INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

PRODUCT DEVELOPMENT IN MANUFACTURING SMES: CURRENT STATE, CHALLENGES AND RELEVANT SUPPORTIVE TECHNIQUES

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ABSTRACT
Small and medium sized enterprises (SMEs) provide the backbone to the world's economy nowadays. These companies represent more than 90% of all the enterprises around the globe and are a major source for providing employment and entrepreneurship. They contribute as much value to the gross world product (GWP) as larger enterprises. However, when it comes to productivity growth, SMEs are falling behind. This paper aims at identifying and evaluating different approaches that have been proposed for supporting various product development activities within manufacturing SMEs. The work of several researchers in this area has been reviewed and various supportive techniques to improve product development practices of manufacturing SMEs have been discussed. The paper concludes by identifying the specific challenges in applying these approaches to address different aspects of SMEs needs and highlights the importance of ascertaining beforehand, the type of activities and businesses that a particular SME is engaged in.

Keywords: SMEs, product development, supportive techniques/methods

1 INTRODUCTION
Small and medium enterprises (SMEs) play a vital role towards the world's economy by contributing to entrepreneurship, employment and innovation [1]. This claim can be backed up by the fact that most of the businesses around the globe are small to medium sized enterprises. There are around 23 million SMEs in the European Union, which provide 65 million jobs and represent 99% of all enterprises [2]. In the US, more than 99% businesses are small [3]. In Australia, these enterprises add to around 96% of non-agricultural industries [4]. In the UK, at the start of 2006 there were an estimated 4.5 million business enterprises, 99.9% of which were small to medium sized [5]. SMEs account for 58.9% of all UK employment and 51.9% of UK's estimated business turnover of £2,600 billion. Thus these enterprises make up a significant portion of the world's economy. In addition to this, the larger companies are also becoming more and more reliant on SMEs for their products and services. In the UK more than 50% of sales in manufacturing sector is generated through subcontracting [6].
The definition of a SME varies throughout the literature. In this paper, a description given by European Commission [2] is adopted (table 1) which categorises a SME as an enterprise employing less than 250 people and an annual turnover less than 50 million Euros.

Table1: Description of small and medium sized enterprises Source: [2]

Enterprise category	*Headcount*	*Turnover (Euros)*
Small	<50	<10 million
Medium-sized	<250	<50 million

1.1 SMEs vs. Larger firms
SMEs have certain strengths when compared to larger firms [6]. These enterprises operate in a very flexible and dynamic environment where changes can be introduced within very short timescales. The results of these changes are also more visible within a short span of time in these companies. They are comparatively less bureaucratic and have simpler and more effective communication channels. Management is more likely to be directly involved with the customers and thus provide rapid

execution and implementation of decisions [7]. Overall these enterprises are more innovative and responsive to changing market needs.
On the other hand, SMEs lack in the level of standardisation and formalisation when compared to larger firms [14]. This means product and processing costs are likely to be higher. There can also be resistance to the introduction of new improvement processes. SMEs also normally lack in expert knowledge and management time which are also necessary for introducing such processes.
The focus of this paper is the manufacturing sector among SMEs. In the UK, the manufacturing sector among these SMEs represents 348,250 enterprises with a turnover of £480,271 million [5]. Similarly in the US, there are around 400,000 small manufacturing firms representing the majority of manufacturers [8]. These small manufacturers contribute as much value as larger enterprises, however, they do not experience the same productivity gains [9]. Some researchers [10] believe that their productivity growth is almost half compared to larger manufacturers.
The aim of the research presented in this paper is to identify and evaluate approaches appropriate for supporting various product development activities within manufacturing SMEs. To achieve this goal the paper has explored the following:

- The specific operational characteristics and the product development activities that currently take place in manufacturing SMEs (section 2).
- The supporting techniques (improvement methods) proposed by various researchers for SMEs targeted at improving their product development practices (section 3).

The implications of the reviewed work are discussed in section 4 and section 5 highlights certain challenges in applying these approaches for certain SME requirements.

2 PRODUCT DEVELOPMENT IN MANFACTURING SMES

Product development in manufacturing SMEs has been an area of interest for a number of researchers. The research work found in the literature can be essentially divided into two categories:

1. Research work dealing with the business aspects of product development in SMEs. Such as implementation of TQM [6] and Six Sigma [7] in SMEs.
2. Research work dealing with improving product design in SMEs [9-17].

