfully developed using a structured stage-gate process, with formal sign-off and design reviews to approve and monitor new projects. In parallel, a product development training programme was implemented across the company. A summary of the training undertaken by Associate A during the TCS programme is given below.

<table>
<thead>
<tr>
<th>TCS Modules</th>
<th>(1) Developing Project Handling Skills; (2) Improving Personal Skills; (3) Commercial and Technological Change; (4) Changing Business Environment. ‘Designing and developing a survival item’</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCS Mini Project</td>
<td>Process FMEA; Marketing for Beginners; Ergonomics; Aesthetics; Design Analysis; NVQ Management; Sustainability in Design; Anatomy and Physiology; Rehabilitation Engineering; Photography.</td>
</tr>
<tr>
<td>Professional Training</td>
<td>Meetings with tool makers, project stakeholders and industry experts (specifically manufacturing technology and techniques); Finite Element Analysis (FEA); MoD Standards; Macromedia Director; Adobe Photoshop.</td>
</tr>
<tr>
<td>Informal Training</td>
<td></td>
</tr>
<tr>
<td>MPhil Degree</td>
<td>Withdrew from higher degree study programme</td>
</tr>
</tbody>
</table>

4.2 TCS Associate B: Injection moulding company

Associate B was employed in a small ‘traditional’ injection moulding company. Their main customer base was the automotive, electrical and electronics industries. However, in order to generate strategic growth, the company needed their own in-house design capability and to explore new high-added-value markets, specifically medical mouldings. The TCS programme facilitated this major change in company structure and direction.

Associate B implemented an I-DEAS 3D CAD workstation to drive the in-house design and development activities. In parallel, a significant amount of work was put in to ensuring that the company systems conformed to the rigorous medical standards required for product development and clinical trials. Working within accredited standards demonstrated that the company was fully committed to developing high-quality medical products. In addition, Associate B implemented and upgraded the company’s quality system (ISO 9001) and
environmental management system (ISO 14001). A summary of training undertaken by Associate B is given below.

<table>
<thead>
<tr>
<th>TCS Modules</th>
<th>[identical to Associate A] 'Material utilisation and waste minimisation'</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCS Mini Project</td>
<td>CAD/CAM modules from UWIC's BEng Mechanical Engineering course; Institute of Environmental Managers Association (IEMA) (1) Foundation, (2) Associate Membership and (3) Internal Auditor courses; NEBOSH General Certificate in Occupational Health &amp; Safety.</td>
</tr>
<tr>
<td>Professional Training</td>
<td>Presentation techniques; Value Stream Mapping; Benchmarking; Statistical Process Control; Design FMEA; FDA &amp; MDA medical device regulatory requirements; Sterilisation techniques; Rapid prototyping techniques; ISO 14001; Investor in People.</td>
</tr>
<tr>
<td>Informal Training</td>
<td>CAM training with PDR personnel; 3D CAD Surface Modelling tutorials; Solid Modelling seminars; questionnaire design and interview techniques.</td>
</tr>
<tr>
<td>MPhil Degree</td>
<td>Title: 'Implementing Product Design within an SME'. Completed UWIC's Certificate in Research Methods; MPhil ongoing.</td>
</tr>
</tbody>
</table>

4.3 TCS Associate C: Mass transit supplier

Associate C was employed by a small manufacturing company that supplied a wide range of components and assemblies for the mass transit sector. Fabrication was based on one of three core in-house technologies: (a) metal alloy castings; (b) polyurethane mouldings; and (c) composite mouldings. The TCS programme was established to implement a knowledge-based in-house design capability, such that essential manufacturing information and constraints could be integrated into a customer's design much sooner in the development cycle. The company aimed to increase their new product development activities and gradually make the transition from 'just manufacture' to 'design and manufacture' contracts.

A 3D CAD workstation, running I-DEAS software, was installed early in the TCS programme. This acted as a very effective customer interface through which all design communications and decisions could be channelled. Associate C then linked this design platform to a 5-axis CNC machining centre, using the appropriate I-DEAS CAM software. This design-to-manufacturing link allowed the company to capture major rail contracts and established a reputation for high-quality, consistent composite products. A summary of training undertaken by Associate C is given below.

<table>
<thead>
<tr>
<th>TCS Modules</th>
<th>(1) Developing Project Management Skills; (2) Improving Personal Skills and Teamwork; (3) Business Management Skills; (4) Exploring Business Opportunities. 'Reducing waste in the aluminium casting process'</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCS Mini Project</td>
<td>Design FMEA; Design with Composite Materials; NVQ Management; Adobe Photoshop; First Aid at Work; Italian.</td>
</tr>
<tr>
<td>Professional Training</td>
<td>Design FMEA; Design with Composite Materials; NVQ Management; Adobe Photoshop; First Aid at Work; Italian.</td>
</tr>
<tr>
<td>Informal Training</td>
<td>Design FMEA; Design with Composite Materials; NVQ Management; Adobe Photoshop; First Aid at Work; Italian.</td>
</tr>
<tr>
<td>MPhil Degree</td>
<td>CAM training with PDR personnel; 3D CAD Surface Modelling tutorials; Solid Modelling seminars; questionnaire design and interview techniques.</td>
</tr>
<tr>
<td>MPhil Degree</td>
<td>Title: 'An evaluation of the commercial and operational impact of implementing design-led technologies within a manufacturing SME'. Completed UWIC's Certificate in Research Methods, conference paper accepted; MPhil ongoing.</td>
</tr>
</tbody>
</table>
5. DISCUSSION

The UWIC Product Design degree represents the common educational element in this paper. The case studies indicate that the degree course provided each of the three Associates with the fundamental technical skills necessary for new product design. However, this level of education alone is insufficient to manage the full design and development cycle within the context of a graduate’s first industrial placement. The degree course provided the graduates with an appreciation of a wide range of design tools and techniques, and the key benefits of the three-year degree can be summarised as follows:

- Introduction to 3D CAD;
- Knowledge of model-making and rapid prototyping techniques;
- Good understanding of design techniques, ergonomics and market research principles;
- Introduction to technical/material specifications and manufacturing technologies.

The implementation of 3D CAD within a ‘traditional’ manufacturing company was an important early deliverable within the three case studies. It is significant that the I-DEAS software taught at university level was the chosen software in each of the three TCS programmes. The benefits of 3D CAD software are numerous, but it would appear that personal choice and experience heavily influence the CAD selection process. Although the CAD training at university level was sufficient to initiate this software-based design technology, two of the three Associates required further CAD training as part of their TCS programmes. This was particularly evident for Associate C, who had the responsibility of combining CAD and CAM software to drive the company’s high-quality machining operations. The university degree did not cover this crucial link between design and manufacturing software. In addition, each Associate undertook Failure Mode and Effects Analysis (FMEA) training. This risk assessment technique was clearly seen as an important element in any new product development process.

The case studies showed a shortcoming within the university degree was a lack of focus on the important design-to-manufacture interface. Within the context of small manufacturing companies, each of the three Associates considered that their degree did not adequately prepare them for design-for-manufacture activities. This is a broad area covering CAD/CAM/CAE integration, appropriate materials selection, tooling design and CNC machining. It would appear that there are no ‘ready made’ training modules whereby a young product designer can quickly acquire these key skills and, as such, they have traditionally been addressed through industrial placements and learning through work experience. With this in mind, the following additions should be considered for the UWIC degree course:

- Industrial placement(s), with emphasis on design-for-manufacture;
- Company case studies to highlight the industrial perspective on design;
- External lecturers from industry – a review of industrial practices (both good and bad) and what industry is looking for in a graduate;
- Management skills – improving communications, facilitating company change and implementing internal audits;
- Introduction to ethical design and environmental/sustainable design issues.

The three Associates reported that ethical design represented an important gap within UWIC’s product design syllabus. Across the three TCS programmes, ethical design manifested itself predominantly through environmental considerations. In order for the Associates to contribute to this important subject, extra training was necessary. Associate B undertook three separate
environmental management courses, which directly helped to implement world-class ISO14001 standards, and this had a significant impact on the TCS programme. In addition, Associate A attended a dedicated sustainable design training course, and Associate C implemented cost reductions through a waste reduction project. However, the key barrier to implementing effective ethical design was not the lack of education and training, but rather it was the idiosyncratic nature of SMEs themselves.

The main challenges faced by the three TCS Associates in implementing new product development were due to the difficulties associated with working in SMEs (6). Manufacturing SMEs tend to be resource-constrained environments in which senior managers focus on reducing time and costs at the expense of product quality and consistency. Education and training can address technical and practical skills, but in this type of working environment communication and interpersonal skills are of equal importance in order to overcome the main barriers to new product development. These barriers can be summarised as follows:

- Dominant owner/managers with a lack of understanding of design, e.g. continual intervention without their full appreciation of the project;
- Inadequate market research and unrealistic expectations with regard to new product development time and costs;
- Failure to understand the need for a structured development process and a resistance to adopt appropriate design documentation;
- Short-term, ‘fire fighting’ strategies encouraged rather than long-term strategic planning;
- A sales-driven ethos at the expense of a robust strategy which integrates business with design.

The fact that successful results were delivered in each of the three TCS case studies is due largely to the commitment and perseverance of the Associates, and the structure and discipline imposed through the university collaboration. The university support team, in combination with the four TCS training modules, ensured that the Associates were given the time and opportunity to develop their technical, managerial and personal attributes to a much higher level. This support afforded an acceleration of the learning process beyond undergraduate degree level that would have been far more difficult had the graduates been alone and isolated in a typical manufacturing SME. The combination of professional and informal training elements undertaken during the TCS programmes enhanced the technical knowledge developed at university level and expanded this within a business context. Consequently, the Associates received a greater understanding of product design with a small company, and learned how to implement effective design and development within the distinctive environment encountered within a manufacturing SME. The TCS-based training also broadened the graduates’ education in terms of management skills, best practice business strategies, communication skills and customer-relation techniques.

The university is an integral part of the TCS programmes, and the academic teams encourage and support education at the higher degree level. Many of the projects within the TCS programmes provided opportunities to undertake research that would be directly applicable to Masters level degree. However, none of the three Associates completed their MPhil degree within the two-year programme period. In fact, only one Associate actively generated research data throughout the duration of the programme, and then continued to pursue the MPhil during his own free time. It would appear that the workload and challenges associated with SME-based TCS programmes are too great to be able to accommodate a MPhil degree. The priority for the Associates was to successfully implement new product development,
therefore any Masters level degree should be able to accredit this significant amount of work towards the higher degree. Other universities have developed an MSc degree by Learning Contract (8), and this work-based learning model should be considered for future TCS developments.

6. CONCLUSIONS

UWIC’s Product Design degree course provides a solid foundation for the application of new product development; however, no three-year degree syllabus can fully prepare young graduates for coping with the unique challenges of working in small manufacturing SMEs. The main deficiency at university level was a lack of training and insight into design-for-manufacture. Greater industrial perspective and targeted educational modules can address this. Within the industrial sector, there is a need to promote systematic design-for-manufacture training, which can compliment the focus on CAD/CAM software technology. The TCS model provides an effective mechanism for continued professional development post-university, and the support structure ensures that training is maintained and expanded, even though the graduates may well be working in resource-constrained restrictive environments. These environments are not conducive to ethical design, therefore this area needs to be addressed within educational and training modules, specifically encouraging ecological and sustainable design issues. Integrating design-for-manufacture and ethical design within a manufacturing SME is a significant challenge, therefore it is PDR’s recommendation that a TCS programme should be the chosen route for small companies wishing to employ a young product design graduate. Future work in this area should examine work-based learning models that successfully incorporate higher degrees into two-year TCS programmes.

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(3) MacDonald A. and O'Neil L. 'In partnership with industry: the educational-industrial interface'. Journal of Art and Design Education 16(1) 1997, 25-34.
ASSESSING THE OPERATIONAL IMPACT OF IMPLEMENTING ADVANCED ENGINEERING DESIGN-LED TECHNOLOGIES WITHIN A SELECTION OF MANUFACTURING SMES

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ABSTRACT
This paper evaluates the impact of implementing design-led technologies such as CAD within a number of small UK manufacturing companies. The paper adopts a case study approach and reports findings from four such companies. The paper assesses the impact of these technologies in three primary areas: lead times, cost and quality. The findings of the research show a positive impact in all areas within all companies. However, the findings also show that there is a difference when comparing time, cost and quality. The paper provides a discussion of these findings and outlines the future work that is being undertaken.

