The Availability and Capabilities of 'Low-End' Virtual Modelling (Prototyping) Products to Enable Designers and Engineers to Prove Concept Early in the Design Cycle

This report provides an insight into the technology of virtual prototyping and its application in the field of design, engineering, production and product development. The report reviews the concept of virtual and digital prototyping, discusses the historical developments and technology, explores some of the wider implications and benefits of the technology, details specific industry applications of virtual prototyping, comments on the availability prototyping systems and provides a summary of the main findings.

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Pera Knowledge

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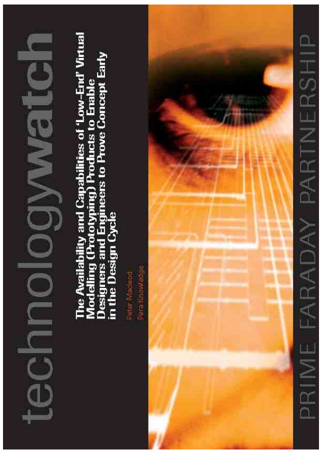

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1.0 Introduction

It is not surprising that many organisations, particularly smaller companies, are confused over the application of virtual (digital) prototyping. It is still the case that many companies are unaware of what virtual prototyping (VP) technology has to offer; many also do not think that it has any applicability to their business needs or simply believe that the technology is too complex and expensive. However, as hardware and software prices continue to fall and technologies converge, we are seeing the development of digital and VP systems specifically optimised in terms of cost and capability for the needs of small and medium enterprises.

Virtual prototyping has come a long way in recent years, away from the production of crude images and the cumbersome headsets that many still associate with the technology. Non-immersive VP, PC-based, coupled with the phenomenal increase in computer processing power means that detailed virtual 'worlds' can be modelled incorporating all the usual features of everyday life such as light, shadow and the laws of physics.

An element of the confusion surrounding VP is that the technology is synonymous with other technologies already utilised widely across industry and the term itself is loosely applied to a wide variety of activities. The term 'virtual prototyping' is not, in our opinion, restricted to the use of a discrete item of software to simulate the behaviour of a real-life product. It also encompasses an approach to product development that takes advantage of individual technologies such as computer-aided design and the successful adoption of email technology to build an efficient product-development capability based principally on greater collaboration between designers, engineers, marketers and customers.

It is the desire to reduce time to market, cut costs and speed up product development that is driving the exponential development and adoption of VP tools. A requirement increasingly being placed on all companies within an array of industrial supply chains is the need for product-development capabilities in order to respond to the needs of the end consumer. This aspect of customisation of industrial products is driving design pressures down the supply chain onto the shoulders of SMEs, who must have the capabilities and tools to respond accordingly if they are to continue to be competitive.

Whilst virtual prototyping can be a discrete software system achieving a range of functions by itself, it is best conceptually represented as the fusion of virtual reality and computer-aided design technologies, which use similar hardware and interface techniques. These technologies in themselves have been available to industry for a number of years and have also suffered their own 'staggered' adoption curves due to cost, complexity, integration issues, lack of skills and lack of market understanding.

However, the growing interest in industrial applications for virtual reality technology and the growth of computer-aided design into a near universal design application, shows the way for the mass adoption of VP tools once their technological maturity has been demonstrated and they are seen to deliver clear business benefits and competitive advantage.

This report seeks to address both discrete VP, and the combination of technologies and techniques that constitute a VP methodology. In doing so it will assess the practical implications, business benefits and pitfalls of virtual prototyping for small and medium sized companies responding to market developments such as increasing customisation and ever shortening time-to-market targets.

2.0 What is Virtual Prototyping?

Industry adoption of virtual prototyping, sometimes referred to as 'digital prototyping' or 'virtual modelling', has been stimulated by interest in simulation and computer modelling techniques. The convergence of technologies such as simulation, computer-aided design (CAD) and virtual reality (VR) have enabled the development of accessible, low cost, user-friendly VP systems. These VP tools are increasingly being viewed as the next generation of computerised design systems. An evolution of CAD, they have proven themselves in applications across a wide range of industries. Ultimately, discrete VP tools and CAD systems with integrated digital prototyping capabilities serve to demonstrate that the technology is maturing in terms of its business applicability, moving away from being perceived as experimental and towards mainstream design.

Depending upon the area of application, differing definitions can apply, but Tim Hodgson (Comptek Federal Systems Inc.) offers an apt one for product design:

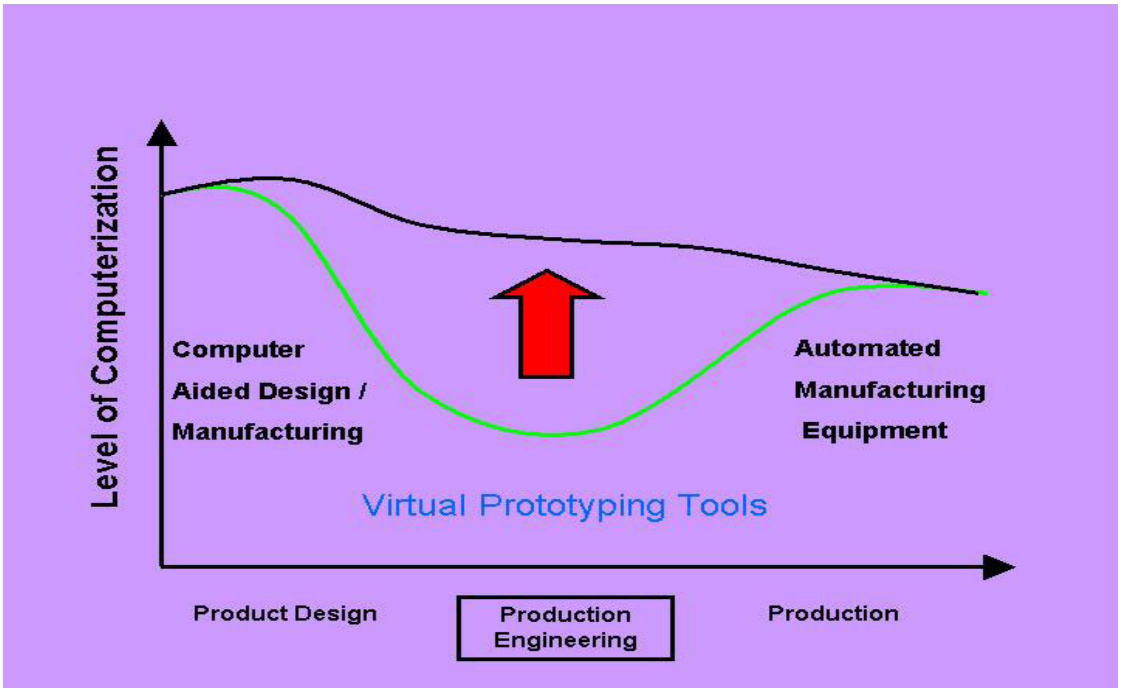
> *Virtual prototyping is a software-based engineering discipline that entails modelling a mechanical system, simulating and visualising its 3D-motion behaviour under real-world operating conditions, and refining/optimising the design through iterative design studies prior to building the first physical prototype.*

Thus, at its most basic level VP is a tool for enabling engineers, designers and product developers to work together concurrently within a virtual environment to solve design, manufacturing and maintainability issues at the earliest stage of product development. It represents a design capability, which allows users to predict and prevent problems early in the product-development process rather than finding and fixing them later on, a situation that can substantially reduce product-development costs. The adoption of tools that help engineers eliminate product flaws at the earliest stages of development also helps organisations to meet critical time-to-market objectives, enabling them to maximise their profit margins.