This paper is mainly concerned with the latter category. The researchers have highlighted a number of issues that need to be tackled in order to increase the productivity and profits of manufacturing SMEs, and these are further discussed in the following paragraphs.
Stauffer and Kirby [9] conducted a survey on smaller US manufacturers. The objective of the study was to gain a better understanding of the product-development needs of smaller manufacturers. There were 61 smaller manufacturing companies surveyed in 10 states across the US. These companies were from mechanical and electro-mechanical domains and employed from 20 to 200 employees. The important finding of their research work was that in order to increase the competitiveness of these manufacturers there is a need to improve product refinement along with reducing the cost of the product and processing. Stauffer and Kirby also highlighted the fact that lack of resources and often ill defined product development processes are hindering the productivity of these firms.
Cederfeldt and Elgh [11] conducted a study on the current state, potential need and requirements of design automation at eleven SMEs. They highlighted four important factors that can ensure and improve competitiveness of SMEs namely: low cost, short lead times, improved product performance and adapting products to different customer specifications. Cederfeldt and Elgh argue that one way to gain competitive advantages is to adopt an approach where products are based upon a prepared design. This helps in making the design process more effective and efficient by automating some of the work related to the products and design tasks. Their study revealed that there is currently a varying state of design automation in SMEs. This ranges from the systems where design knowledge is fully integrated and orders are automatically processed with generation of machine code for manufacture and BOM-lists for assemblies, to the use of spreadsheets for specific design tasks. The study also expressed the need for more efficient and effective design processes.
Bradford and Childe [12] argue that most of the approaches for the redesign of manufacturing systems are linear, which are not suitable for the needs of SMEs. They explain that it is not always possible to foresee all the issues during early design phases that may arise later and affect the final design. SMEs are largely affected by this due to uncertainty of their environment (responsiveness to changing demands of customer). According to Bradford and Childe, SMEs have to redesign themselves more extensively and frequently than a larger business thus making linear models of designing ineffective

for product development in SMEs. They also highlighted the scarcity of resources in SMEs in terms of financial support, available expertise and managerial time.

Maupin and Stauffer [10] highlight the problem of product proliferation in SMEs. They argue that these manufacturers are often less profitable when compared to large manufacturers. There is a common practice of instant introduction of new products, which is done with a little regard for compatibility with other products in production. The result is a large portfolio of products. The other challenges to SMEs highlighted by Maupin and Stauffer include lack of resources, lack of an adequately trained workforce and ill defined product development processes. They also indicate the need for simple and easy product development processes. The complex design processes that are normally successful in larger manufacturing firms are not utilised in smaller firms. One reason for this is that their technical team wants to see immediate reduction in product cost or time required, which may only be long term goals with available design process models.

The problem of product proliferation in SMEs is also illustrated by Berti *et al.* [13]. According to them, these enterprises are more customer focused (concentrating on getting product to the customer) than market focused. There is little attention given to product development or long-term planning to bring new products to the market. This results in a large product portfolio without any real rationalisation. The improvement of product development practice can be reached only with less complex modification of processes suitable to small manufacturers who are usually short of financial resources and lack a broad range of technical skills.

Yan *et al.* [14] expressed their concern on growing complexity within product development process due to the ever changing needs of the customer and the high pace of change of the current product markets. They suggest that the problems for SMEs are amplified due to their common practice of instant introduction of products.

Schofield and Kelly [15] highlight the lack of a formalised database and product coding/classification system in SMEs that results in a tendency for designers to create new designs instead of utilising existing ones. This means increased cost of manufacture and inventory. They argue that product rationalisation based upon effective coding/classification techniques, on the other hand, can reduce lead times, reduce manufacturing costs and facilitate a more effective spares operation.

O'Donnell *et al.* [16] also discuss the issues of unnecessary numbers of variants in manufacturing enterprises. The variants, which are determined during the initial design phase, can increase dramatically and in a poorly controlled manner due to efforts to satisfy every potential customer and the increasing global market requiring country specific products. They highlight the need for a corporate product structure model that can provide help to manage variants, promote design reuse and support the tasks of configuration design and management.