INTRODUCTION
Small and medium-sized enterprises (SMEs) represent a key element in national economies around the world, and they play a significant role in the design, development and manufacture of new products. In the EU an SME is categorised as a company employing fewer than 250 people. In fact, more than 95% of the three million businesses in the UK employ fewer than 20 people [1]. In order for SMEs to maintain their competitive advantage in an increasingly harsh international market, they need to be receptive to operational change that promotes innovation. One mechanism for this is the adoption of design-led technologies. We can categorise design-led technology as equipment and/or processes that facilitates improvements in the design-to-manufacturing process. Examples include: computer aided design (CAD) and computer aided manufacturing (CAM) software; finite element analysis (FEA); rapid prototyping; and soft/aluminium tooling.

CAD/CAM software is a typical example of design-led technology. It speeds up design and engineering activities by rapidly capturing design intent and reducing the errors between the development stages [2]. A number of researchers have highlighted the benefits of integrating CAD/CAM systems within the product development process [3,4], with particular emphasis being placed on reducing the time and cost of bringing new products to market. However, it has been noted that CAD systems can inhibit innovation, especially radical innovation [5]. Generally, these systems have been implemented inappropriately and used ineffectively; therefore the methods by which design-led technologies are implemented are an important consideration.

Some areas of the manufacturing industry, especially those dependent upon ‘traditional’ fabrication techniques (for example, metal casting) have been slow to adopt design-led technologies. The majority of the literature focuses on well-established sectors, such as aerospace and automotive industries [6]. Advanced design-led technologies are likely to have a significant beneficial impact on small ‘traditional’ manufacturing companies, but research in this area is limited [7]. Furthermore, design and development literature that actually quantifies the operational impact of these technologies within SMEs is very scarce. This paper will measure the impact of design-led technologies within manufacturing SMEs by presenting quantitative and qualitative data generated from a series of structured case studies. The objective is to highlight the tangible effect of design led technologies on operational and, to a lesser extent, commercial performance in this key sector.
METHODOLOGY

A case study approach was adopted for this research. PDR have utilised TCS programmes (formerly known as the Teaching Company Scheme) as an effective mechanism for collaboration with a wide range of SMEs. TCS has been in operation in the UK for over 20 years, and is a government-backed technology and knowledge transfer scheme. The aim of the scheme is to strengthen the competitiveness and wealth creation of the UK by stimulating innovation in industry through structured collaborations between universities and research organisations. A typical TCS programme runs for two years, between one company, one university and Technology Transfer and Innovation Ltd (TTi – who organise the programmes on behalf of the government). A graduate is placed within the company to carry out a project, which involves technology or knowledge transfer of some kind. The projects chosen are aimed primarily at helping SMEs take advantage of the new expertise that the graduate and university partner can bring to the company.

Currently 48% of all TCS schemes are design-based, and of these 61% are based in small companies. All the PDR-based TCS programmes are, or have been, focused on product design, and the numbers reflect the UK trend in that the majority have been based in small companies (i.e. companies with less than 50 employees). PDR have successfully completed 9 TCS programmes since 1995, 7 of which have been with small companies.

In common with other researchers [8], it can be seen that TCS schemes provide a rich source of data within the context of the implementation of design-led technologies. As such, this paper will use a small selection of anonymous PDR-based TCS programmes as case studies, to explore the operational impact of implementing advanced engineering design-led technologies within SMEs. One balancing case study from a non-TCS manufacturing SME will be included for completeness. The selection criteria for the case study companies is as follows:

a) Small company, between 10 and 100 employees, currently implementing new design-led technologies or having implemented design-led technologies during the last 5 years.
b) UK based.
c) Easy access by the researchers to key employees for data gathering.
d) Manufacturing bias.

In terms of data gathering, it was felt that a semi-structured interview would be the most suitable way to collect data. Interviews were conducted one-to-one with the senior technical staff within each company who have the greatest involvement with the new design-led technologies in their company. The use of one-to-one interviews using a semi-structured approach allowed for a degree of control whilst also letting the respondent elaborate on their own views/thoughts.

There were two trials of the interview, which used many ‘open’ questions allowing the respondent to answer with greater freedom. The purpose of these trials was to ensure that the best use of time and interview structure was made when gathering the actual data. The pilot interviews also highlighted the fact that companies often have different manufacturing scenarios, e.g. they may have certain projects requiring specialist manufacturing processes or other certain projects that are volume specific. The implementation of design-led technologies has affected these project scenarios in different ways, consideration for this was therefore necessary.

A variety of techniques were used within this questionnaire, for example open and closed questions and Visual Analogue Scales (VAS). Visual analogue scales are proper ratio scales, which have two fixed ends with descriptions, and the respondent marks a line between them accordingly. They provide the respondent with a better range with which to express their opinion compared to Numerical Rating Scales. These techniques ensured that a good mix of qualitative and quantitative data was collected.
CASE STUDIES

On the basis of the criteria set out for company selection, the following case studies are reported here:

Case Study A
Case study A is a traditional manufacturing company based in South Wales. They manufacture products for the mass transport industry, and have a staff of 50. Prior to the implementation of the TCS programme the company had no in-house design or CAD resource. This meant that their capacity to interpret clients’ designs (from a manufacturability point of view) was limited. This was also complicated by the fact that the specialist knowledge of the key process characteristics that influence a design’s viability was dispersed among a number of management and operational staff. Furthermore, this implicit knowledge resource was not formalised, i.e. recorded or categorised in any way. Thus there was no channel through which it could be systematically made available to clients and their designers. This led to a situation where the Company was failing to be proactive enough in liaising with clients at an early stage in their design process. The only way for clients to submit data was to issue hard copy manufacturing drawings. These designs often required modifications, and time was lost in seeking approval for changes. Also the nature of the 2D CAD meant that it was also difficult to interrogate designs fully.

In September 2001, a two year TCS programme was established, with the main project aim of implementing an in house-design facility. As part of this plan design-led technologies such as Computer Aided Design (CAD) and Computer Aided Engineering (CAE) have played a major role, and will be discussed in relation to the operational impact that they have had on the company.

Case Study B
Case study B is also manufacturing SME based in South Wales. The company manufactures tools for the automotive industry and domestic goods packaging industry. They also manufacture patterns, and have a staff of 16. Traditionally, the company manufactured these tools and patterns using manual machining techniques and labour intensive processing. The director of the company saw an opportunity to keep pace with competitors and improve profit margins by implementing CAM systems. Their first CAD/CAM package was bought on a customer recommendation, but nobody was able to use it for tasks other than viewing models/drawings. This lack of skills in-house to drive a CAM system and supporting CAD software needed to be addressed in order to realise the commercial benefits of the new technologies, therefore this company linked up with PDR to undertake a TCS programme. Through the TCS a graduate Mechanical Engineer was commissioned to implement a CAM system and train other employees in its use. In addition to this there was the requirement to train staff in the use of CAD. Case study B has successfully increased the complexity of its products using these new design-led technologies, and increased the output of the company’s work.

Case Study C
Case study C is an automotive mouldings manufacturer. The company has 120 staff in its UK branch and is part of a global group. The CAD/CAM and plant monitoring equipment technologies were selected due to the company owner’s own philosophy and insight. He was driven by engineering challenges. Particular research within the area of over-moulding of metal components for the automotive industry was undertaken in conjunction with PDR. The most up-to-date rapid prototyping technology was utilised within PDR’s research group to realise this method as a new design verification tool, enabling rapid prototypes to be manufactured and tested before committing to expensive production tooling. This had a considerable effect upon time, cost and quality of this company’s components.

Case study C was not a TCS programme, but their close working relationship with PDR allowed access to their key technical staff. It was also selected to provide a source of control data within this study.

Case Study D
Case Study D is a supplier of survival equipment. It has 45 staff. Their main business involves buying in products, which are then sold on to customers through the company’s product literature and website. Principal customers include the UK Government and international aid and disaster relief charities. A few years ago the MD decided that they could add value to their service by using their market knowledge to develop their own products. This, he felt, would bring more money into the company, and improve profit margins.
Subsequently a TCS scheme was established. The TCS project brought in a Graduate Product Designer to implement an in-house design department, over a period of two years. The implementation of design technology has brought significant resources to the company. They now have a design department that is able to react to market requirements and develop and manufacture their own products. This company didn't have a capacity to develop products prior to the implementation of the TCS scheme, and as such the implementation of new technology has not affected lead times.

RESULTS
The main operational areas chosen to concentrate on were lead times, project costs and product quality. Lead times and project costs are an effective metric, as they are easily quantifiable. The use of these as indicators has been discussed in previous literature [3,4,9]. Product quality is less tangible but is an important area of consideration. A summary of the manufacturing scenarios and the data gathered is shown in Table 1, and a graphical representation of the average impact factors, across all scenarios, for time, cost and quality is shown in Figure 1.

<table>
<thead>
<tr>
<th>Company</th>
<th>Manufacturing Scenario</th>
<th>Quantified Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>lead times</td>
</tr>
<tr>
<td>A</td>
<td>A1-Phenolics moulding process</td>
<td>(Y), 0.75</td>
</tr>
<tr>
<td></td>
<td>A2-Polyurethane RIM casting</td>
<td>(Y), 0.59</td>
</tr>
<tr>
<td></td>
<td>A3-Casting, low to medium volume, simple jobs</td>
<td>(Y), 0.20</td>
</tr>
<tr>
<td></td>
<td>A4-Casting, low to medium volume, complex jobs</td>
<td>(Y), 0.48</td>
</tr>
<tr>
<td>B</td>
<td>B1-Toolmaking</td>
<td>(Y), 0.78</td>
</tr>
<tr>
<td></td>
<td>B2-Patterns</td>
<td>(Y), 0.74</td>
</tr>
<tr>
<td>C</td>
<td>C1-High variety mass customisation</td>
<td>(Y), 0.75</td>
</tr>
<tr>
<td></td>
<td>C2-High volume &amp; mass production</td>
<td>(Y), 0.28</td>
</tr>
<tr>
<td>D</td>
<td>D1-New designs</td>
<td>too early</td>
</tr>
</tbody>
</table>

1) is the Yes/No answer to the question “have design-led technologies reduced times/reduced costs/improved quality?”

The figures which follow are the scores from the VAS scale.

Table 1. Manufacturing scenarios and associated impact of design-led technologies upon lead times, project costs & product quality

![Figure 1. Average VAS impact factors of lead-time, project cost & product quality](image)
Lead Times
In case studies A, B and C lead times have been reduced with the introduction of the new technologies. Within Company A four different scenarios have been investigated. Scenario A1 shows a particularly high score in comparison to the others. The reason for this is that this scenario concerns the company’s new phenolics moulding plant which needed to produce its first products in a very short time, in order to win the business. The production manager said that “There would be no phenolic business without the new technologies”. He was referring to the fact that all the implemented technologies, i.e. phenolic moulding, CAD and CAM were integral to producing the finished article. Scenario’s A2, A3 and A4, all showed decreases in lead times, although less dramatic than for case A1. The reasons for these reductions, even though they refer to different processes, were due to the use of rapid prototype models in making the tooling. The ability to interrogate 3D model files and make them suitable for RP models, which could then be used for tooling, greatly reduced product lead times. Scenario A3 also showed reductions for similar reasons, however as the products are simple ones, the impact was less as they could be made by more traditional pattern making techniques.

The capacity of design-led technologies to reduce lead times in both scenarios of case study B was very high. The ability to work with 3D data and a CAD modelling system was beneficial to both project situations. However, it is the ability of the CAM technology to process complex paths for the machine tools to follow (i.e. toolpaths) that made this difference. Previously toolpaths would have been programmed manually, and complex machining could have taken days. Some of the companies new projects would have been far too complex to programme manually.

In case study C, for the high volume and mass production scenario (C2), the low impact on lead times is typical of this scenario, due to the fact that the projects have already been condensed as much as possible. These projects are within a very competitive market, in which a company has to be operating at the limits of cost and time in order to enter it. However in C1, lead times were greatly reduced due to the ability of being able to use Rapid Tooling, in order to run tools a lot quicker, and create first-off samples much faster for testing. In case study D, the projects were not lead-time dependent as they had fewer time constraints and, as a result, its company did not report benefits in this area.

Project Costs
All companies had reported that the implementation of advanced engineering design-led technologies reduced project costs. Looking at case study A, it is seen that Scenario A1 witnessed the largest reduction in project costs. This was partly due to the reduction in labour during the moulding process and regulation of material used. CAD has been used to create patterns for tooling purposes, but this has not had a great impact on cost. Scenario A2 showed that a score below the combined average score had been reported for reducing costs (see table 1.0). The main contributory factor for this is the ability to communicate the design for manufacture process to the customer, by viewing and adapting their concept CAD model files. Scenarios A3 and A4 both showed a reduction in project costs, but not as significantly. In the case of casting complex jobs, cost reductions were nearly twice as much as simple jobs. Again, this was due to the ability of being able to use in-house CAD facilities to generate files for rapid prototyping of patterns. By using RP models as patterns, more complex jobs such as those with complex curvature, or non-uniform walls, were much quicker to produce than when made manually. This in turn reduced costs.

