Challenges in implementing design-led technologies in small manufacturing companies

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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 (Carwood, 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 (Kassler and Chakravarti, 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...
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industries (Milton 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 insufficiency 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 (Filsen 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 (t3 Ltd). A typical KTP programme is a two-year partnership between one company, one university and t3 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 (49%) 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 t3 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 (Lipcomb and McBryan, 2003), 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 1. Percentage of KTP programmes by company size and programme objective, based on 953 pan-UK schemes from 1 April 2002 to 31 March 2003. |
|---|---|---|---|
| Micro (≤ 10) | Small (10–49) | Medium (50–299) | Large (500+) |
| 15% | 42% | 32% | 11% |
| Design & development | Manufacturing | Management | Other |
| 49% | 21% | 12% | 18% |

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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 utilised by support from the universities 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 the 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 laid 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, sample parts 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
collapsed to appreciate the time and costs associated with
design and development work. The result was that
costs and machine hours were under-estimated. The
result was 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
donor had no formal training or professional
experience in the area of product design, development
and manufacture; his background was in accounting.
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 sub-
contractors. 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, 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, 2002). 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>
<thead>
<tr>
<th>Company</th>
<th>Scenario</th>
<th>Lead times</th>
<th>Project costs</th>
<th>Product quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(1) Composites and polyurethane mouldings</td>
<td>67</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>A</td>
<td>(2) Metal alloy castings</td>
<td>34</td>
<td>23</td>
<td>65</td>
</tr>
<tr>
<td>B</td>
<td>Pattern making and precision tool machining</td>
<td>76</td>
<td>63</td>
<td>77</td>
</tr>
<tr>
<td>C</td>
<td>Manual machining and injection moulding</td>
<td>10</td>
<td>53</td>
<td>80</td>
</tr>
<tr>
<td>Mean values</td>
<td></td>
<td>47</td>
<td>49</td>
<td>77</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>90</td>
<td>18</td>
<td>11</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 major 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 PDQ’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 (Fornoff and Kroeter, 2002). Their domineering 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 development aspects.
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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