Hicks *et al.* [17] state that the majority of machinery manufacturing SMEs have relied upon natural evolution of their existing machine designs to meet the performance requirements demanded by the customers. This natural evolution involves continual refinement and development of particular aspects of existing machine designs. However, the problem with this traditional approach is that revisions to the designs are often carried out within shortened development times, with a little consideration being given to the effect of the changes on other aspects of the machine. It often leads to problems with other machine parts or assemblies, which again may be solved in isolation. Lack of documentation is another impeding factor here. Due to shortened time scales the important design activities and associated changes are not necessarily documented in these firms. Thus the company becomes reliant on key persons' knowledge regarding the history of a particular machine development. This design knowledge is lost when these individuals leave the enterprise and this can result in serious problems.

2.1 Important findings from the literature

The following points summarises the factors mentioned above, which are limiting effective product development in SMEs.

1. The product development processes are often not clearly defined in SMEs. The design process models which are successful in larger manufacturing firms are normally not utilised in these enterprises due their nature of complexity and longer development times required.
2. SMEs, in general, lack resources in terms of cash flow, available expertise, management time and adequately trained workforce.
3. These enterprises are opportunistic in nature and very much focused on individual customers. Due to this, there is often a practice of instant introduction of products. This often results in a

large portfolio of products which in turn increases the internal costs incurred by these enterprises in order to develop and support these products.
4. Some other factors highlighted by various researchers include lack of design knowledge, poor documentation, lack of formalised databases, shortened development times and absence of a corporate product structure.

Based upon the literature reviewed in section 2, Figure 1 shows the categories of main barriers and their root causes to effective product development in manufacturing SMEs.

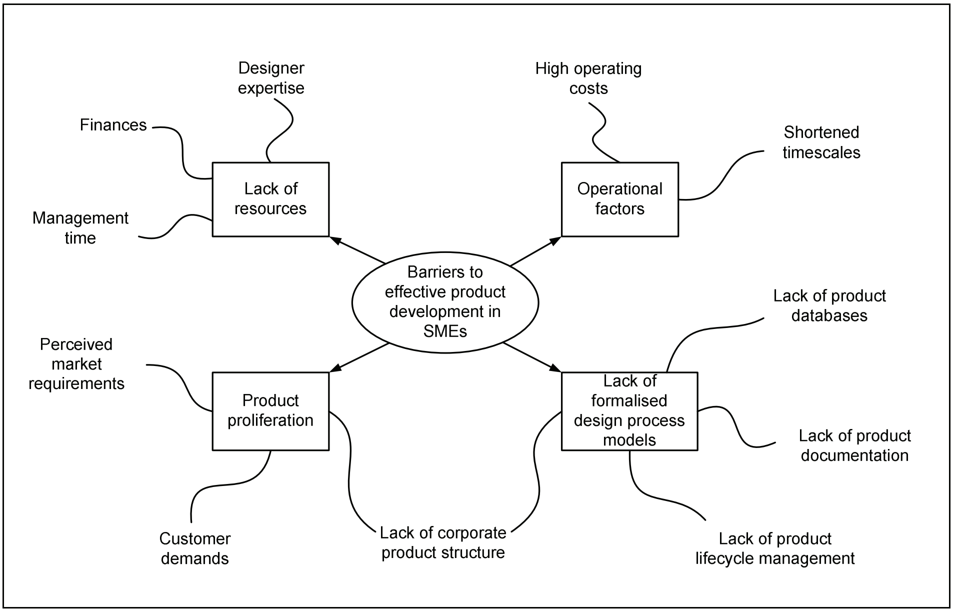

Figure 1: Main barriers to effective product development in manufacturing SMEs

There are also some basic needs of SMEs that have been highlighted in the literature reviewed above. These can be summarised as follows:

1. Most of the researchers agree that there is a need for simpler effective techniques to develop and refine products that can be easily understood and implemented in these firms.
2. Several authors have advocated the need to tackle product proliferation. They have also stressed that this can be effectively dealt with by basing new product designs upon existing designs (design reuse).
3. There is a need to lower product and processing costs along with reducing lead times.
4. These enterprises also need to improve the performance of their products.
5. Automating design related activities (design automation) is also considered to be an important need for SMEs by some researchers.

The following sections discuss some of the supportive techniques (improvement methods) that can be used to meet some the current needs of SMEs.

3 SUPPORTIVE TECHNIQUES

The techniques identified here are essentially divided into the following two categories.

3.1 Techniques aimed at improving product architecture for reducing product and processing costs

Most of the work described in this category has stressed the need for effective design reuse for tackling product variety as well as lowering product and related processing costs. This essentially means deriving knowledge from existing products and applying it to new products which is mainly accomplished by making products modular. These approaches are described in the following sections.