Case study B showed one of the largest perceived reductions in project costs. The introduction of CAM software had enabled toolpaths to be created much quicker than could manually be programmed. Also, the ability to simulate programmes before running them gave the engineer the confidence to run machines overnight, thus maximising machine running time and further reducing cost. This applied to both project scenarios. It is interesting to note that the cost reductions in situation B2 refers to pattern making, again, as reported in Scenarios A3 and A4 for case study A. Across all case studies and all manufacturing scenarios, the greatest impact on cost saving, was made in the case of high variety mass customisation project in company C. It was the ability to use the CAD/CAM technologies to produce rapid tooling alongside permanent tooling that made the most significant impact on these projects. For example, permanent high volume tooling costs many thousands of pounds and takes months to make. Therefore, once permanent tooling production has begun, rapid tooling and sample products can be manufactured in a matter of weeks. These can then be tested and checked, and any changes can be made to the permanent tooling at an early, less costly stage. For high volume mass production projects, cost savings were also made, as a result of the use of specialist monitoring technologies which
monitored and measured process parameters. The data from this was used for statistical process control, which enabled process optimisation and a further reduction in costs.

For case study D project costs were shown to have a rating of 0.53, which is above the calculated average value of 0.49. One contributing factor is the ability to communicate with manufacturers using CAD, and discuss product designs as early as the concept stage. However there was a lack of data to draw upon which further supported this due to the very limited number of projects completed by the company. An interview in the future may give more insight into the impact that the new technology had on project costs.

**Product Quality**

Eight out of the nine company scenarios reported an increase in product quality as a result of the application of these technologies. It is interesting to note that case study A contains the scenario with the highest perceived product quality, as well as a scenario whereby it was too early to rate (A1 and A2 respectively). In the first scenario for example, the product was being manufactured using a bespoke tooling process, and trimmed using 5-axis CAM technology (which enabled difficult toolpaths to be created quickly and accurately). This method gave the customer products which are more accurate and repeatable than competitors can achieve. Adversely the technology on the Polyurethane manufacturing scenario has been seen to have less of an impact on the products. There are a number of reasons for this; firstly that little time was invested in exploiting and advertising this side of the business, and secondly a reluctance to develop projects when they arose due to key personnel and their involvements in other projects. The latter describes the situation where a considerable amount of capital has been invested into the new phenolic manufacturing facility, and as such time and effort for this side of the business have been in proportion to this, leaving the investment in the Polyurethane facility trailing behind.

For scenarios A3 and A4, considerably higher ratings were given than were for lead times and project costs. Reasons for this were the use of “modern methods which provide far superior patterns”. They use resin models which are more accurate than traditional wood materials, and have no wood grain and a better finish.

Case study B reported high scores for the effect that technology has had on its production quality for both its pattern making and tool making projects. One of the major contributing factors for this was the ability to create more complex toolpaths and vary a range of parameters. Such parameters as cut type and feed rate may not have been easily altered before or were very time consuming, or impossible to do manually.

Both scenarios in Case study C have the same high rating of 0.83. Evidence for this is that the number of products which fail are in single figures in terms of parts per million made. A large contributory factor to this is the complex process control systems of the company’s moulding machines as mentioned previously. Case study D reported that the ability to communicate concepts with manufacturers and customers enabled the high increase in product quality. The use of 3D CAD modelling and 2D drafting enabled the designer to get feedback on designs, and if necessary, adjust them according to the most suitable method for manufacture. The ability to use rendered 3D models in conjunction with other graphics packages allowed the designer to produce presentation visuals for customers very quickly.

**DISCUSSION**

In all case studies it is clearly seen that by implementing advanced design-led technologies time, cost and quality are factors which are all positively influenced. The results from this paper support findings that CAD and CAM software speed up design and engineering activities [2]. One of the main contributory factors for this was the enhanced level of communication reported, throughout all stages of the product development process. For example, the ability of a designer to discuss the manufacturability of a concept at an early stage saved additional development work at the manufacturing stage. The other main factor was the speed with which complex toolpaths for CNC machining or rapid prototyping could be programmed using CAM software. This significantly reduced manual programming time and enabled the construction of particularly complex 3D toolpaths. These findings support views of a number of other researchers in this field [3,4].
Actual impact data on implementing advanced design-led technologies within manufacturing SMEs is limited. Issues relating to quality are often overlooked, however the findings from this paper show that the most significant effect has been observed on product quality. In Figure 1 it is clearly seen that the scores for product quality were higher (ranging from 0.65 to 1.00) than for lead times and project costs. The range is also less, displaying a much higher agreement between the different case studies. It is surprising that this is the case as quality is the least tangible of the three factors examined within this paper.

We can categorize the overall impact of the design-led technologies in the following manner:

<table>
<thead>
<tr>
<th>Level of Impact</th>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major impact</td>
<td>Manual manufacturing to automated low</td>
<td>A1, phenolics production</td>
</tr>
<tr>
<td></td>
<td>volume production</td>
<td></td>
</tr>
<tr>
<td>Moderate impact</td>
<td>High volume, automated mouldings</td>
<td>C2, automotive mouldings manufacturer</td>
</tr>
<tr>
<td>Low impact</td>
<td>Immature company</td>
<td>D1, new design department</td>
</tr>
</tbody>
</table>

Case Study A showed that for its phenolic manufacturing scenario, the technology implemented had the ‘best possible’ effect upon product quality. The company represented by case study A carried out market research prior to creating its new phenolic moulding plant, which showed a clear gap in the market for producing composite products that have uniform wall section, and are trimmed to a high accuracy, using closed moulds instead of hand-lay up systems. This company then introduced a bespoke production plant utilising appropriate advanced engineering technologies. The result is that these technologies have had the greatest possible impact on product quality, and hence the maximum recorded value.

The CAD/CAM technology introduced in case study B has increased the quality of products by enabling more complex toolpaths and finishing paths to be created. In addition to this, the ability to adjust machining parameters quickly and easily has resulted in a smoother surface finish, for example the way in which a tool enters a workpiece can affect the surface quality, but with CAM this parameter is easily adjusted for optimum performance. The customer is interested in the quality of their moulded components, which is greatly affected by the quality of the tool.

Within case study C, the investment in continual process improvement and advanced engineering technologies to monitor the many moulding parameters during production has had an enormous impact upon product quality. This company has reduced its rejects to single figures for millions of parts produced.

The way in which the advanced design-led technologies are implemented can lead to their success or failure within a company [5]. Results from Case study D supported these findings. It was apparent that within this company the new in-house design department offers significant resources to the company, however lack of commitment from senior levels of management have prevented it from reaching its full potential. As mentioned previously, due to the immature nature of the design department within the company, there was a lack of data for completed projects in comparison to the other case studies. Future work may include a repeat visit to the company to observe the developments as the design department grows and completes further projects. It should be noted that four case studies does not represent a significant amount of data, however this paper shows that by using a sound methodology, useful results can be obtained and conclusions drawn.

**CONCLUSIONS & FUTURE WORK**

The ability to implement design-led technologies has been shown to significantly benefit project lead times, project costs and product quality within a variety of project scenarios. Future work will investigate these areas further in a number of other small manufacturing companies. This work will also examine other factors influenced by the implementation of design-led technologies including inter and intra-company communication, staff motivation and training.
REFERENCES

CHALLENGES IN IMPLEMENTING DESIGN-LED TECHNOLOGIES WITHIN SMALL MANUFACTURING COMPANIES

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ABSTRACT

This paper discusses some of the challenges of implementing design-led technologies, such as computer-aided design (CAD), within the context of small manufacturing companies. The research is based on knowledge transfer collaborations using the KTP model, and the paper adopts a case-study approach based on three such companies. The paper assesses the operational impact of these technologies in three key areas: lead times, project costs and product quality and evaluates the product development challenges that were addressed in each case.

KEYWORDS: SME, Knowledge Transfer, Product Development Challenges.

INTRODUCTION

Small and medium-sized enterprises (SMEs) represent a key element in national economies around the world, and they play a significant role in the design, development and manufacture of new products. In the EU an SME is categorised as a company employing fewer than 250 people. In fact, more than 95% of the three million businesses in the UK employ fewer than 20 people (Cawood, 1997). In order for SMEs to maintain their competitive advantage in an increasingly harsh international market, they need to be receptive to operational and strategic change that promotes innovation. One mechanism for this is the adoption of design-led technologies. We can categorise design-led technology as equipment and/or procedures that facilitates improvements in the design-to-manufacturing and new product development processes.

Computer-aided design (CAD) and computer-aided manufacturing (CAM) software are typical examples of design-led technologies. They speed up design and engineering activities by rapidly capturing design intent and reducing the errors between the development stages (Robertson and Allen, 1993). A number of researchers have highlighted the benefits of integrating CAD/CAM systems within the product development process (Droge et al., 2000), with particular emphasis being placed on reducing the time and cost of bringing new products to market. However, it has been noted that CAD/CAM systems can inhibit innovation (Kessler and Chakrabarti, 1999); therefore the mechanisms for knowledge and technology transfer into SMEs are important considerations.

Some areas of the manufacturing industry, especially those dependent upon traditional fabrication techniques have been slow to adopt design-led technologies. The majority of the literature focuses on well-established sectors, such as aerospace and automotive industries (Millson et al., 1992). Advanced design-led technologies are likely to have a significant beneficial impact on small ‘traditional’ manufacturing companies, but research in this area is limited (Brown et al., 1996). This paper will highlight the impact of design-led technology within small manufacturing companies, and draw attention to the challenges that such companies face in the resource-constrained environment in which they operate. In particular, it reveals that whilst design-led technologies can have a positive impact on the day-to-day manufacturing performance, strategic long-term product development tends to be conducted in an ad hoc manner, characterised by insufficient planning, inadequate resources and inattention to detail. This paper examines the challenges that small manufacturers face in the
application of product design and development, and confirms that these frequently arise from the idiosyncratic nature of senior management within such companies (Filson and Lewis, 2000).

METHODOLOGY

PDR have employed the KTP model as an effective mechanism for partnership and collaboration with a wide range of SMEs. KTP (formerly known as TCS or Teaching Company Scheme) has been in operation in the UK for over 20 years, and is a government-backed knowledge transfer scheme. The aim of the scheme is to strengthen the competitiveness and wealth creation of the UK by stimulating innovation in industry through structured collaborations between universities and research organisations. A typical KTP programme runs for two years, between one company, one university and tti Ltd. Each individual programme is designed to address the key elements central to the successful development of a specific company. Hence, the KTP model is an ideal model though which to analyse the knowledge transfer process (Lipscomb and McEwan, 2001), and thereby identify factors that have a beneficial or detrimental impact on its success.

PDR has extensive experience of KTP programmes as a route for strategic knowledge transfer to UK companies, and the majority of these programmes have been based in small companies. PDR have successfully completed over twelve KTP programmes since 1995 with six PDR-based KTP programmes currently on-going. All the PDR-based KTP programmes are, or have been, focused on product design and development. These collaborations are characterised by a commitment to effective project management through mandatory monthly and quarterly meetings. The documentation arising from the structured meetings (technical reports, presentation material, etc.), in parallel with the weekly informal meetings, results in a comprehensive portfolio of case-study material. This research study has selected a series of anonymous KTP-based case studies to illustrate the impact of design-led technologies and the challenges to strategic product development within SMEs. The selection criteria for the case-study companies were as follows:

a) Small company - between 10 and 50 employees - currently undertaking or recently completed a KTP programme with PDR;
b) Resource-limited company with regard to funding and personnel constraints;
c) Traditional manufacturing company, where fabricating products is the core business;
d) Commitment from within the company to enhance its design capability in order to undertake new product development activities in-house.

In addition to the standard KTP case-study material, a series of structured interviews were conducted with senior technical staff that had a close working involvement with the design-led technologies. The primary aim of the interviews was to measure the operational impact of the new design-led technologies. A mix of qualitative and quantitative data was collected through the use of open and closed questions, in combination with Visual Analogue Scale (VAS) ratings for lead times, projects costs and product quality. The output from these interviews also clarified some of the longer term strategic challenges associated with new product development within the manufacturing companies.