VP is best envisaged as an evolution of CAD and VR, and as Figure 1 illustrates, it bridges the gap between current design tools and automated manufacturing system. It allows engineers and designers to utilise CAD data and techniques to construct interactive simulations that model the key aspects of the product's physical behaviour, all at the 'digital' development stage. This allows for product testing at the earliest moment possible, which has beneficial consequences of the cost of getting the design to market.

In a wider context, VP represents the application of computer technology to the areas of product design, development and manufacture. It shares close associations with the whole field of computer-aided-engineering (CAE), which covers the application of information technology to the whole spectrum of engineering from initial design through to delivery to the end customer.

Figure 1 Virtual prototyping tools fill the gap in automating industrial systems.



(Lederer 1995)

VP tools can be used to support and accelerate the product-development process; its visualisation capabilities can be used to convey product aesthetics with greater clarity than static 3D CAD images, accelerating product conceptualisation greatly. Clarity of design information represents a significant advantage in checking product form, clearances and mating features.

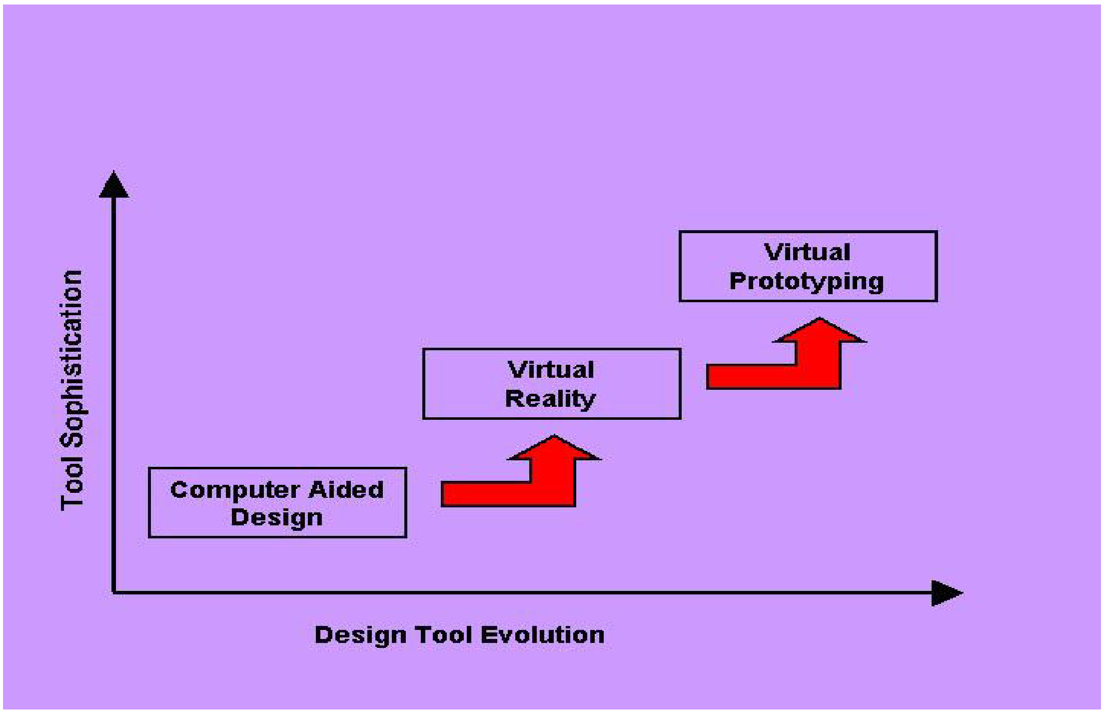
VP simulation is also a suitable tool for developing factory layouts and planning production lines. As well as modelling products, it can be used to realistically model machine tools, workstations and the dynamic movement of items between them. Such capabilities lend themselves readily to the identification of production bottlenecks and work-flow constraints, all within a virtual factory environment.

Visual prototyping as a technology has slowly evolved in line with technical advances in computing to become an invaluable tool in a number of key engineering areas. From the perspective of industrial application, the technology has the potential to revolutionise design and production planning. However, to realise this greater potential, it must overcome acceptability barriers such as technological prejudice and affordability.

3.0 The History of Virtual Prototyping

To appreciate what VP has to offer small and medium enterprises, it helps to consider first the individual technologies that have converged to form the current generation of design tools. VP is a natural development of VR and CAD. Figure 2 illustrates the evolution that is taking place in the field of computerised design tools. Technology convergence is leading to the marketing of affordable, fully functional, SME-friendly VP-enabled design systems. As indicated, the history of VP is ultimately the combined history of CAD and VR, within which lie the interactive simulation techniques and refined engineering data that make digital prototyping of industrial products possible.

Figure 2 The evolution of computerised design tools



3.1 Computer-Aided Design

CAD has been a revolutionary development for a wide range of industries including manufacturing, architecture and construction – especially so, as it eliminated the need to create design drawings by hand. The *Hutchinson Concise Encyclopaedia* defines CAD technology thus:

> *The use of computer facilities for the creation and editing of design drawings.*

The advent of CAD meant that changes to drawings, previously a time-consuming manual process, could be incorporated with significantly greater ease. CAD also provided a means of standardising the drawing process, which removed a significant amount of the ambiguity in processes and procedures that design departments at the time were operating under. Furthermore, CAD provided a relatively simple tool for 3D visualization; manual 3D perspectives had relied on slow, painstaking drafting techniques and were not interactive. CAD has therefore altered the very nature, definition and the scope of the design process. Table 1 below details some of the milestones in the progress of CAD to its current position of design dominance.