Maupin and Stauffer [10] present a methodology that can help small manufacturers to reengineer a product family. The methodology presented is based upon the application of four metrics: simplicity, standardisation index, direct cost and delayed differentiation index. These metrics help designers to evaluate their progress while reengineering a product family. Simplification helps reducing the complexity of a product and it can be achieved by removing redundant components and integrating (consolidating) component functions into a few components. Standardising components and operations provides cost reduction. Direct cost provides a measure of materials and labour cost. The aim is to reduce the direct costs by minimising the number of components, operations required to assemble the product family, required handling and insertion times. Delayed differentiation is a concept where manufacturing starts with making a generic product which is later differentiated into specific products. It helps in tackling uncertainty in the demand of products.

Berti *et al.* [13] developed a method to support the design of modular products in SMEs. This method is based upon digital spreadsheets linked to a CAD system. The basic idea behind their methodology is to support the definition of functional structure by providing well-documented studies of product types for an application field. The different product types are decomposed according to various functions. The functional groups thus identified can serve as a basis for selecting modules for new products. A library of modules is thus created that can be used by the designer. The system developed supports the configuration of single modules and their assembly. The designer enters the design parameters relating to product geometry in the spread sheet. This spreadsheet contains all the design knowledge such as design rules, dimensioning relations and standard component dimensions. This spreadsheet is connected to a three dimensional CAD system and a semi-automatic parametric design can be achieved using this system. The system can be further connected to down stream applications such as FEM (Finite Element Method) and CAPP (Computer Aided Process Planning).

Buske and Liu [18] provide computer integrated support for design and manufacture of packaging machinery. They argue that thousands of machines have been developed over the years to automate every aspect of the packaging industry and these machines must be constantly redesigned to accommodate ever changing packing requirements. For SMEs especially there is little time to make these changes and no room for error. Buske and Liu's aim is to automate the entire customisation process of complicated packaging machines. They accomplish this by embedding a knowledge base into a solid modelling software system. The knowledge base contains information regarding different parts such as parametric descriptions regarding parts and their assembly and material types. The designer can create a custom machine by entering the different input parameters according to the changed requirements. The knowledge base is capable of checking for errors in the user input, part interferences in the assembly and sends warning signals in the event of a problem. It also contains algorithms capable of creating new parts numbers and CNC tool paths can also be generated automatically using this system.

Yan *et al.* [14] argue that modularity within a product can help facilitate enhanced design reuse, reduce lead times, decreased cost and higher level of product quality for SMEs. They introduce a methodology, named GeMoCURE, which can provide an integrated total solution to modular design based on reuse of identified modules from similar previous designs. It contains four methods namely generalisation, modularisation, customisation and reconfiguration. The generalisation process is aimed at creating generalised and generic product development primitives (PDP) by studying existing similar products. The output of this process is a series of PDP models and knowledge for each PDP. Modularisation is the next stage of the methodology which aims at generating and structuring a family of generic modules derived from generalisation. These modules are used at the next stage of customisation in order to meet new requirements. The relevant modules are first identified and then tailored to suit a new design solution. Reconfiguration is the last stage where available modules are utilised and rearranged in different forms to investigate spatial and structural configurations.

3.2 Techniques aimed at improving product performance characteristics

These form the second category of approaches that are aimed at improving product performance characteristics. These are discussed below.

Hicks *et al.* [17] propose a constraint based methodology for the design and redesign of packaging machinery. This methodology incorporates a constraint based modelling technique [19], which involves identification and resolution of all the constraints known to be acting on a system. It is argued that the requirements of SMEs for support during redesign (such as the need to represent and manipulate design knowledge, model and analyse systems and provide support over conceptual, embodiment and detailed phases of design process) can be met in part or in full using constraint based modelling techniques. The design knowledge is gained through the process of refining constraints and models. The results and implications about the design decisions are embodied in the various sets of constraint rules, which are later resolved in order to achieve a successful solution.

The main feature of their methodology is its incorporation of two parallel activities: practical and analytical (computer based). The practical (experimental) investigation helps to identify and develop design constraints and to validate the modelling and analysis data resulting from the analytical study. This approach is very useful especially for redesign activities carried out in SMEs. A computer model (constraint based model in this case) can always be generated by identifying the main design constraints embodied in the existing design. The model can be further validated and refined through comparing predicted results with those obtained from experimental investigation. Once a successful computer based model is obtained, it can be tested with different redesign strategies such as adaptive and variant. The designer can interact with the system to change design parameters and investigate their effects. Thus the key parameters can be identified and an assessment of the robustness of the design can be made. Optimisation techniques can then be applied to search for improved designs.