CASE STUDIES

Analysis of the series of PDR-based KTP programmes showed that eight programmes conformed to the selection criteria highlighted in the previous section. Three KTP case studies were selected as exemplar material, and a review of each company is given. Many other PDR-based KTP case studies could have been selected, but the manufacturing impact and product development challenges are best illustrated in the companies presented below.

KTP case study A: Mass transit supplier
Company A is a traditional manufacturing company producing products for the mass transport industry, with a staff of 47. Prior to the implementation of the KTP programme the company had no in-house design or CAD resource. This meant that their capacity to interpret clients’ designs (from a manufacturability point of view) was limited. This was also complicated by the fact that the specialist knowledge of the key process characteristics that influence a design’s viability was dispersed among a number of management and operational staff. Furthermore, this implicit knowledge resource was not formalised, i.e. recorded or categorised in any way. Thus there was no channel through which it could be systematically made available to clients and their designers. This led to a situation where the Company was failing to be proactive enough in liaising with clients at an early stage in their design process. The only way for clients to submit data was to issue hard copy manufacturing drawings. These designs often required modifications, and time was lost in seeking approval for changes. The KTP programme implemented 3D CAD-based design facility to act as customer interface, but also to integrate the design and manufacturing processes through a dedicated CAM system.

KTP case study B: Automotive tooling manufacturer

Company B is manufacturing business, employing a range of CNC machining centres. The company manufactures tools for the automotive industry and domestic goods packaging industry. They also manufacture patterns, and have a staff of 16. Traditionally, the company manufactured these tools and patterns using manual machining techniques and labour intensive processing. The director of the company saw an opportunity to keep pace with competitors and improve profit margins by expanding their product range through the implementation of a specialised CAD/CAM system. Their first CAD/CAM package was bought on a customer recommendation, but nobody was able to use it for tasks other than viewing models and drawings. This lack of in-house skills to drive a CAM system and supporting CAD software needed to be addressed in order to realise the commercial benefits of the new technologies; therefore this company linked up with PDR to undertake a KTP programme. Through the KTP a graduate mechanical engineer was commissioned to implement a CAM system and train other employees in its use. In addition, there was the requirement to train staff in the use of CAD. Company B has successfully increased the complexity and range of its products using these new design-led technologies.

KTP case study C: Safety equipment manufacturer

Company C is a supplier of safety and survival equipment, with a staff of 45. Their main business involves buying in products, which are then sold on to customers through the company’s product literature and website. Principal customers include the UK Government and international aid and disaster relief charities. The managing director decided that he could add value to the company by using their market knowledge to develop their own products, in particular, focusing on more high-risk/high-profit-margin products to increase turnover and penetrate new markets. Subsequently, a KTP scheme was established to implement a 3D CAD-based design department, over a period of two years. The implementation of design technology has brought significant resources to the company. They now have a design department that is able to react to market requirements and develop and manufacture their own products. The company didn’t have a capacity to develop products prior to the implementation of the KTP scheme, and as such, the implementation of new technology had the potential to make significant impacts.

RESULTS: MANUFACTURING IMPACT

The main operational areas chosen to concentrate on were lead times, project costs and product quality. Lead times and project costs are an effective metric; they are relatively easy to quantify and have been employed as indicators by other researchers in the field (Sanchez and Perez, 2003). Product quality is less tangible but is an important area for consideration. A summary of the manufacturing scenarios that employed the design-led technologies, together with the data gathered from the case-study interviews is shown in Table 1.
Table 1: Manufacturing scenarios and associated impact of design-led technologies.

<table>
<thead>
<tr>
<th>Company</th>
<th>Manufacturing Scenario</th>
<th>Quantified Impact*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Phenolics and Polyurethane Mouldings</td>
<td>67% 58% 92%</td>
</tr>
<tr>
<td>A</td>
<td>Metal Alloy Castings</td>
<td>34% 23% 65%</td>
</tr>
<tr>
<td>B</td>
<td>Pattern Making and Precision Tooling Machining</td>
<td>76% 63% 77%</td>
</tr>
<tr>
<td>C</td>
<td>Manual Machining and Injection Moulding</td>
<td>10% 53% 80%</td>
</tr>
<tr>
<td></td>
<td>mean values =</td>
<td>47% 49% 77%</td>
</tr>
</tbody>
</table>

*The percentage figures are the values from a series of VAS ratings in response to the question: 'What impact have the design-led technologies had in terms of reduced lead times / reduced project costs / improved product quality?' Note: 0% = no positive impact, and 100% = best-possible positive impact.

In all the case-study companies, the results clearly show that by implementing design-led technologies, such as CAD/CAM systems, key operational factors (time, cost, quality) are all positively influenced. The mean values across all manufacturing scenarios show that the impact on lead times and project costs are at a similar level. These results support findings that design-led technologies speed up design and engineering activities, enhance communications throughout all development stages and reduce the costs associated with complex manufacturing operations. Issues relating to product quality are often overlooked; however, Table 1 shows that the mean overall impact for product quality was higher (77%) than the two other factors, time and cost. This is somewhat surprising in that product quality is the least tangible of the three factors examined within this paper.

The mean values show the overall trend, but we can categorise the manufacturing scenarios into two broad areas. Firstly, the design-led technologies have had a major impact on the phenolics, polyurethane and precision tooling scenarios (A1 and B), which we can classify as the transition from manual techniques to automated low-volume production. The production manager for Company A said that ‘there would be no phenolics business without the new technologies’. In the case of Company B the new CAM software enabled complex tool paths to be created much quicker than could be programmed manually, and this gave the engineers the confidence to run the machines overnight, thus maximising machine-time availability and further reducing costs. Secondly, the new technologies have had a minor impact on the metal castings and injection-moulding manufacturing scenarios (A2 and C), which can be classified as high-volume and low-risk. The main benefit for Company A in this area was the use of rapid prototype models as a replacement for the traditional pattern-making techniques, but the products were simple and therefore the impact not as high as with complex components. Company C reported the ability to communicate concepts with customers produced an increase in product quality, but this was accompanied by only a 10% improvement in lead times. In this case study, a lack of commitment from senior management prevented the design-led technologies from reaching their full potential, imposing a restricted approach to product design and development.

**DISCUSSION: PRODUCT DEVELOPMENT CHALLENGES**

The main objective of the three KTP programmes was to implement design and development capabilities within ‘traditional’ manufacturing companies, such that they could reposition themselves and change from ‘just contract manufacturers’ to adding an element of in-house new product development. These small companies are innovative and operate closely alongside their customers and suppliers, therefore regularly generate new product concepts. The results from the previous section show that the immediate impact of implementing design-led technologies has been a quantifiable improvement in manufacturing operations. However, when we analyse the individual case-study company’s abilities to execute strategic new product development the findings are less positive and highlight a number of barriers that need to be addressed.
In PDR’s experience (borne out by these case studies), the role of the owner/manager (usually operating in the role of managing director) within the small family-run manufacturing businesses can often have a detrimental effect on the successful implementation of the product design and development process. One reason for this is that such owner/managers often do not have experience of, or knowledge of successful new product development; they attempt to cultivate design and development knowledge and experience “through osmosis”, rather than through formal training (Formosa and Kroeter, 2002). Their domineering personalities result in them making a disproportionately high number of key design and development decisions. In effect, they act as sole design authority, even though they do not possess the knowledge to make informed judgements on prototyping, tooling and other key product development elements. Rather than talking a longer term strategic and management role, they seek to control all design and manufacturing activities (Lewis and Filson, 2000). Furthermore, such owner/managers often tend to resist delegating responsibility. This situation is exacerbated by the often ineffective management structures observed within all three case-study companies. It would seem that within the small company environment, owner/managers frequently do not have the time or inclination to fully commit to the organisational and operational changes that are necessary in any successful KTP programme.

As a direct result of the dominant owner/manager, product development lead times were hampered from the outset by unrealistic expectations. Decision making was highjacked by short-term considerations, and all three case-study companies demonstrated a lack of planning with regard to implementing long-term product design activities. In an attempt to drive down lead times, activities such as design iteration or evaluation of alternative concepts were seen as unnecessary, and key development stages, such as prototyping, were omitted. In the case of Company C, the new product development activities were highly speculative, with no regard for adequate development time, such that the KTP Associate was expected to simply ‘draw it – make it – sell it’. When this approach failed, the managing director would quickly switch attention to another new idea. Long-term product development was further suppressed within Company A by their willingness to nurture a ‘quick fix’ reputation with their key multinational customer.

The small companies that are the subject of this paper function within very restricted financial and operational circumstances, and that this resource-constrained environment put pressure on all three KTP Associates to reduce costs. However, within Company A and B there were no cost control or cost monitoring mechanisms in place; costing methods were purely empirical. Company C represented an extreme case; technical meetings focused just on sales and profit-margins, such that product development was absurdly cost-sensitive. The result was that senior management were willing to sacrifice quality in order to reduce costs. The net effect of the twin obsessions of time and cost was to produce situations in all the case-study companies where product design and development proceeded in a highly constrained manner. Such circumstances are very different from those that prevail within larger companies, whereby systematic design and development activities tend to follow a multistage-gated process (Cooper, 1990).

Finally, there is the question of vision. Many owner/managers of small companies find it difficult to maintain a long-term vision for their company in the face of constantly dealing with day-to-day economic and operational pressures. This was certainly the case in the three case study companies discussed here. The result was that the potentially greater long-term benefits of the KTP programmes were often sacrificed to meet short-term requirements. PDR’s experience suggests that convincing such owner/managers to commit to a long-term approach will continue to be a major challenge for future KTP supervisors.

CONCLUSIONS

From the perspective of the knowledge-base partner, KTP programmes can generate an in-depth understanding of the commercial and operational impact of design-led technologies within small manufacturing companies. The implementation of CAD/CAM-based systems have been shown to have
a positive impact on the lead times, project costs and product quality in relation to specific manufacturing scenarios. The major impact pertaining to the transition from manual techniques to automated low-volume production, especially for bespoke products. In addition, the case-study material has revealed the more subtle challenges associated with traditional manufacturing companies attempting to initiate strategic new product development activities. The main barrier to successful, long-term product development is the lack of an understanding of product design and development on the part of the dominant owner/managers. A systematic approach to the design and development process should be adopted in order to counteract the 'short term' tendencies of SME managers, and hence develop more realistic expectations with regard to the time and costs associated with new product development. The fact that some degree of change was imposed, and successful results were delivered in each of the three case-study companies, is due as much (and possibly more) to the commitment and perseverance of the graduate KTP Associates who were implementing the various programmes, than to the leadership and vision of senior company managers.

Data based on three companies does not represent a significant amount of case-study material, but this paper shows that by employing a sound methodology it is possible to extract meaningful results. Future work in this area will expand on these case-study findings, increase the number of case-study companies analysed and attempt to highlight best practice for new product development within small manufacturing companies. The disparity between immediate manufacturing impact and long-term in-house design and development has clear implications for knowledge transfer within this sector, and the results can also be applied, to some extent, to medium-sized and large enterprises.

REFERENCES

Challenges in implementing design-led technologies in small manufacturing companies

Huw Millward, Peter Dorrington and Alan Lewis

Abstract: This paper examines some of the challenges of implementing design-led technologies, such as computer-aided design (CAD), in the context of small manufacturing companies. The research is based on university–company collaborations in the UK using the Knowledge Transfer Partnership (KTP) model, and the paper adopts a case-study approach based on three such partnerships. The authors assess the operational impact of design-led technologies in three key areas: lead times, project costs and product quality. The general design-based challenges are evaluated by examining the management and new product development culture in small manufacturing companies.

Keywords: SMEs; knowledge transfer; product development challenges

Small and medium-sized enterprises (SMEs) represent a key element in national economies around the world, and play a significant role in the design, development and manufacture of new products. In the European Union an SME is defined as a company employing fewer than 250 people. In fact, more than 95% of the three million businesses in the UK employ fewer than 20 people (Cawood, 1997). In order for SMEs to maintain their competitive advantage in an increasingly harsh international market, they need to be receptive to operational and strategic changes that promote innovation. One mechanism for this is the adoption of design-led technologies. We can define design-led technology as equipment and/or procedures that facilitate improvements in the design-to-manufacturing and new product development processes.

Computer-aided design (CAD) and computer-aided manufacturing (CAM) software are typical examples of design-led technologies. They speed up design and engineering activities by rapidly capturing design intent and reducing the errors between the development stages (Robertson and Allen, 1993). Various researchers have highlighted the benefits of integrating CAD/CAM systems into the product development process (Droge et al., 2000), with particular emphasis on reducing the time and cost of bringing new products to market. However, it has been noted that CAD/CAM systems can inhibit innovation (Kessler and Chakrabarti, 1999); therefore the mechanisms for knowledge and technology transfer into SMEs are important considerations.