Table 1 The history of computer-aided design

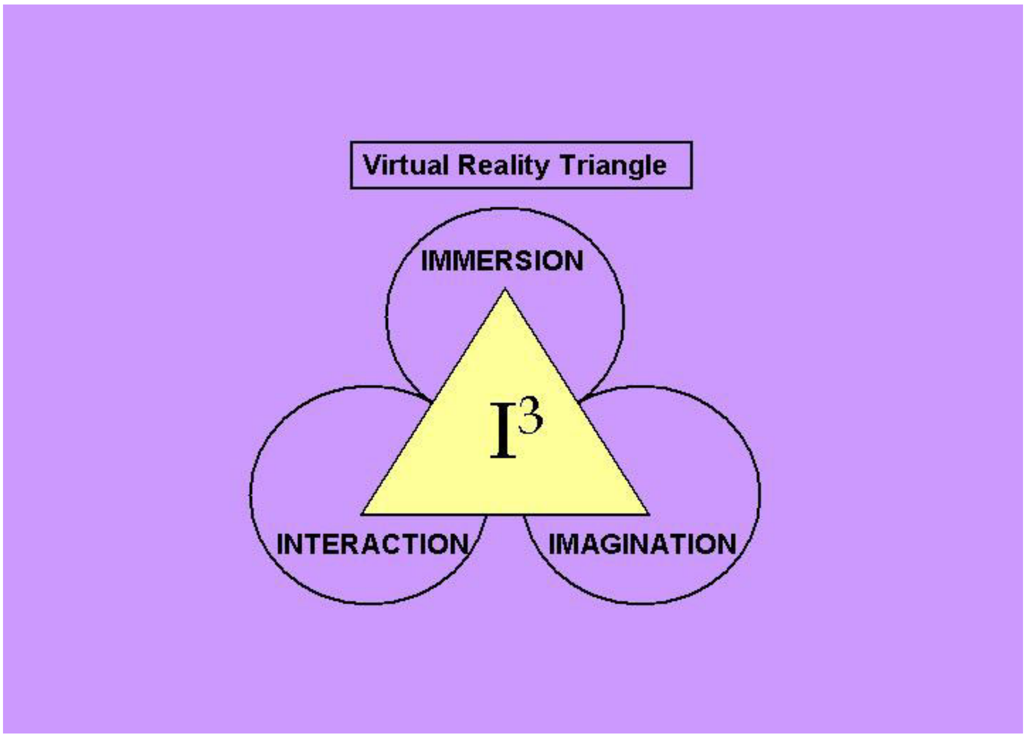
History of Computer-Aided Design
Before 1970 CAD developed in the 1950s for use by the Air Force. The first graphic system, the SAGE (Semi Automatic Ground Environment) air defence system, was used to display computer-processed radar data and other information. By the 1960s, CAD systems were being tested for their usefulness for designing interior office spaces. In 1968 crude 2D drawing systems were available using terminals linked to large mainframe computers.
1970s Several companies began to offer automated design/drafting systems in the early 70s. Names include CATIA and CADLink. 3D capabilities emerged in some programs being offered. At the end of the 70s, a typical CAD system was a 16-bit minicomputer with a maximum of 512 Kb memory and 20 to 300 Mb disk storage at a price of $125,000.
1980s Autodesk arrived on the scene with the aim of creating a CAD program to be used on the PC, priced at US$ 1,000. Soon AutoCAD caught on as the most popular CAD software. Many other programs followed suit. CAD programs were still used primarily for engineering applications.
Early 1990s CAD entered the architectural industry. 3D visualization was added into CAD programs. AutoCAD Release 12 for Windows became the most successful CAD program.
Mid 1990s CAD programs were now available in the market for a variety of uses and applications. CAD viewers were developed for viewing and redlining drawings.
Late 1990s Although many more people were using CAD, there was stiff competition to attract users. Better programs were being created to satisfy the ever-growing needs of industry. 3D CAD packages abounded in the market. High-end CAD software migrated to mid-range prices. Many simpler CAD programs were made available to diversify the market.

Autodesk

3.2 Simulation and Virtual Reality

The term virtual reality is used to describe the simulation and construction, through the use of computers, of virtual environments in which users can immerse themselves and experience sensory feedback; VR conveys a sense of 'being-there'. Thus, whilst VR is both interactive and immersive, it also offers the potential to be applied to real-life engineering and processing problems through the use of simulation techniques. In this regard it has an 'imagination' element (see Figure 3) that provides it with unbounded potential applications.

Figure 3 The virtual-reality triangle



(Burdea & Coiffet 1994)

3.2.1 HISTORICAL DEVELOPMENTS

Whilst the history of simulation is a long one, it can be argued that modern simulation technology owes its current degree of development to a renaissance enjoyed in the first half of the twentieth century. In the run up to the Second World War the number of training aircraft for trainee pilots became very limited. This led to the development and application of mechanical flight simulators to teach fighter pilots basic flying skills. Consisting of a motion platform, a seat, a control stick and an artificial horizon, the Link Flight cockpit (1932) was state-of-the-art simulation at the time. Military researchers were quick to spot the potential application of simulation and VR technology and one of the first real-time applications for VR was in the introduction of radar tracking screens in the early 1960s.

It was not until the early 1960s that Morton Heilig, heralded as the inventor of the modern concept of VR, patented a commercial VR design for his invention entitled “Sensorama Simulator”. This primitive virtual-reality video arcade booth, well ahead of its time, provided multi-sensory stimulation to attempt to fully immerse the user into a virtual world, which in Heilig’s case was a motorcycle ride.

As technology progressed, supercomputers combined with large 180° theatre screens were used to enhance the sensation of immersion into a virtual world. Images could be produced artificially and then controlled by a human-machine interface. In the late

1980s and early 1990s, headsets with motion detectors became the preferred medium by which to display the images. These gave the user the sense of being able to walk around in a simulated world and interact with virtual objects. This approach proved too slow, cumbersome and expensive for the wider commercial market at the time, but recent developments have opened up VR for wider exploitation.

Table 2 Potential VR application areas

Applications of Virtual Reality		
manufacturing industries • digital prototyping • collaborative design and engineering • ergonomics/human factors • maintenance analysis • training and education • sales and marketing	**medicine & healthcare** • surgical simulation for diagnosis, pre-operative planning, treatment and training • anatomical simulation • psychiatric treatment simulation • training and education	**scientific data visualisation** • computational fluid dynamics • molecular modelling • computational steering
architecture/engineering/ construction • building and plant design, construction and simulation • human factors • sales and marketing • community advocacy	**entertainment** • performance animation • digital theme parks • virtual sets • film production • gaming industry	**government usage** • flight simulation • vehicle simulation • battlefield visualisation and mission planning

Overall, VR technology has been long in the making. It has been adopted slowly ultimately because it failed to deliver on its over-hyped early promise. In the case for business and industrial applications, the technology is still maturing. Many people's perceptions of VR are of monster helmets and operators wired up to Frankenstein-like sensory-feedback suits and gloves. Whilst such contraptions from early VR research still have some currency, they are not representative of the commercial capabilities of contemporary VR. In essence, the development of the personal computer has liberated VR from cumbersome mainframes and heralds a step-change in the technology and its potential applications, some of which are listed in Table 2.