Matthews *et al.* [20] present a modelling technique which can assist small manufacturers to assess the capabilities of their existing machine designs in order to cope with new or changed user requirements. They argue that the SMEs lack the expertise and time to perform in-depth analysis of how well their existing designs perform or what constraints are present that may stop the designs reaching the new performance requirements Their approach, termed “limits modelling”, begins with a parametric computer-based model of the existing (or proposed) equipment. Initially, potential failure modes are identified by consultation with users (and designers) of the equipment. A study is then undertaken in which the parameters within the model are adjusted, the equipment simulated and tested against each of the identified failure modes. This establishes a region (in a multi-dimensional space) comprising workable combinations of design parameters. A failure mode map [21] is then created in which the allowable design space is shown bordered by edges which represent failure modes. The form of the region is likely to vary with product requirements. So from the point of equipment set-up, it is desirable to look for a combination of parameters which allows the greatest range of product variation to be handled. From the point of view of design, it is essential to try to maximise the acceptable region. The overall process allows a variety of graphical representations to be created that can illustrate and compare the limiting conditions for different machine designs.

Singh *et al.* [22] present a multi-instance technique that can help SMEs to increase fundamental design knowledge about their product performance characteristics and helps to provide a sound basis for redesign activities. They argue that the ability to visualise and explore the space of feasible design solutions is important in all design tasks. It is often complicated by the large number of design parameters involved and the fact that their interaction is poorly understood. However, a simplified investigation, which is based upon the existing workable designs (variants), can be performed. The multi-instance modelling approach helps in performing such an investigation. It starts with the known successful variants of a design. The parametric models of these base designs are morphed (interpolated) in order determine the resultant performance space which can be visualised as a surface. The surfaces help in understanding the performance capabilities of existing designs and further help in locating better design solutions which may exist within the morphed design space. Overall their technique helps in evaluating merits of different design options.

4 IMPLICATIONS FOR SMES

The research work reviewed in this paper has been essentially divided into two categories. The first category includes the research work that has stressed the need for effective design reuse for meeting some of needs of SMEs such as reducing product and processing costs, supporting product variety, lowering lead times and promoting design automation. This essentially means deriving knowledge from existing products and applying it to new products. The common factor in different approaches is the identification of standard parts or components (in the form of modules) that serve different functions. A generic product model (product platform) can be generated from them. These parts (parametric descriptions) are then stored as a database that can be accessed during similar product development processes. Most of the approaches reviewed under this category are based upon the modularisation concept. These are useful for generating custom designs based upon the existing designs and also make sure that there is always a consistent assembly generated. These can certainly help to lower product costs, support product variety and promote the use of standard components. However, there are some limitations associated with these techniques.

- Developing a new product by incorporating these techniques (based upon modularisation concept) in design methods can be a one-off task. But redesigning current products can be a difficult and cumbersome process. Sometimes a complete redesign of existing products is required in order to make a design modular. In such cases these methods are beneficial in the long run but initially require a lot of redesign effort. Yan *et al.* [14] describe a case where the concept of modularity was applied to a SME producing mechanical products. It was hard to reconfigure the product as its design was well founded and had evolved (having been in production for twenty years).
- Another drawback of adopting modular architecture is highlighted by Ulrich [23]. He says that a modular architecture can help in optimising local performance characteristics but fails to address global performance characteristics, which can only be dealt with using an integral architecture. Local performance here relates to performance characteristics arising from only a local region of the product (such as the tail light of a car which can fixed independently of other parts of that car) and global performance stands for performance characteristics arising from the physical properties of most components of a product (such as mass, shape and material that is constituted by all components of any machine). These techniques provide no direct support for evaluating or modifying (refining) the design for changes in global performance requirements such as optimising accelerations produced and increasing efficiency.
- Also, it is not always efficient to spend time and great effort to create modules to develop different products when the product variety is low [24]. Optimising and developing products in the individual form (integral architecture) can be a better option in theses cases.