Some areas of the manufacturing industry, especially those dependent on traditional fabrication techniques, have been slow to adopt design-led technologies. The majority of the literature focuses on well-established sectors, such as the aerospace and automotive
Implementing design-led technologies in small companies

industries (Millson et al., 1992). Advanced design-led technologies are likely to have a significant beneficial impact on small ‘traditional’ manufacturing companies, but research in this area is limited (Brown et al., 1996). This paper will highlight the impact of design-led technology in small manufacturing companies, and will draw attention to the challenges that such companies face in the resource-constrained environment in which they operate. In particular it reveals that, while design-led technologies can have a positive impact on day-to-day manufacturing performance, strategic long-term product development tends to be conducted in an ad hoc manner, characterized by insufficient planning, inadequate resources and inattention to detail. The paper examines the challenges that small manufacturers face in the application of product design and development, and confirms that these frequently arise from the idiosyncratic nature of senior management in such companies (Filson and Lewis, 2000).

Methodology

The UK’s National Centre for Product Design and Development Research (PDR) has employed the Knowledge Transfer Partnership (KTP) model as an effective mechanism for partnership and collaboration with a wide range of SMEs. KTP was formerly known as the Teaching Company Scheme (TCS), and these government-backed knowledge and technology transfer programmes have been in operation in the UK for approximately 25 years. The aim of the KTP scheme is to strengthen national competitiveness and wealth creation by stimulating innovation in industry through structured collaborations with leading universities and research organizations. KTP is run for the government by Technology Transfer and Innovation Limited (tti Ltd). A typical KTP programme is a two-year partnership between one company, one university and tti Ltd. Each individual KTP programme is designed to address the key elements central to the successful development of a specific company. The two-year project provides employment for a well-qualified graduate KTP Associate for the duration of the programme.

KTP programmes are open to companies working in almost any sector, in all regions of the UK. However, the programmes are designed primarily to help SMEs take advantage of the expertise available in the knowledge-based sector. A breakdown of recent KTP programmes, in relation to company size and programme objective, is given in Table 1, and this demonstrates the bias towards SMEs (DTI, 2003). Further figures indicate that, of the 415 (48%) design and development KTP programmes from 2003, 62% were based in small companies. These data demonstrate that new product development in small companies is a dominant element in the broad KTP portfolio, providing a rich resource for product development empirical data. It is worth noting that tti Ltd defines a small company as one employing between 10 and 50 people, and we shall retain this definition for the purposes of this study.

All the PDR-based KTP programmes are, or have been, focused on product design and development, and the numbers reflect the UK trend in that most have been based in small companies. PDR has successfully completed 15 KTP programmes since 1995, 11 of which have been with small companies. A typical PDR-based KTP programme implements a new product development capability in a ‘traditional’ small manufacturing company. In line with other researchers (Lipscomb and McEwan, 2001), we have found that the KTP model is an ideal vehicle through which to analyse the design, engineering and manufacturing interfaces, and the associated technical and managerial challenges in small companies.

The well-defined management and structure of the KTP process promotes a detailed analysis of the company from the university partner’s perspective. The KTP Associate is assigned at least one PDR-based

<table>
<thead>
<tr>
<th>Company size (employees)</th>
<th>Design &amp; development</th>
<th>Main programme objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro (&lt; 10)</td>
<td>15%</td>
<td>46%</td>
</tr>
<tr>
<td>Small (10–49)</td>
<td>42%</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Medium (50–249)</td>
<td>32%</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Large (251+)</td>
<td>11%</td>
<td>Management</td>
</tr>
<tr>
<td>Other</td>
<td>18%</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Percentage of KTP programmes by company size and programme objective, based on 903 pan-UK schemes from 1 April 2002 to 31 March 2003.

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supervisor and at least one supervisor from the company. A proportion of the KTP grant allows the PDR supervisors to be released from their normal duties and to spend between half a day and one day per week working on the project and closely supporting the Associate. This regular contact with the company fosters a level of trust and co-operation that generates an in-depth understanding of the subtle issues and problems inherent in any small company. These collaborations are characterized by a commitment to effective project management through mandatory monthly and quarterly meetings.

The monthly meetings focus on the technical issues in the programme, while the quarterly ones are underpinned by support from the tti Ltd consultant, and act as the programme’s steering group discussions to ensure that the long-term objectives are met. The documentation arising from these structured meetings (technical reports, presentation material, etc), together with weekly informal meetings, results in a comprehensive portfolio of case-study material.

This research study has selected a series of anonymous KTP-based case studies to illustrate the impact of design-led technologies and the challenges to strategic product development in SMEs. The selection criteria for the case-study companies were as follows:

- the companies had to be small – between 10 and 50 employees – and currently undertaking or having recently completed a KTP programme with PDR;
- they had to be resource-limited with regard to funding and personnel;
- they had to be traditional manufacturing companies, in which fabricating products was the core business; and
- they had to be committed to enhancing their design capability in order to undertake new product development activities in-house.

In addition to the standard KTP case-study material, a series of structured interviews was conducted with senior technical employees who had a close working involvement with the design-led technologies. The primary aim of these interviews was to measure the operational impact of the new technologies. To facilitate an effective mix of qualitative and quantitative data, a questionnaire was designed and this guided the interviewer during each session. The questionnaire contained open and closed questions in combination with Visual Analogue Scale (VAS) ratings. A series of 100 mm VAS was used to assess the impact of design-led technologies in terms of (a) reduced lead times; (b) reduced project costs; and (c) improved product quality. For each of these three key elements, the lower and upper bounds of the VAS were marked as 0% = no positive impact and 100% = best-possible positive impact. The output from these structured interviews also clarified some of the longer-term strategic challenges associated with new product development in the small manufacturing companies.

Case studies

Analysis of the series of PDR-based KTP programmes showed that eight programmes conformed to the selection criteria highlighted in the previous section. Three KTP case studies were selected as exemplar material, and a review of each company is given here. Many other PDR-based KTP case studies could have been selected, but the manufacturing impact and product development challenges are best illustrated in the companies presented below.

KTP case study A: quality component supplier

Company A, employing 47 staff, is a traditional manufacturing company producing a wide range of components and assemblies for specialist engineering applications, such as those in the automotive, transport and medical sectors. Fabrication is generally based on one of three core in-house manufacturing technologies: metal alloy castings, polyurethane mouldings, or composite mouldings. Prior to the implementation of the KTP programme, the company had no in-house design or CAD resource. This meant that its capacity to interpret clients’ designs (from a manufacturability point of view) was limited. This was also complicated by the fact that the specialist knowledge of the key process characteristics that influence a design’s viability was dispersed among a number of management and operational employees. Furthermore, this implicit knowledge resource was not formalized—that is, it was not recorded or categorized in any way. Thus there was no channel through which it could be systematically made available to clients and their designers. This led to a situation in which the company was failing to be sufficiently proactive in liaising with clients at an early stage in their design process. The only way for clients to submit data was to issue hard-copy manufacturing drawings. These designs often required modifications and time was lost in seeking approval for changes.

The aim of the KTP programme was to implement a knowledge-based design resource to improve customer communications and enhance the design-for-manufacturing process. In addition, the company wanted to undertake new product development in-house on a number of projects, and gradually to make the transition from ‘just manufacture’ to ‘design and
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manufacture' contracts. The design-led technology implemented during the KTP consisted of a central 3D CAD-based design facility, which then linked to a 5-axis machining system through specialist CAM software. The direct link between the design facility and the computer-numerically-controlled (CNC) machine tools provided the company with an opportunity to improve the quality of composite mouldings dramatically and so to obtain a number of prestigious transport contracts. This provided the company with an opportunity to set new safety standards in the industry and to generate a competitive advantage over its competitors.

Company A is a family-run business, with the managing director playing a dominant role across all sections of it. He frequently described himself as the best ‘technician’ in the company, and this ‘hands-on’ approach meant that he spent too much time being closely involved with design, prototyping and shop-floor issues, rather than managing the long-term strategic nature of the business. This situation was not helped by the fact that the managing director had failed to implement a clear managing and reporting structure. For example, management meetings were very rare and there were no mechanisms for communicating job priorities. The company was organized by manufacturing function rather than by a project-based culture, with the result that operations were governed by the personality of each function head. This meant that the senior managers were in permanent conflict with one another and the environment was therefore not conducive to new product development.

During the KTP programme, only three products were designed and developed in-house. The design facility was kept in isolation and treated simply as a ‘customer interface’. The new design resource was not used as a positive marketing tool and it failed to become fully integrated with all the manufacturing systems. The use of effective CAD/CAM software was sporadic, and so a number of precision machine tools were severely under-utilized. The KTP Associate did not get managerial backing for expanding the use of design documentation, and the company was very reluctant to incorporate design procedures within its overall quality system. This inability to commit to long-term design and development projects has resulted in the company failing to harness its inherent expertise. Instead, it preferred to rely on a few powerful key customers to provide the design impetus.

KTP case study B: specialist engineering company

Company B is a manufacturing business, with a staff of 16. The company uses a range of in-house CNC machine tools for pattern making and precision tool making. These components are produced to order for specialist engineering projects, such as mould tools for the automotive industry or the domestic-goods packaging industry. Traditionally, the company had manufactured these patterns and tooling systems using manual machining techniques, whereby the CNC code was entered manually for each separate job. In addition, hand-crafting techniques were employed through the production cycle, such as the hand-finishing of tooling. These labour-intensive procedures were not the best use of time and resources. The managing director of the company saw an opportunity to keep pace with competitors and improve profit margins by expanding the product range through the implementation of a specialized CAD/CAM system. The company’s first CAD/CAM package was bought on a customer’s recommendation, but it was found to be unproductive: nobody was able to use it for tasks other than viewing 3D models and 2D drawings. This lack of in-house skills to drive a dedicated CAM system and supporting CAD software needed to be addressed if the commercial benefits of the new technologies were to be realized – this company therefore linked up with PDR to undertake a KTP programme.

The aim of the KTP programme was to establish the company as a market leader through its ability to offer customers an intelligent CAD-based design resource linked directly to the manufacturing technology. A graduate mechanical engineer was recruited as the KTP Associate and, following a review of the manufacturing systems, it was decided to upgrade both the software and the machine tools. A dedicated CAD/CAM software package was implemented to handle customer design iterations as well as the crucial automated tool path configuration. In order to harness the accuracy of this new system, a new CNC machine tool was purchased to handle complex machining projects, offer additional capacity and further reduce lead times.

The implementation of design-led technologies had a significant impact on pattern making and tool making. Sub-contractors were no longer used to produce complex patterns and additional prototyping work could be undertaken in-house (for example, samples could be manufactured directly in model material). Detailed design work could now be carried out on behalf of the customer, and this in turn would make more efficient use of the manufacturing processes. A targeted training programme was delivered by the KTP Associate to raise the skill level and awareness of all employees involved in the direct or indirect use of the CAD/CAM system. The skill level and confidence of some of the key personnel improved to a level at which ‘lights out’ machining could be considered. However, the weak link in the new process
was the lack of understanding of CAD/CAM technology on the part of the managing director, who failed to appreciate the time and costs associated with design and development work. The result was that complex machining jobs were under-priced and the lead times for simple jobs were underestimated. The consequent series of unrealistic timescales and costs meant that the company had to focus on dealing with problems with its current customers rather than taking a long-term view and attempting to expand the business.

**KTP case study C: leisure equipment manufacturer**

Company C has a staff of 45 and has been in existence for over 20 years. Its range of leisure, safety and survival products can be classed as low-risk, low-technology components and assemblies. The in-house manufacturing facility includes simple manual machining operations and manual assembly lines. The company's main business involves buying in products which are then sold on to customers through its product literature and Website. In addition to general mail order, principal customers include the UK government and international aid and disaster relief charities. The managing director decided that he could add value to the company by using its market knowledge to develop its own products — in particular, focusing on more high-risk/high-profit-margin products to increase turnover and penetrate new markets. Only a small proportion of the company's products were designed and developed in-house and it therefore did not have sufficient control over lead times, costs and product quality. A KTP programme was established to implement a 3D CAD-based design department over a period of two years.