3.2.2 TYPES OF VR

There are essential three forms of VR technology – immersive, projection and desktop VR. In the past few years, the use of large headsets within immersive VR has given way to more portable and comfortable visors capable of displaying the three-dimensional information and continually falling in cost. Operating alongside immersive VR is projection VR, which involves displaying model/product data on large-scale flat or wrap-around screen to give a sense of scale and immersion. Projection VR has found a niche in the bringing together of small groups of designers and engineers in an environment where collaboration efforts can be undertaken in relative comfort.

However, the biggest innovation has been in the area of desktop VR. The growth of the personal computer industry and the phenomenal increase in computer processing power has enabled desktop computers to cope with the intensive mathematical calculations required to provide realistic 3D VR graphics applications. This has entailed significant developments in the VR field, with the cost of software systems falling significantly, but more importantly this has led VR vendors to align their product functionality with that of conventional computerised design tools such as CAD, so that the technology can now start to deliver on the promise of process and product improvement.

CAD vendors dominate the current design-tool market. Having established a flagship, they were quick to see the potential union between CAD and VR to develop a new generation of multifunctional design tools. Consequently, many CAD vendors have merged or procured VR tool vendors, and now offer VR and VP solutions as modular extensions to their core CAD systems.

3.3 The Impact of the Internet

The single greatest benefit of Internet technology and the World Wide Web (WWW) is that there is a significant and growing number of users adopting what is a common and open communications architecture, which opens up new possibilities to facilitate product design and development (Berners-Lee *et al.* 1994). The development of the Internet has presented a stable, common and increasingly secure platform for small and medium-sized design offices to engage in product development and prototyping activities that are becoming increasingly virtual in nature. On a basic level, it is now common practice for companies with very limited design departments to have the capability to receive and send by electronic means drawings, sketches and accompanying design data to customers and suppliers around the world.

Cooperation between design-session participants of different backgrounds is a necessity in the modern product-development process (Tuikka & Samela 1998). Increasingly the development of new products requires not only individual design efforts but also communication and coordination between different design disciplines. These design partners often engage in designer-customer relationships with various design partners holding responsibility for certain product features. In such relationships, it is typical that the customers make the important decisions on the product, whereas the designers introduce design choices to them. Often, these networks of expert knowledge are geographically widespread, which requires people to travel or to communicate their ideas in other ways. The Internet represents the initial platform of choice in the facilitation of such relationships.

The Internet represents both a source of unrivalled opportunity and unrivalled threat to enterprises both large and small (Small 2001; Statham 2001). For larger enterprises the choice with regard to adopting the Internet is clear-cut. It is a must for many, particularly if they are to continue to service their customers through all of the communication channels and formats they demand. For such enterprises, finance and access to equipment do not, typically, represent significant barriers. Neither does possessing or obtaining the ICT skills necessary to operate effectively in the new virtual business arena. As the reports by Small (2001) and Statham (2001) attest, many larger enterprises are utilising the Internet to establish economies of scale in their purchasing functions. They are also using the Internet and Internet communications protocols as a platform to reduce and streamline communications and administration processes between their national and international operations. Furthermore, both they and new entrepreneurs are developing new virtual business models and process, which, combined with savings and improved efficiencies in areas such as purchasing and administration, have demonstrated significant cost, operational and competitive advantages over existing business models.

It must be recognised that the opportunity of the Internet and the utilisation of Internet communications protocols for smaller enterprises are just as significant as for larger enterprises. The major issues for smaller enterprises are the presence of more significant barriers to usage, lack of finance, access to equipment and appropriate skills. These are often combined with a lack of comprehension as to the realistic potential business benefits that the adoption of Internet-based communications, and protocols and design tools, can deliver.

Overall, it is clear that the evolution of design tools is moving away from the use of static CAD models into an area where VR and product simulation, combined with increased processing power, promise the development of affordable desktop-based VP systems.

4.0 Why Virtual Prototyping

The highly accurate and realistic design of 3D engineering environments and products can be used to assess and evaluate new product designs and explore opportunities for savings in production cost. The capability to model in a virtual environment manufacturing processes or a new product design enables both designers and engineers to conduct rapid what-if evaluations that allow them to explore new product features, seek cost-reduction opportunities, optimise the use of automation, plan efficient factory layouts and assembly ergonomics all in a single integrated simulation environment. It is through the ability to explore what-ifs early in a product or process development that the true and full advantages of VP tools to organisations of all sizes emerge.

Until the increase in computing power and the reduction in both hardware and software costs brought VP tools within the reach of SMEs, they remained the preserve of larger organisations that for sound business reasons pioneered the application of the technology in their own industrial arenas. The Chrysler corporation was one of the first companies to use digital prototyping with its own software, CDV (Chrysler Data Visualiser). It was able to use the software to reduce the development time for new cars from six to less than three years, using the software to identify over 1,200 engineering and design issues before the first production vehicle rolled off the manufacturing line. Other success stories include Boeing, whose 777 airliners were the first aeroplanes to be developed from a purely digital design. The approach saved Boeing millions of dollars, reduced the need for engineering change and re-works by 70-90% and saved more than 100,000 hours of design time.

Blue-chip organisations such as General Motors, British Aerospace, Marconi, and Scottish Nuclear Power have actively explored the application of VP tools over a number of years and through a number of innovative in-house development programmes to assess the efficiencies and completive advantages that the technology could deliver. In almost every case, VP tools exceeded their expectations in enabling significant reductions in getting products to market, getting quality right first time, and enabling the rapid design, development and implementation of efficient manufacturing operations.

4.1 Advantages of VP

Academic exploration of VP tools has indicated for many years that the technology has the potential to revolutionise both new product and new manufacturing-process developments (Schmitz 1998). However, the ongoing publication of case studies detailing industrial organisations' adoption, development of, and successes with VP tools has been a significant influence in kick-starting other industrial enterprises to seek the significant business and process advantages that have been achieved by early technology adopters.

In attempting to establish the opportunity and benefits associated with the uptake of VP tools it is important firstly to understand the advantages and capabilities that the technology and approach provides in relation to the business and supply-chain pressures that such organisations typically operate under. An assessment of VP tools, through experiences, published academic research and a number of leading industry case studies highlights a clear number of advantages. These are listed in Table 3.

Table 3 Advantages and benefits of VP tools

Advantages and Benefits of Virtual Prototyping Tools
Enables a reduced time to market. Allows for early testing. Can conduct expensive or impossible tests. Reduces the need for a physical prototype. Improves operator safety and comfort. Removes geographic boundaries. Provides a common design standard and language. Protects profit margin. Increases company agility. Reduces development costs. Reduces the scope and scale of engineering changes. Engenders a right-first-time attitude. Unravels design complexity . Enables full participation by all interested parties in the product-development process.