The second category includes the research work that is targeted at increasing product performance characteristics. Here researchers have tried to meet some of the other needs of SMEs such as increasing product performance characteristics and improving methods for product refinement. The proposed techniques utilise computer based models of the product designs in order to analyse their performances. Once created and validated these models serve as the basis for further analysis which can involve optimising the existing designs, analysing their capabilities to handle new or changed requires or just simply to rationalise existing designs. Following are some of the some shortcomings of these methods:

- The techniques proposed in this category are mainly concentrated on machine/mechanical system designs. There is limited applicability of these in other domains such as electronics and fluid dynamics.
- There is no clear support for reducing product and processing costs.
- These techniques do not provide support for promoting design reuse or automating design related activities.
- Although there is no explicit support for managing issues related product variety, it can be reduced in some cases by achieving product performance rationalisation.

5 CHALLENGES FOR SMES

The research work reviewed above has shown that various approaches exist to address different aspects of SMEs needs. The techniques identified were broadly divided into two categories. Each category described has its benefits and shortcomings over the others. Even within the same category, the methods reviewed seem to address different needs of SMEs. For example in the first category reviewed (section 3.1) some techniques are focused upon cutting product costs [10, 14] while others are focused at automating design related activities [18]. There is not a single solution available for all problems that SMEs face.

One obvious way to address this issue is to achieve a single supportive approach by generalizing and combining these techniques to meet needs of every SME. Such a unified global approach can be expensive and time consuming. As seen for the cases of complex design process models, SMEs are reluctant to use a technique which is complex and take longer development times. Also, there is the diverse nature of environments in which different SMEs operate and consequently their needs differ accordingly. What is true for one SME may not be true for the other. Thus, it becomes important to clearly define the needs of a particular enterprise and select an improvement technique accordingly. One way to address this problem is by investigating the reasons for the creation of a particular SME and more importantly to find out the basis on which it survives in the first place. Such an investigation can lead to the determination of level and type of support a SME requires. Following three steps are recommended to carryout such an investigation.

5.1 Understanding the background of a SME

There can be many and diverse reasons for the creation of a SME. Some of the examples of these, drawn from a wide experience of industry, are listed as follows:

- *The 'spin-out' company*

  Here members of an existing company recognise that it is not completely fulfilling the needs of its customers. A small group of people decide to separate and set up a competing company. They see themselves as directing their efforts at making products/solutions for the original customers and thus are direct competitors of the original company.
- *The technology based company*

  Often in the early days of a new technology, a company can find it difficult to incorporate this change in technology into its existing organisational structure. This can lead to the creation of a technology based company which acts as a subcontracting SME.
- *Skill in a particular market sector or the fully flexible type company*

  Such an enterprise is formed by a group of people who know a sector well and can build anything that the particular sector demands. Normally they have established a reputation with the customers.

These are a few of the reasons for the creation of a SME. Knowing why a SME was created in the first place can help identify the initial vision of the enterprise thus, uncovering important factors that needs to be strengthened for a sustained growth.

5.2 Selecting an appropriate supportive technique

The existence of the SME is solely based upon the need of others in the industry or the market. If it is to survive it needs to ensure that its products are truly competitive. This may be on price or on technology depending upon the initial vision of the enterprise. To compete on price rather than technology, it needs to be very efficient and thus needs techniques that help in lowering product and processing cost. To compete on technology it needs to invest in high levels of technology and be seen at the cutting edge. Trying to do both is dangerous as a streamlined management system can restrict the creative design activity and, conversely, a free creative approach to a highly constrained and cost sensitive market can rapidly lead to the company's products being uncompetitive and unsalable.

5.3 Proper implementation

Once the type and level of support required have been identified, it is straightforward to identify the suitable techniques for a particular SME. However, it is also important that these techniques are properly implemented in the enterprise as it is widely acknowledged [17, 25, 26] that incomplete, partial or incorrect implementation of a technique can result in little or no measurable improvements.

6 CONCLUSIONS

The aim for conducting the research presented in this paper was to identify and evaluate different approaches that have been proposed for supporting various product development activities within manufacturing SMEs. It has been found that there are several techniques proposed by various researchers that address discrete problems in discrete areas. While some techniques are essentially aimed at reducing product and processing cost, others are focused on improving product performance characteristics. It was argued that care must be taken while selecting a supportive technique for product development needs of a particular SME. It is the core purpose of the SMEs and the type of activities that these are engaged in that determines which of the techniques will be of benefit to their business. It is possible to give them a competitive edge by identifying where their market advantage comes from and then employing appropriate supportive techniques that can strengthen those areas of advantage.

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