This company is a family-owned business, with strategy dictated by the managing director. Although other family members were in (somewhat undefined) positions of responsibility, the managing director dominated all areas of the business. The managing director had no formal training or professional experience in the area of product design, development and manufacture: his background was in accountancy. Consequently, the company was firmly orientated towards sales, with an emphasis on generating profit from minimal expenditure. There was poor communication between company functions, and this was further exacerbated by a lack of project meetings. During the early stages of the KTP programme, the company did not put enough emphasis on market research because the managing director thought he had a good understanding of the needs and aspirations of the end users. His assumptions would soon be challenged as it became clear that competitors had better patent protection and a better understanding of industry standards. There was a clear tendency for the company to jump from one project to another: it lacked the rigour for structured product development. For example, the managing director resisted the use of design and development documentation because he thought that it stifled creativity and innovation. The KTP Associate was a design engineer by training, but the company treated him as a graphic designer. The production of brochures and presentation materials did very little for new product development.

The only new product development projects that were successful during the KTP programme were those that were strongly driven by a customer (when a clear market need was identified early on). Under these conditions the team used a structured design process. Although the managing director thought that this process took too long, the customers were happy, so he did not block the process. The new design approach evaluated the ergonomics of the product, reviewed new tooling options and made contact with new subcontractors. This new knowledge has been captured and integrated in a formal stage-gate review process to approve and monitor new product development projects. The new design procedures, in tandem with the design-led technology, have brought significant resources to the company, which is now in a much better position to react to market requirements and develop appropriate products.

**Results: manufacturing impact**

The main operational areas selected for concentration were lead times, product costs and product quality. Lead times and project costs are an effective metric: they are relatively easy to quantify and have been employed as indicators by other researchers in the field (Sanchez and Perez, 2003). Product quality is less tangible, but is an important area for consideration. A summary of the manufacturing scenarios that employed the design-led technologies, together with the data gathered from the case-study VAS ratings, is presented in Table 2.

For all the case-study companies, the results clearly show that by implementing design-led technologies, such as CAD/CAM systems, key operational factors (time, cost, quality) are positively influenced. The mean values across all manufacturing scenarios show that the impacts on lead times and project costs are at a similar level. These results support findings that design-led technologies speed up design and engineering activities, enhance communications throughout all development stages and reduce the costs associated with complex manufacturing operations. Issues relating to product quality are often overlooked; however, Table 2 shows that the mean overall impact on product quality was higher (77%) than on the two other factors

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Table 2. Manufacturing scenarios and associated impact of design-led technologies.

<table>
<thead>
<tr>
<th>Company</th>
<th>Scenario</th>
<th>VAS Impact rating (%)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Lead times</td>
</tr>
<tr>
<td>A</td>
<td>(1) Composites and polyurethane mouldings</td>
<td>67</td>
</tr>
<tr>
<td>A</td>
<td>(2) Metal alloy castings</td>
<td>37</td>
</tr>
<tr>
<td>B</td>
<td>Pattern making and precision tool machining</td>
<td>76</td>
</tr>
<tr>
<td>C</td>
<td>Manual machining and injection moulding</td>
<td>10</td>
</tr>
<tr>
<td>Mean values</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

(time and cost). This is somewhat surprising, in that product quality is the least tangible of the three factors examined in this paper. In addition, the standard deviation results show that the values for the product quality scores are the most consistent in terms of spread. Although the level and consistency of the product quality scores are unexpected, they emphasize the positive attributes associated with implementing design-led technologies. The results presented here are derived from a relatively small sample size, and therefore further interviews and data gathering would be required to build on these initial conclusions.

The values reported in Table 2 show the overall trend from the case studies, but we can categorize the manufacturing scenarios into two broad areas. First, the design-led technologies have had a major impact on the phenolics, polyurethane and precision tooling scenarios (A1 and B), which we can identify as the transition from manual techniques to automated low-volume production. The production manager for Company A said 'there would be no phenolics business without the new technologies'. In the case of Company B, the new CAM software enabled complex tool paths to be created much more quickly than with manual programming and this gave the engineers the confidence to run the machines overnight, thus maximizing machine-time availability and further reducing costs. Second, the new technologies have had a minor impact on the metal castings and injection-moulding manufacturing scenarios (A2 and C), which can be classified as high-volume and low-risk. The main benefit for Company A in this area was the use of rapid prototype models as a replacement for the traditional pattern-making techniques, but the products were simple and therefore the impact was not as high as with complex components. Company C reported that the ability to communicate concepts with customers had produced an increase in product quality, but this was accompanied by only a 10% improvement in lead times. In this case study, a lack of commitment from senior management prevented the design-led technologies from reaching their full potential, imposing a restricted approach to product design and development.

Discussion: product development challenges

The main objective of these three KTP programmes was to implement design and development capabilities in 'traditional' manufacturing companies, so that they could reposition themselves and improve their status of 'just contract manufacturers' by adding an element of in-house new product development. These small companies are innovative and operate closely alongside their customers and suppliers, thereby regularly generating new product concepts. The results discussed in the previous section show that the immediate impact of implementing design-led technologies has been a quantifiable improvement in manufacturing operations. However, when we analyse the individual case-study companies' abilities to execute strategic new product development, the findings are less positive and highlight a number of barriers that need to be addressed.

In PDR’s experience (borne out by these case studies), the role of the owner-manager (usually operating in the role of managing director) in a small family-run manufacturing business can often have a detrimental effect on the implementation of the product design and development process. One reason for this is that such owner-managers often do not have experience of, or knowledge of, successful new product development; they attempt to cultivate design and development knowledge and experience ‘through osmosis’ rather than through formal training (Formosa and Kroeter, 2002). Their engineerly personalities lead them to make a disproportionately high number of key design and development decisions. In effect, they act as sole design authority, even though they do not possess the knowledge to make informed judgements on prototyping, tooling and other key product developments.
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development elements. Rather than taking a longer-term strategic and management role, they seek to control all design and manufacturing activities (Lewis and Filson, 2000). Furthermore, such owner-managers frequently tend to resist delegating responsibility and this tendency is exacerbated by often ineffective management structures, such as those observed in all three case-study companies. It would seem that in the small company environment owner-managers frequently do not have the time or inclination to commit fully to the organizational and operational changes that are necessary in any successful KTP programme.

As a direct result of the dominant owner-managers, product development lead times were hampered from the outset by unrealistic expectations. Decision making was hijacked by short-term considerations, and all three case-study companies demonstrated a lack of planning with regard to implementing long-term product design activities. In an attempt to drive down lead times, activities such as design iteration or the evaluation of alternative concepts were seen as unnecessary and key development stages, such as prototyping, were omitted. In the case of Company C, the new product development activities were highly speculative, with no regard for adequate development time, such that the KTP Associate was expected to simply ‘draw it – make it – sell it’. When this approach failed, the managing director would quickly switch attention to another new idea. Long-term product development was further suppressed in Company A by its willingness to nurture a ‘quick-fix’ reputation with its key multinational customer.

These three small companies function in very restricted financial and operational circumstances, and this resource-constrained environment put pressure on all three KTP Associates to reduce costs. However, in Companies A and B there were no cost-control or cost-monitoring mechanisms in place: costing methods were purely empirical. Company C represented an extreme case: technical meetings focused merely on sales and profit margins, such that product development was absurdly cost-sensitive. The result was that the senior management was willing to sacrifice quality in order to reduce costs. The net effect of the twin obsessions of time and cost was to produce situations in all the companies in which product design and development proceeded in a highly constrained manner. Such circumstances are very different from those that prevail in larger companies, where systematic design and development activities tend to follow a multistage-gated process (Cooper, 1990). One aspect of the design and development process that was influenced by the time and cost constraints in the small companies was the creation of adequate design documentation. In fact, in Companies A and C structured documentation (such as product design specifications and market analysis) was actively discouraged because the generation of such material was not seen by the owner-managers as a necessary prerequisite for a successful product outcome. The absence of structured design documentation allowed the owner-managers to impose their own impromptu design philosophy on the KTP programmes, whereas the implementation and maintenance of appropriate design documentation would have forced the companies to consider a systematic design process – but this appears to be a common problem among many small manufacturing companies (Lewis and Walters, 2002).

Finally, there is the question of vision. Many owner-managers of small companies find it difficult to maintain a long-term vision for their company in the face of constant day-to-day economic and operational pressures. This was certainly true in the three case-study companies discussed here. The result was that the potentially greater long-term benefits of the KTP programmes were often sacrificed to meet short-term requirements. PDR’s experience suggests that convincing such owner-managers to commit to a long-term approach will continue to be a major challenge for future KTP supervisors.

Conclusions

From the perspective of the knowledge-base partner, KTP programmes can generate an in-depth understanding of the commercial and operational impacts of design-led technologies in small manufacturing companies. The implementation of CAD/CAM-based systems has been shown to have a positive impact on lead times, project costs and product quality in relation to specific manufacturing scenarios. The major impact pertains to the transition from manual techniques to automated low-volume production, especially for bespoke products. In addition, the case-study material has revealed the more subtle challenges associated with traditional manufacturing companies that attempt to initiate strategic new product development activities. The main barrier to successful, long-term product development is the lack of an understanding of product design and development on the part of the dominant owner-manager. A systematic approach to the design and development process should be adopted to counteract the ‘short-term’ tendencies of SME managers, and hence to develop more realistic expectations with regard to the time and costs associated with new product development. The fact that some degree of
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change was imposed and successful results were delivered in each of the three case-study companies is due as much (and possibly more) to the commitment and perseverance of the graduate KTP Associates implementing the various programmes than to the leadership and vision of senior company managers.

Data based on three companies do not represent a significant amount of case-study material, but this paper shows that, by employing a sound methodology, it is possible to extract meaningful results. Future work in this area will expand on these case-study findings, increase the number of case-study companies analysed and attempt to highlight best practice for new product development in small manufacturing companies. The disparity between immediate manufacturing impact and long-term in-house design and development has clear implications for knowledge transfer in this sector, and the results can also be applied, to some extent, to medium-sized and large enterprises.

References


ORGANISATIONAL CHANGE REQUIREMENTS FOR ADVANCED MANUFACTURING TECHNOLOGY (AMT) IMPLEMENTATION

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Abstract

The implementation of AMTs is seen as an important research topic due to its potential impact on competitiveness of smaller companies. A survey of existing literature on organisational change leads the authors to categorise the previously published research into three broad categories: organisational learning, operator empowerment and internal politics. The results of the literature survey are used to aid analysis of a case study company's organisational change performance. The consensus from both the literature review and case study findings are that in order to utilise AMTs to their full potential SMEs must be willing to undergo a degree of organisational change. Such organisational change must incorporate a degree of organisational learning, which is likely to include increasing the skills of employees and adapting the ways in which they work. In turn, this encourages companies to take an enabling approach to technology implementation that allows operators to interact more creatively within an organisation. Both organisational learning and operator empowerment are tools that will impact upon the internal politics of an organisation. A positively influencing approach to internal politics within an organisation has the potential to create an environment conducive to change. The findings from this paper are to be used as part of a wider study that will further investigate the impact of AMTs on small Welsh manufacturing companies.
Introduction

The purpose of the research presented in this paper is to develop an understanding of the organisational change requirements for small companies planning to implement an advanced manufacturing technology (AMT). Much of the published research regarding AMT implementation has concentrated on large US manufacturing organisations, however, AMT has been identified as an important research topic that may aid improvement in the competitiveness of smaller European manufacturing companies [1, 2]. This paper reports a survey of published outcomes examining issues of organisational change within manufacturing companies. The results of the literature review are used to aid analysis of a small company’s achievements in AMT implementation. This paper forms part of a wider research project to identify the critical factors for the selection, implementation and development of AMT in small Welsh companies.

Over the last two decades, quality and flexibility in manufacturing have become as important a focus as cost reduction in Western companies [3]. Due to such a shift in focus, much research has been conducted into the application of AMT. The importance of these new manufacturing objectives are indicated in the UK Government’s Manufacturing Strategy which advocates that, “in the face of low-cost competition, firms must move up the value added chain and embrace knowledge-intensive, high skilled manufacturing” [4].

Youssef [5] defines AMT as “a group of integrated hardware-based and software-based technologies, which if properly implemented, monitored and evaluated, will lead to improving the efficiency and effectiveness of the firm in manufacturing a product or providing a service.” Common examples of AMT include Computer Aided Design and Manufacture (CAD/CAM), Computerised Numeric Control (CNC) machines, industrial robots, etc. Successful implementation of AMT has been associated with numerous tangible and intangible benefits [6]. Tangible benefits include: Inventory savings; reduced floor space; improved return on equity; and, reduced unit costs. Intangible benefits include: Enhanced competitive advantage; increased flexibility; improved speed of response; and, improved product quality and reliability [7, 8].