(Norton 2001)

4.1.1 REDUCE TIME TO MARKET

‘Digital economy’ is a frequently used term that has relevance for all manufacturers. The application and convergence of ICTs (information and communications technologies) is directly driving end-customer expectations and opening up new channels for manufacturers to create, market and sell their products to consumers (Norton 2001). A key development is the trend towards consumer demand for high-quality, low-priced individualised products. This increasing demand for customisation is expected to continue as customers’ demands for lifestyle and niche-market products is not expected to decline. Taking account of the demand for product customisation has led many organisations to radically rethink their business model and their manufacturing philosophy. As a result, competition amongst firms in the digital economy has ceased to be restricted largely to quality, cost, delivery and price and embraced other factors such as product variety and speed to market important (Pine 1993).

An example of an industrial sector that has experienced a fundamental shift in consumer demand is the bicycle industry. Previously dominated by a mass-production philosophy focused on producing large runs of near identical products and targeted around reducing end-product costs, the industry now exemplifies the customisation approach. The current bicycle market is dominated by niche sectors such as mountain, racing and hybrid bike designs, amongst others, and within each of these sectors are companies operating at both ends of the cost spectrum; those producing high-value professional bikes competing on quality and functionality, and those producing increasingly smaller runs of bikes aimed at targeted customers such as keep-fit enthusiasts.

Overall, the market demands for customisation are now entrenched in sectors such as electronics, white goods and the lifestyle industries, where the philosophy is increasingly to replace old products with new or revised models over shrinking product life cycles. Such developments demand that companies become more efficient in developing rapid time-to-market capabilities if they wish to preserve their profit margins.

4.1.2 MEETING THE CHALLENGE

The real challenge for SMEs and others within the supply chain is that these forces, particularly the demand for customisation, product development and reduced time to market are increasingly being fed down the supply chain as competitive pressures. The development of customisation is contradictory to the current tactics of many low-tier supply-chain organisations, namely the pursuit of low production costs by establishing fixed product and process parameters. However, companies must endeavour to meet this challenge; they must seek to build uniqueness and individuality into their goods by increasing their customisation activities, if they are to remain competitive in the longer term.

It is particularly clear that customisation and associated developments pose a special challenge to the product-development process because customisation makes it increasingly vital for designers to be provided with feedback from production, testing, quality and marketing activities.

The selection of suitable VP tools must be undertaken to engender in organisations the ability to reuse economically and in timely fashion previous design and product information in the development of new product variety, reducing design changes and speeding up process development. However, it should be pointed out that improving product development does not rest purely on the adoption of VP tools. Companies, particularly SMEs, must endeavour to structure their often limited financial, technical and skills resources to best capture and recycle design information. It is acknowledged that one of the starting points for such an endeavour is the systematic capture and storage of past product-development efforts. Modern design systems, such as CAD and drafting packages allow companies to undertake this task in a very simple but effective manner.

4.1.3 EARLY TESTING

The starting point for the utilisation of VP tools is their capability to import product data created in CAD. Thus, once a product is given form using a conventional 3D CAD system, it can be transferred to a virtual development environment where physical properties and constraints identical to those in the real world can be applied, giving a virtual product with perfect visual appearance and the functionality of a real object constructed from a material of choice. As VP tools widely utilise CAD data, the creation of which is a necessary step in any modern product-development process, reclaiming this information for testing can result in greatly reduced development time and costs.

Once a functional, virtual product model has been created it can then be tested in a number of ways, obviating the usual need for a physical model. For examples, if a full 3D virtual prototype of an assembly exists, then it is possible to apply an assembly simulation package to obtain a full mechanical and kinematic simulation of the proposed assembly sequence, allowing potential insertion paths to be checked for access clearance and clashes. Engineers can also use VP to measure tiny components that ordinarily would be difficult to instrument without affecting test conditions. VP testing has also been applied to the ergonomic design of automobiles, aeroplanes and assembly workstations.

Furthermore, as VP tools can perform all of the above forms of testing on a personal computer, the opportunity to run a greater number of tests is evident. An additional advantage is that the technology can be readily used to test the behaviour of products under conditions that are not feasible in the laboratory or are difficult and costly to undertake in real life, such as extreme pressures and extreme loads or even zero gravity. Virtual models can also be cost-effectively tested to destruction. The ability to refine a digital prototype before constructing a real prototype for expensive proof testing is a significant benefit of VP tools. Overall, the versatility of VP tools permits testing information to be fed back into a modified and refined CAD model much more rapidly than with conventional design tests.

4.1.4 REDUCED NEED FOR PHYSICAL PROTOTYPES

For many organisations the production of a physical prototype is an essential step in the process of developing a new product. However, a physical prototype often requires manual tooling, skilled hand assembly, delicate testing instrumentation and time spent interpreting prototype data. As such it represents a necessary but ultimately time-consuming step in the development cycle. Engineers typically understand and incorporate what was learned from constructing and testing a prototype by revising the design, making a new prototype, and repeating the entire process. The time associated with making more than one prototype, especially with design revisions between each prototype, can tie up engineers and equipment for days or weeks at a time. The uptake of rapid prototyping has reduced prototyping time a great deal, but there is still time consumed in constructing physical models that have to undergo physical testing and subsequent revisions. For many companies, particularly SMEs, rapid prototyping means contacting a local bureau and incurring the costs of contracting out the prototyping work. VP allows multiple prototypes to be constructed and optimised on the desktop to ensure that the physical prototyping should hold no real surprises.

4.1.5 COMMON DESIGN STANDARDS REMOVES BOUNDARIES

With the Internet now a powerful global communications tool, new product visualisation and dynamic testing can be performed online, and importantly the technology is available to a wider range of businesses than ever before. Current CAD and computerised design tools permit design data to be shared with third parties and with other departments within the enterprise, allowing them to view and comment upon proposed designs. VP tools are the evolution of CAD. As such they allow product data to be transferred and shared between companies, in real time, without the initial need for a physical model or the exchange of paper drawings. This development removes the geographic barriers that are a hindrance to new product-design activities. Overall, it is through this potential of increased collaboration that the significant time reduction opportunities of VP arise.

The current emphasis within the VP tool industry is on the development of open Internet-based communications protocols for data transfer, using the same open channel to facilitate collaborative design-review sessions. This is a positive advantage to SMEs as the technology is clearly migrating to a platform that is becoming ever cheaper and more reliable, opening the doors in particular to smaller businesses.

4.1.6 REDUCED DEVELOPMENT AND ENGINEERING CHANGES

It is argued that the current manufacturing environment is unforgiving of products that are late to market, as much as 50% to 70% of the potential profit margin from a new product is lost when it is introduced late. Also, the costs associated with finding defects in industrial products are a function of where in the design-to-production process the problems are found. Often the "rule of 10" law is applied: the cost of fixing a problem that should have been avoided in the design phase is increased 10 times if found in the physical layout stage, 100 times if found on the shop floor, and 1,000 times if found by a customer. It is clear that these are the most powerful arguments for the adoption of VP tools.

4.1.7 UNRAVELS DESIGN COMPLEXITY

Design complexities are growing every day, product life cycles are shrinking and the time available to finish a working design is being compressed. Design tools developed for the 1980s or even the early 1990s were built around the "find and fix" mentality. This approach may have worked for the product life cycles of the 1980s and early 1990s, but it is not adequate for the more time-critical products being designed and built today. VP is representative of an evolving new generation of tools that enable the "predict and prevent" approach to design. They are not a luxury; they are a requirement. These tools help reduce frustration among design-team members, shorten the time to finish a design, and improve the quality of the design by allowing exploration of design alternatives and engendering a right-first-time attitude to product manufacturing.

5.0 Specific Industry Applications of Virtual Prototyping

The benefits of VP extend across a wide range of industry sectors, so it is important to look beyond the general benefits to assess what specific benefits VP may offer your particular business. A number of manufacturers have long-established virtual manufacturing tools that they have developed to support their business processes. Such companies were early adopters for VR and CAD and are predominantly blue-chip organisations. But other organisations, including many innovative SMEs, are rapidly closing the gap, migrating to virtual manufacturing and VP tools as they did to CAD in the 1980s. The principal challenge that such industrial concerns are now facing is keeping abreast of design-tool evolution, whilst identifying ways in which to capitalise fully on the benefits of VP.

The application areas of VP tools are closely aligned with those of VR. Table 2 identifies the areas that research and commercial exploitation of VR technology are most likely to follow in the short-to-medium term. In order to fully associate the capability of VP methods with real bottom-line business benefits, an assessment of the achievements of VP in specific industries has been undertaken through case studies.

5.1 Automotive

Automotive companies around the globe have invested significant capital in CAD/CAM systems and in computerised design tools because they enable production of high-quality vehicles with lower development and design costs, fewer prototypes and reduced overall risk. Even more significantly, a greater amount has been invested in computerised production machinery for the manufacturing process, greatly automating activities such as component handling and storage, welding operations, machining operations and assembly activities.

However, as these design tools and automated systems have become the industrial standard, automotive manufacturers have had to look elsewhere to maintain their competitive edge. It is within this area that VP software is enabling automotive manufacturers to close the gap between their design tools and automated manufacturing systems through the creation of life-like full-action mock-ups of vehicle bodies, the modelling of vehicle subassemblies, the design of vehicle components and even the creation of virtual production systems to validate and improve upon product manufacture.

In light of the benefits of VP systems, automotive manufacturers are clearly demonstrating significant benefits in using VP tools, including significant reduction in the time to market for new products. It is claimed that the development cycle for modern production cars has fallen from 5 years to 2.5 years, and that there has been a significant reduction in engineering changes made after production has got under way (Stone 1995).

Automobile manufacturer Renault started using virtual manufacturing and prototyping software in 1989, initially in the design of spot-welding production lines. Today, the use of such software is Renault's mainstream production-engineering solution. Such software complements the company's approach to concurrent engineering in its vehicles division, which merges the former product design and production engineering departments.

By integrating designers and production engineers, CAD and CAPE (computer-aided production engineering) solutions are combined in one environment. Manual Roldan, vice-president of vehicle engineering at Renault, says:

> *Virtual manufacturing solutions allow us to start manufacturing process design at the same time as production design. We are able to anticipate problems before they reach the production floor. This benefit of such software helps us to reduce car programme costs drastically, while improving car quality, cutting production time, and getting to market quicker.*

5.1.1 AUTOMOTIVE ASSEMBLY

New simulation tools, fundamentally based around virtual reality, are also being adopted by the automotive industry for the development and design of assembly stations. In developing the production and assembly plant for their Freelander sports utility vehicle, Land Rover UK successfully explored the use of simulation tools to enable engineers to design and develop a dedicated new manufacturing facility (Kochan 1998). Managing director, Ian Robertson, says:

> *We simultaneously worked on the car, the factory and the production process. We modelled the whole manufacture of the car before starting to cut tooling.*

In selecting tools to model the manufacturing process, Land Rover pointed out that the choice is not easy. The company were experienced in the use of 3D CAD for facilities layout (factory planning) but were looking for a tool that would enable them to visualise production facility designs. In effect, their existing CAD and visualisation tools only allowed them to look at key aspects of the proposed facilities layout in isolation, such as a conveyor line, a key part of the building or a part of the car on the line. What they wanted was the capability to pull these events together in an inclusive virtual environment that would allow them to see larger areas of the factory in operation.

Land Rover UK opted for a software tool known as Jack. Originally employed within the company to design passenger and driver compartments, it could also be used in the development of production facilities. Jack offered not only the sophisticated computer graphics and visualisation techniques that Land Rover were looking for; it also provided a versatile virtual 'human mannequin' which could provide a human component in designing the facility. Design process manager, Robin Wilson, Land Rover UK comments:

> *When we saw how Jack was being used in the concept [passenger and driver*

compartment] design area, we suddenly realised that this software could not only let us view the layout of the factory, but we could also incorporate the people working there, and view them walking around and performing tasks.

A key feature of Jack for Land Rover was its ability to interface with immersive virtual reality systems and its motion-capture capabilities. This enabled an engineer who had just constructed a virtual work cell to put on a display headset and motion sensors and calibrate the mannequin, Jack, to his own actions, which would typically be undertaking an assembly task within the cell. This way the layout of the cell, in terms of reach, space allowance, efficiency of movement and accessibility could all be validated before construction began.

In its utilisation of Jack, Land Rover concentrated on improving facility layout, job design and time, method and motion studies and the system enabled verification of the re-designing of work spaces to be undertaken with improved efficiencies. In adopting VP tools such as Jack, Land Rover improved what they called their 'time-to-insight', which is a measure of the time it takes for production engineers and designers to gain a detailed understanding of the assembly processes and the issues that will make work stations more or less efficient. Robin Wilson, design process manager at Land Rover UK, again:

We can say that it [Jack] has accelerated time-to-insight by four to eight months which is extremely valuable. When you make a mistake and have to re-work any bits of layout the costs immediately runs into tens of thousands of pounds.

5.1.2 OFFLINE PROGRAMMING

Within the automotive industry two significant activities relate to the painting of vehicle bodywork and the welding of vehicle components. Both of these activities have been the subject of intensive study by car manufacturers leading to the development of highly sophisticated, automated systems. In following the automation route, both of these activities brought with them the requirement for extensive programming of the spray and associated welding equipment and robots.