The potential benefits of AMT are widely reported, however, much of the literature on AMT indicates that companies are often dissatisfied with the benefits that such technological investment has brought to their businesses [3, 8, 9, 10]. Difficulties with the implementation and maintenance of AMT include: Communication; commitment; education; investment in support mechanisms; and, lack of previous experience in AMT implementation [11, 12]. A well-documented and significant barrier to successful implementation is resistance to change at various levels within the workforce. Tantoush and Clegg [13] advocate that it may not be politically possible to implement technological change within an organisation even if such changes have been rationally deemed necessary. Even small organisations, often regarded as naturally inclined to change, suffer political barriers to technology implementation [14]. Following a review of the literature, the authors have categorised the previously published research in regards to organisational change in manufacturing companies into three broad categories: Organisational learning; operator empowerment; and, internal politics.

Organisational learning

The published literature on technological change within manufacturing companies has indicated that the drivers of such change include: To obtain competitive advantage; to obtain financial benefit; to counter competitive threat; to improve product quality; etc [5, 15]. However, when examining three UK automotive component suppliers, Lee et al [16] found that the drivers for change in these organisations was pressures imposed by their customers, i.e. major vehicle manufacturers. The authors note that smaller companies face numerous barriers to technological change including: negative attitudes and perceptions of
the effects of change; resource constraints; and, a lack of interaction with external expertise to facilitate technology implementation. However, the authors also advocate the importance of innovation and high skilled manufacturing stating that:

Most of the resources within a company are accessible by competitors (e.g. capital, raw materials, standard technologies), therefore competitive advantage derives from the knowledge and abilities of the workforce.

In order to aid analysis of the efforts of their case study companies' attempts to become more competitive during a period of technological change, Lee et al developed eight characteristics of organisational learning. These characteristics were based on those developed by Weaver (1994, cited in Lee et al [16]):

- **Shared mental models**: Encouraging a shared vision of the organisation
- **Learning values**: Encouraging individual and group interaction to create new organisational learning
- **Experimentation and innovation**: Mechanisms to tap creativity from employees
- **Legitimate politics**: Encouraging employees to pursue their own goals and interests where these can be aligned to the needs of the business
- **Learning from the past**: Monitoring and evaluating results to guide future decision-making
- **Synthesising perspectives**: Encouraging employees to be responsive to alternative perspectives
- **Commitment to professional development**: Encouraging employees to develop their knowledge and skills
- **Participative information search**: Analysis of the business environment to enhance company planning

Following evaluation of the performance of the case study companies against these characteristics, Lee et al suggest that small and medium sized enterprises (SMEs) have a tendency to focus on those areas of organisational change that present least challenge in implementation. The authors suggest that these changes centre on improvements in face-to-face communication between managers and workers, an aspect of organisational change that is easier for the smaller firm to maintain than it is for the larger company.

Sherer et al [17] examined the importance of investment in organisational change management in aiding the successful implementation of a new technology. The authors argue that many companies fail to place enough emphasis on the changes that employees must make to the way that they work in order to successfully utilise a new technology. The study focussed on a single multi-national company's perspective, however, the particular technological implementation examined was a corporate wide system upgrade. The authors concluded that the investment that the company had made in managing the change had a significant impact in improving client satisfaction and reducing resistance from the workforce.

**Operator empowerment**

Adler and Borys [18] state that efficient manufacturing requires certain levels of formalisation of processes and procedures. However, they also note that bureaucracy often
has a negative impact on innovation and change within companies. In their study of organisational bureaucracy, the authors identified two types of formalisation, coercive and enabling. The authors advocate an enabling approach when implementing an AMT that requires increased skill levels on the part of the operator. Such an approach requires the company to allow more discretion in the ways in which people work, with procedures that empower users of technology. This provides an environment in which operators interact more creatively within the organisation. The study therefore suggests that with this type of formalisation there is reduced risk of inhibiting organisational change.

The literature on AMT has often advocated the importance of operator empowerment to successful implementation [13, 14, 18, 19]. Macri et al [14], state that it is important that proposed changes within an organisation are understood to be both desirable and necessary by shop floor operators. Should this not be the case, the authors warn that production operators may engage in acts of sabotage towards new systems and procedures.

Udo and Ehie [19] identified four determinants of AMT implementation success:

- **Triple C factors**: Communication, co-ordination and commitment
- **Self-interest factors**: Employee morale, satisfaction, belief in AMT, appropriate reward
- **Housekeeping factors**: Action plan, effective team, vendor support, cost justification, functions integration, effective facilitator
- **Literacy factors**: Understanding of AMT, understanding of firm business, training, clear goals and objectives, expectations of AMT

Each of these factors was shown to significantly affect AMT implementation success measured through AMT benefits. However, results of the study indicated that self-interest factors were the most critical determinant of AMT success. The implication of this result is such that where shop-floor operatives can be encouraged to perceive a technological investment as a system that can yield personal gains to them, the likelihood of the company achieving successful implementation is increased. Literacy factors relate to education of the workforce; the results of the study indicate that investment in education of shop-floor operatives is directly related to many of the AMT benefits.

In developing a framework to assess change management success, Taskinen and Smeds [20] undertook research to ascertain the state of the art in measuring change management projects. This research took the form of interviews with the managing directors of three global consulting companies. Each of the consulting companies highlighted the importance of measuring the ‘willingness to change’ of personnel. Such findings add weight to the importance of both the self-interest factors and literacy factors as identified by Udo and Ehie.

The findings of Lee et al [16] are also in keeping with the theme of operator empowerment and enabling formalisation. The authors state that it is important to encourage legitimate politics within the company and suggest the dispersal of power and authority throughout the organisation, providing autonomy of departments in addressing their own objectives.

**Internal politics**

According to Taskinen and Smeds [20] there is a ‘shift from the requirement of the effective management of operations to the efficient and effective management of change.’
The study suggests that the identification of resistance to change within an organisation is an important aspect of successful change implementation. The literature regarding organisational learning and operator empowerment present these issues as tools designed to impact upon an organisation's internal politics in such a way as to create an environment that is conducive to change. The existence of political barriers to change within organisations has been noted many times in the published literature. Tantoush and Clegg [13] assert that although many firms adopt AMT for profit-motivated reasons they fail to achieve such benefits because they are unable to manage the politics of the technology and its impact upon organisational design. According to Macri et al [14], even small organisations, often regarded as naturally inclined to change, suffer political barriers to technology implementation. Although, as noted above, it is the position of Lee et al [16] that when small companies are determined to implement change, communication is an area in which they out-perform larger companies. However, a contradictory example is provided by Jones[21] in a case-study paper examining the management style within a small company. In this paper the author notes that, 'the MD expressed little interest in developing the workforce and was more concerned to investigate opportunities for outsourcing existing activities or investing in new machinery'. Whilst this particular publication is concerned only with a single organisation, the autocratic nature of the company studied shares many parallels to the case-study company that is the focus of this research.

Organisational change and technology implementation

The case study company examined in this paper is an automotive component manufacturing company, with 50 employees, based in South Wales. A number of AMT implementations were undertaken by this company, including the installation of 3D CAD/CAM facilities, the development of a phenolics moulding plant and the installation of 5-axis CNC machining capabilities. The CAD/CAM implementation was undertaken in order to improve communication with clients during the early stages of their design work. Being a supplier to larger automotive companies, the majority of their clients wished to discuss and review design requirements and modifications with the aid of 3D CAD data. Therefore, the Company perceived that the installation of sophisticated 3D CAD would allow them to safeguard their position as a supplier to their current clients and improve their prospects for winning new contracts. In addition, the Company believed that such technological implementation would allow the company to pursue new markets through the exploitation of their new in-house design facilities. Having no previous experience of product design, the company identified an opportunity to partake in a Teaching Company Scheme (TCS) to aid both the technological implementation and new strategic direction of the organisation. In addition, following quite extensive market research into the phenolics and rail industry an opportunity was identified to develop a plant that could produce phenolic mouldings with uniform wall sections from closed moulds, with repeatable accuracy through use of a 5-axis CNC machine.

TCS, recently renamed Knowledge Transfer Programme (KTP), is a UK government-backed scheme aimed at strengthening the competitiveness and wealth creation of the UK by stimulating innovation in industry through structured collaborations with universities. The case study company's involvement with the TCS was typical in that a graduate (TCS associate) was placed within the company for two years to provide expertise relevant to the development being undertaken.

The managing director (MD) of the company had created a vision that the company would become a 'one-stop shop' for the mass transport industry, providing aluminium castings, polyurethane mouldings and phenolic mouldings. However, the communication of this vision to staff below the management level was not demonstrated to be a high priority. Communication of the company vision and direction to shop-floor workers was occasionally discussed, however, no time was ever allocated to develop mechanisms to achieve this. Due
to this lack of communication, production operators and in some cases higher managers, remained unaware of the company's technological aspirations and new strategic direction until the TCS associate was in place. Even at that juncture, explanation of the proposed changes was left to be provided by the TCS associate in ad hoc conversations with operators.

Further to the vision of being able to provide the 'one-stop shop', it was also the MD's vision to unite the three factions of the company (casting, pu, and phenolic) and integrate the use of technology. However, this created political barriers within the organisation. The company had recently purchased an advanced 5-axis CNC machine, principally for trimming phenolic mouldings. However, as part of the MD's wider company vision use of the new CNC was to be instrumental in the development of in-house casting pattern making. This presented a problem as the Phenolics manager had assumed 'ownership' of the CNC following its installation in his department. The Phenolics manager was uninterested in further development of the casting side of the company and attempted to prevent access to the CNC for such development work. In addition, further development was also hindered by the autocratic management style of the Business Development Manager. The MD actively encouraged the TCS Associate to explore the use of the CNC machine for in-house pattern toolmaking. However, the Business Development Manager remained unconvinced that the use of CNC and CAM could lead effective in-house development opportunities. It was perceived by the TCS associate that the Business Development Manager actively resisted such change by generating tasks that prevented further AMT development.

Resistance to change was not contained to management, there was also deep suspicion of the impact that such technological implementation would have on the organisation from the shop floor. One of the perceived advantages of using CAD to drive casting production was the use of rapid prototyping (RP) techniques to create complex resin patterns that would be extremely difficult to replicate by traditional techniques. In addition, patterns created from RP resins have the potential for a superior surface finish than traditional wooden hand patterns. At the time of implementation, it was not explained to the pattern-makers that the production of CAD driven patterns was intended to secure additional contracts that would otherwise be unattainable. The strategy was such that this should strengthen the casting division of the company, thereby improving the security of the pattern makers' employment.

The structured nature of the TCS requires the participating company to commit to the personal development of the TCS. Usually, this commitment takes the form of the provision of time away from the company for appropriate training. The benefit to the company is increased knowledge on the part of the associate that can be utilised to improve some aspect of the business. Although, the company never tried to prevent such off-site training, it was made clear that the company viewed time away as non-productive. As such, it was perceived by the associate that such time away was viewed as an interruption to productivity that the company was required to endure in order to partake in the TCS. The company was not contractually obliged to provide personal development opportunities to any other employee. Therefore, requested training was routinely declined on the grounds of cost, without analysis of the potential benefits employees with increased skills might bring to the company. Communication between the shop-floor operatives and the TCS associate indicated that operators suffered rather low morale levels that might have been improved had some form of personal development been accessible. However, as is often the case when implementing a new manufacturing technology, additional expertise was required from certain members of the workforce. The CNC operator was required to update his skills from 3-axis knowledge to 5-axis. The TCS associate required further training on both CAM and CNC operations. The new phenolic mouldings operation resulted in a number of staff being trained in this area. The TCS associate and the CNC operator were both afforded increased
levels of autonomy in order to develop their skills, however, the phenolics staff were trained in a more structured manner under the direction of the Phenolics Manager.

**AMT implementation success indicators**

The findings of the literature review suggest that resistance to change; internal politics; ineffective communication; and, low operator morale has a negative impact upon organisational change. The case-study company that is the focus of this paper has demonstrated problems in each of these areas. However, such a negative impact on organisational change does not necessarily imply that AMT implementation will be unsuccessful. In a questionnaire designed by the authors to assess the operational impact of AMT, the company indicated that they felt that they had achieved significant improvements in their overall competitiveness following the introduction of AMT. Once the CAD/CAM link had been established, the company were able to produce phenolic mouldings that they considered to be of far superior quality to their competitors. It was this quality, the company believes, that was of paramount importance in the successful tendering of their first contracts. In addition, the ‘traditional’ manufacturing nature of the casting industry meant that very few foundries had CAD facilities Therefore, a competitive advantage was secured in being able to easily communicate with design consultants and large clients that regularly produced data in CAD formats.