By utilising VP tools that enabled the reuse of CAD data on part design to develop paint-spray and welding paths in a virtual environment (offline), automotive manufacturers were able to move away from the expensive and time restrictive practice developing and validating manufacturing and machining programmes using the production equipment itself. Within the industry one of the most popular tools is RobCad, which is a virtual manufacturing software solution. According to companies such as Mercedes Benz, the use of offline programming using software such as RobCad is responsible for time savings of 30–40% (Lederer 1995).

The extra capabilities that VP tools give automotive manufacturers not only help save time; they increase their production capability in responding to customers' demands for individualised products. Modern vehicles feature many options within their manufacture. This translates into a variety of car models which in turn places great pressure on the manufacturing facility. Companies such as Nissan are responding to this challenge by building innovative, cost-saving, multiple-car single-line manufacturing plants. However, within such plants, the use of computerised tools to validate and programme robots is essential to their initial development and ongoing efficient operation.

Within Nissan's Tokyo plant a single production line handles four car models. Considering the model configurations, which cover different numbers of doors and seating arrangements, there can be 20 individual programs each for the facilities' 117 robots. Systems engineering group manager at Nissan, Mr Yamagishi, comments:

> *Producing so many different models on one line is unprecedented in the automotive industry. It requires very complex production facilities, as the production cells and tooling must be suitable for a large number of components. We are designing cell layouts on RobCad and then proceed to simulate and off-line program. Today all the production cells within the Tokyo factory are designed and verified this way.*

By utilising VP tools Nissan were able to reduce from five months to three the time to build the new production line. Given the project's total duration, 18 months, the reduction represented a significant saving in time to market and led to increased vehicle production numbers and longer product life. The approach was also seen as generating significant savings in tool and fixture building costs.

5.2 Aerospace

The aerospace industry is one of the driving sectors behind the adoption of VP technologies and systems (Prue 1998). The sector is typified by large-scale projects involving highly complex, relatively low-volume products. Furthermore, complications arise in the aerospace sector because of its global nature. Within the aerospace sector many design and development projects are undertaken on an international basis. This introduces into the design process the issue of communications between separate design partners, which increases project- and design-coordination requirements significantly.

The aerospace industry has been a key proponent of exploring the use of new technologies to simplify and standardise the design process and its related communications and information-exchange requirements. Leading aerospace organisations, like Boeing and British Aerospace, were early adopters of now established technologies such as CAD and CAM (computer-aided manufacture) and have subsequently moved on to exploring the advantages of VP technologies.

Within the aerospace industry a significant number of processes and manufacturing requirements have been affected by VP technologies. A long-running VP program at British Aerospace has reportedly revolutionised the methodology they employ to bring their products to production (Bennett 1997). The major applications for VP within the sector are as follows:

- process and assembly planning and estimating
- simulation and validation of NC programming and NC machining
- simulation and validation of the programming of coordinate measuring machines (CMMs)
- tool design and manufacture
- factory and cell design and simulation
- ergonomic assessment.

Within these areas, assembly and process planning are highlighted as key areas for VP tool use.

5.2.1 AEROSPACE ASSEMBLY

The needs and problems encountered by Sikorsky Aircraft Corporation typify those encountered in this sector. Sikorsky is one of the world leaders in the design and manufacture of advanced helicopters for commercial, industrial and military use. Their products are used by all five branches of the US armed forces, the military services of more than 30 countries and by commercial operators around the globe. In developing the S-92, a medium-sized, 19-passenger transport helicopter, the company acted as an integrator, leading an international team of some of the world's most prominent aerospace manufacturers.

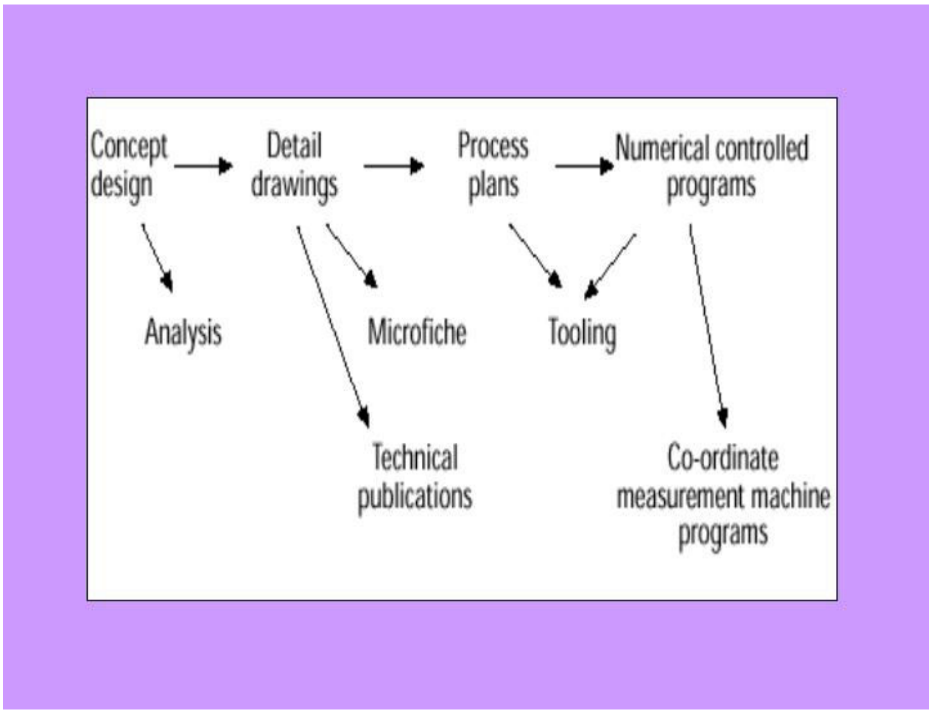
Sikorsky's key role lies in manufacture of composite materials. Previous projects had suffered from the need for extensive rework beyond the design and development stage. The company's key task was to develop the composite structure of the helicopter. This required the precise arrangement of up to 300 plies of composite material to produce a single finished component. Misalignment or inaccurate placement of just one of these plies would compromise the part and require significant rework. Other problems were encountered due to complex component geometry, areas of stress concentration on parts and reworking tooling. Tooling was a particular concern; faulty tooling was often shipped back to international manufacturers, causing significant delays.

In 1998, the company decided to develop a more 'virtual' approach to the complex design issues associated with its projects. By combining their existing CAD and CAM systems with an integrated composite material simulation package, they sought to prototype their products in a digital environment. The VP approach produced significant benefits. The reworking of plies was reduced from 40% to 4% and the number of engineering changes slashed from the original level of 120. By identifying problems early, engineers and designers were able to make changes at one-tenth to one-hundredth of the cost that would have been involved if the problems had gone undetected to the shop floor. Overall, adopting VP techniques enabled Sikorsky to save four months on the project time, a reduction of 27% over similar previous projects. The number of engineering revisions was cut by 90% (Forster *et al.* 1998).