In order to assess the companies performance in a number of key AMT implementation success markers the authors developed a number of visual analogue scales (VAS) [7, 19]. VAS are ratio scales that have two fixed ends with descriptions. The respondent is requested to mark a line between the two ends to indicate performance in the area being considered. Such scales allow for easy comparison between events providing the respondent with a better range with which to express their opinion than with numerical rating scales. These scales indicate that the implementation of AMT had a positive impact on: Volume throughput; recall times; lead times; customer complaints; production flexibility; and, product quality (see figure 1).

![Relative impacts following AMT implementation](image)

**Fig. 1. VAS results showing relative impact of AMT on a number of AMT success markers**

**Discussion**

The implementation of a new technology within a company often requires significant organisational change. In addition, the literature indicates that companies of all sizes potentially face barriers to organisational change. It may be reasoned that such barriers
contribute to the dissatisfaction of many companies with the benefits that they have achieved following AMT implementation. That AMT implementation may have a negative impact on organisational design is supported by Gupta et al [22] in a study examining the effects of organisational commitment on AMT implementation success. The authors found that AMT implementation could have an adverse effect on the commitment of employees due to increased uncertainty in the manufacturing environment making it more threatening to work in. Udo and Ehie [19] found a number of critical success factors for AMT implementation, including employee training, intra-organisational communication and employee moral. Making improvements in any of these areas may require significant organisational change. Lee et al [16] argue that SMEs may be better placed to deal with such issues than larger companies, as it is easier for smaller companies to maintain face-to-face communications between management and the workforce.

The literature indicates the importance of considering organisational learning, operator empowerment and company politics during periods of organisational change. The experience of the TCS associate indicates that the case study company considered in this paper did not place high levels of importance on these issues during its AMT implementation. However, it is also important to note that the company still achieved many of the anticipated benefits following implementation. Communication of product ideas between the clients and the company was improved and products of increased complexity and quality were produced to shorter timescales. Ultimately, the company believes that the implemented technological changes were paramount to the continued growth of the firm.

Further Work

The authors recognise that the research presented here has a limitation is respect to quantifying any additional gains that may have been available to the case study company had they better addressed the political and motivational barriers to organisational change. However, it is felt that the case study does provide an insight into the issue of organisational change and technological implementation in a small company that will be useful to the development of further research into the impact of AMT implementation on small companies. The impact of AMT on small companies has been shown to be an under researched area [1].

The purpose of this paper is to examine the AMT and organisation change literature in preparation for in-depth study on the impact of AMT on small Welsh companies. The merit in studying small Welsh companies is demonstrated by the high percentage of Welsh manufacturing companies that fit such a description. The Welsh Assembly Government’s Wales in Figures publications show that in 2002 over 90% of manufacturing companies employed less than 100 people and that 88% of manufacturing companies employed less than 50 people [23]. Further argument for the importance of small business to Wales is given by the Federation of Small Businesses who state that 71% (compared with 57% in the UK) of all Welsh private sector employment and 63% (54% UK) of business turnover in Wales is generated by SMEs [24]. Previous research has indicated that companies from differing geographical locations invest in AMT for similar reasons and face similar adoption issues [25, 8]. Therefore, it is believed by the authors that a study of the impact of AMT on small Welsh companies has the potential to make a significant contribution to knowledge in the wider field through the identification of generic issues.

References


The use of Technical Files to initiate and formalise New Product Development in small manufacturing companies

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ABSTRACT
Small and medium-sized enterprises (SMEs) within the UK, particularly those in the manufacturing sector, operate in a harsh economic climate. Consequently, many UK manufacturing SMEs have made the transition from contract manufacture to design and manufacture, in order to generate a clear competitive advantage in the international marketplace. This paper is informed by projects undertaken by the government-funded Manufacturing Advisory Service: MAS Cymru. A case-study methodology is employed based on detailed projects within three ‘traditional’ manufacturing companies. The output from these small companies shows that a Technical File can be harnessed to act as a roadmap for design and development. Rigid NPD models are inadequate for SMEs, and the research shows that Technical Files provide a more flexible tool to cope with emergent actions within resource-constrained SMEs.

1 INTRODUCTION
Small manufacturing companies within the UK operate in a harsh economic climate with increased low-cost competition from overseas. Government strategy advocates that manufacturing companies must move up the value-added chain in order to generate a clear competitive advantage. New product development (NPD) represents one route for SMEs to harness product innovation and apply their core knowledge in new directions. Studies have shown that successful NPD provides higher returns than practically any other type of similar investment (Berliner and Brimson, 1988). NPD in large multi-national companies is well understood and documented; however, the literature on design and development within SMEs is more limited. The management culture and operational resources within SMEs are very different to those that exist within large companies, therefore it is important to evaluate the critical product development issues within the small company context. Barnes (2002) indicates that a rigid, top-down strategic planning model is inadequate for SMEs in practice.
Often managers regard the concept of ‘gated’ processes, with checks and sign-offs at the various stages, as being unnecessary and over-complicated. It has been reported by Woodcock et al. (2000) that SMEs typically avoid the implementation and use of documented design and development procedures.

An alternative approach to rigid, top-down NPD models for small companies is to support and define design and development activities through a Technical File. Early NPD challenges include hazard identification and risk analysis, which can take the form of a Design Failure Modes and Effects Analysis (DFMEA). These NPD tools frequently evolve and culminate in Technical File that can be used to document design alterations, demonstrate due diligence and conformance to EU standards. The aim of this research paper is to investigate how the Technical File can facilitate a formal NPD process, and thus promote successful NPD activities within SMEs. The paper employs a case-study methodology based on three detailed NPD projects. The companies are all ‘traditional’ manufacturers: a specialist machining company, a sheet metal fabricator and a company producing domestic goods. The output from the three case studies show how the Technical File can be harnessed to act as a roadmap for design and development. The Technical File can provide a practical approach to NPD within SMEs, and can compliment the traditional ‘gated’ multistage development process commonly used in larger, well-established companies. The preliminary findings from this paper can be used as a basis for refining the NPD process in the context of manufacturing SMEs.

2 METHODOLOGY

The empirical findings from projects carried out by the government funded advisory service MAS Cymru draw attention to the issues that SMEs face in the resource-constrained environment within which they operate. MAS Cymru are an advisory body that provide impartial help and advice to manufacturing SMEs. ‘Figures show that MAS has continued to play a vital role in helping UK Manufacturing share knowledge, improve productivity and achieve success in an increasingly competitive global economy’ (DTI report, 2005). There are a variety of ways in which they can help: diagnostic visits including up to two days free consultancy work (called Level 2s), subsidised projects for more than two days (Level 4s) and seminars covering current manufacturing issues (Level 3s). The research team within MAS has observed that a number of SMEs making the change from ‘just manufacturing’ to ‘design and manufacturing’ encounter a number of problems documenting this NPD process. Furthermore, with increasing European legislation for new products, evidence that products have been designed with the essential health and safety requirements in mind, must be documented by the manufacturers. A number of level 4 projects have been carried out to help document this NPD process, and the data gathering from these company visits has provided a wealth of case-study material in the form of technical reports, risk assessments, project documentation and employee testimonials. This material forms the basis of the case-study methodology that has been adopted for this paper. The selection criteria for the case study companies were as follows:

- An SME with fewer than 25 employees,
- Currently undertaking the design, development and manufacture of new products,
- Having an immature new product development process,
- Having approached MAS Cymru for advice and support.
Following an in-depth review of all Level 4 projects, three projects were selected that best exemplify how SMEs can use NPD tools to create a Technical File, which in turn can be used as the foundation for their NPD process. The MAS researchers were able to observe and gather data directly by having an active role in the Level 4 company projects within the three chosen companies. In addition, the case-study methodology based on MAS Cymru projects has been shown to be effective in analysing NPD issues within small manufacturing companies (Walters et al. 2004).

3 CASE STUDIES

3.1 Case Study 1 – Specialist Machining Company

This company is a general engineering fabrication workshop; they manufacture standard engineering products from stock metal using lathes and milling machines. Due to the recent decline in their industry they decided to expand their business to include the design and development of bespoke products. The first product that they decided to develop was a product for the sports industry. They felt that this product would make good use of their existing manufacturing capabilities, reducing the need to sub-contract components. MAS Cymru were contacted to review their first prototype and offer NPD advice. The project consisted of a review of current product legislation, an on-site risk assessment and thorough hazard identification. The results of which were compiled into a Technical File. MAS Cymru has created standard templates for Hazard Identification and Risk Assessments. The generic template was used across a range of companies, and applied to a variety of products and provide the manufacturer with a way of assessing the safety of their products. In the case of this company, a number of issues were raised including hazards associated with transporting the product and hazards associated when using the product. The use of these tools provided the company with information to further develop their design and enable critical design decisions to be addressed.

3.2 Case Study 2 – Sheet Metal Fabricator

Company 2 manufacture lifting equipment for the automotive industry. They approached MAS Cymru for an on-site review of their new portable lift. A Level 4 project followed which included a hazard identification, a risk assessment with recommended design changes and additional advice for creating instructions for the safe use of the product. The product was drastically re-designed to include the safety issues raised from this project. MAS Cymru used a team approach to highlight product risks and recommend design developments. It was reported that the person responsible for the design had become ‘blinkered’ in his approach to the product and the team method helped him to see the greater implications and hazards. The NPD tools were collated into a Technical File allowing Company 2 to develop their process documentation.

3.3 Case Study 3 – Domestic Goods Manufacturer

Company 3 is a recently formed company. It has spent a large amount of time developing expertise within a specific area of electronics, and as such has a number of patent applications pending based on this technology. They approached MAS Cymru whilst developing their first product utilising this new technology. MAS Cymru were asked to provide an input into the
design of the product for manufacture. The MAS Cymru team decided that to provide satisfactory advice for this electromechanical device, the functions of each of the components, the limitations and impact of the technology upon the user and the relevant legislation needed addressing. Thus, a risk assessment was undertaken based on Design Failure Modes and Effects Analysis (DFMEA) principles. This was carried out on the mechanical construction of the unit along with an electrical safety appraisal of the control circuit and ancillary wiring. Advice and documentation was also provided with regard to the Low Voltage Directive. Using this information, Company 3 were able to carry out the detailed design for manufacture with a greater degree of confidence, with records of the key design alterations that had been made. This is of particular importance for a product aimed at the consumer market because this demands the highest safety standards.

4 DISCUSSION

The typical stage-gate model used by large companies for driving new products to market has been discussed by Cooper et al. (2002) with regard to best practice. This process is represented in Figure 1. One of the main problems that SMES have in adopting an NPD process similar to this one is a lack of resources in the form of personnel, budget and time constraints. SMEs do not have the manpower, level of skill or management necessary to carry out a regular gated process.

![Figure 1 - Typical example of a stage-gate product development process](image)

The results of the three case studies presented within this paper illustrate that by adopting a straightforward approach to product development, where the essential health & safety risks are addressed along with relevant product legislation, the foundations of an NPD process can be established in the form of a Technical File. A suggested flow chart for this process is outlined in Figure 2. It can be seen that the proposed model for a Technical File runs in parallel to the standard NPD process. Key drivers for the Technical File are regulations and standards, but companies still need to undertake appropriate market research and achieve clear, early product definition (Design Brief and Product Design Specification). The Technical File is not prescriptive with regard to form of these additional elements, but can provide a time-plan for integrating the Design Brief and Specification with the other NPD tools. In practice there will be a number of iterations between the Design Specification, the risk analysis/DFMEA and the detailed design stages.

Small companies often establish a need for a new product and rush through the analysis/research stage, and design brief stage, and focus on making prototypes. This model suggests that by taking the time to research relevant standards and use the NPD tools such as
DFMEA, the resulting Technical File can be used as a template for future projects. This in turn will broaden the understanding of the design process within SMEs and accelerate the decision making process at each stage-gate.

**Figure 2 – Minimal documentation to support NPD in small resource-constrained companies**

5 CONCLUSIONS

The interaction of MAS Cymru within the three case study companies aimed to promote a more systematic approach to new product development. It is acknowledged that rigid, top-down practices are not appropriate for SMEs but the results of this paper have shown that structured design documentation can impose rigour without adding levels of inflexible bureaucracy. The adoption of simple design tools within the NPD process culminating in a Technical File provide the foundations of a solid NPD process within a resource-constrained environment. This Technical File can then be used as a vehicle around which an SME can plan, configure and monitor new product development, particularly the transition from design to manufacture.

This research is part of an ongoing Masters research degree, and further work will investigate other issues that may impact upon how successful the NPD process is within SMEs; for example, factors such as the management structure within the company and use of product design briefs earlier in the NPD process will be researched.
REFERENCES