5.2.2 SCOPE FOR COST REDUCTION

Within the aerospace sector, the savings achieved by adopting VP are evident in two significant ways. Firstly, the benefits of using advanced technologies to assist in the engineering design is a significant sources of time and cost saving, allowing errors to be detected as early as possible. Secondly, the extension of digital technologies into the design process enables it to be more fully integrated with the 'production' side of product development. Hence the streamlining and control of data and information exchange, particularly on large projects, reduces the scope for bad design due to incorrect information. Figure 4 shows a typical project introduction process route, applicable to the aerospace and related engineering sectors.

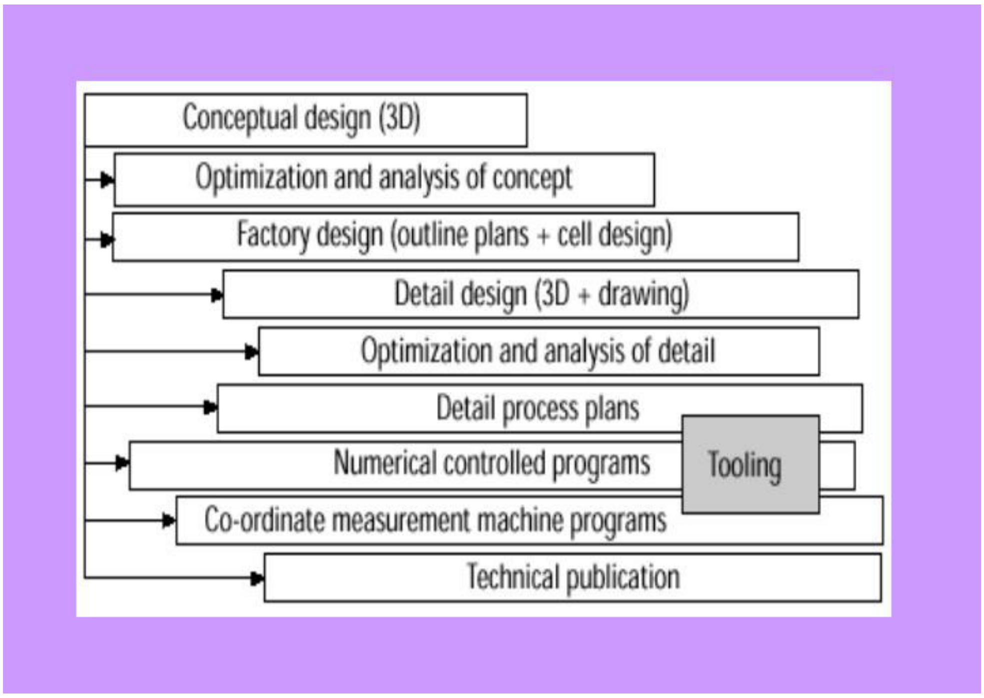
Figure 4 Traditional product-introduction method



(Bennett 1997)

With the adoption of VP methodologies, companies are better prepared to move away from sequential manufacturing and adopt a more concurrent or simultaneous approach to getting their products to market. British Aerospace is one such organisation. It has implemented a VP approach based on a commercially available feature-based CAD/CAM toolset, kinematic CMM, assembly simulation and verification, rules-based process planning, an ergonomics assessment system and rapid prototyping. They highlight that such an approach has enabled the company to develop complete concurrent engineering. This process is detailed in Figure 5.

Figure 5 Concurrent engineering as applied at British Aerospace



(Bennett 1997)

British Aerospace have commented that the system is controlled by an engineering data management system and has facilitated a radical concurrent engineering activity, which has brought down the cost and lead times for product introduction and allowed right-first-time manufacture.

6.0 Availability of VP Tools

The selection of a suitable VP tool or VP-enabled CAD system is business-critical. The decision also depends on many factors that are unique to individual enterprises, such as available operator skills, legacy systems, network requirements and budget. In seeking to identify and implement a VP approach to design, it is essential that a methodical effort be adopted to obtain the right system at the right price – one that will deliver the functionality required and achieve rapid organisation-wide acceptance.

The pace of technological change within the CAD and VP sectors is significant and it is accelerating. In undertaking this study, information has been sought on some of the leading VP tools available on today's market. The details of this effort are contained in section 7's survey of VR tools, which details for each product its vendor, the systems application area and basic information on the product itself. It is intended as a starting point for companies beginning the process of identifying potentially suitable VP vendors. The system functionality areas, as identified by the survey, cover the following applications:

- computer-aided industrial design (CAID)
- design review and motion simulation
- ergonomics, maintainability and assembly sequencing
- factory layout, simulation and robotics
- CAE visualisation
- virtual training.

Before system identification, many engineers and designers must construct a suitable business case prior to system procurement. This issue is addressed below.

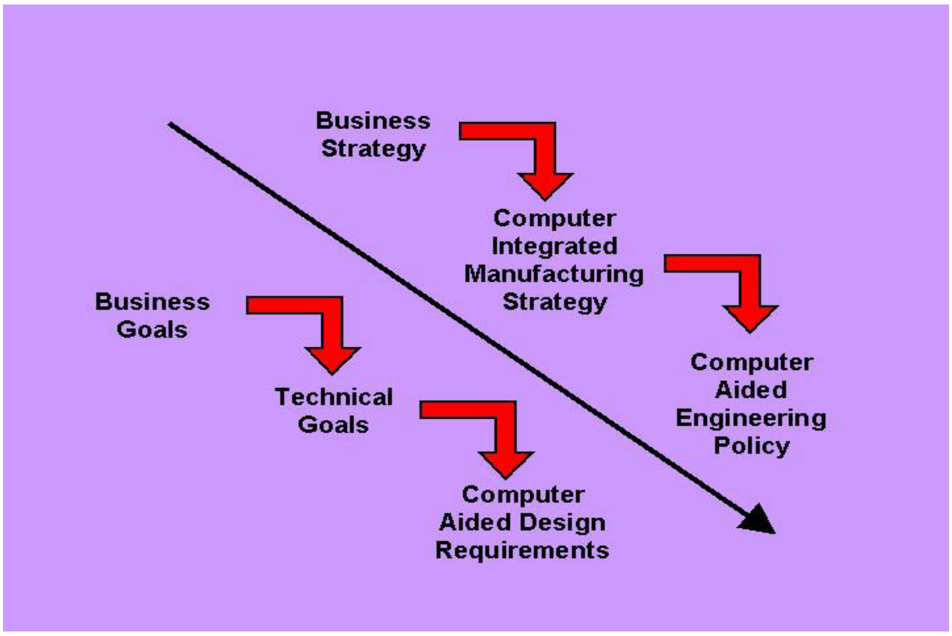
6.1 The Business Case

It is essential that the introduction into an enterprise of a computerised engineering system such as VP is accompanied by a strategy that fully supports the business and operational goals of the organisation. If not, it runs the risk of becoming an expensive exercise in technical innovation that will not yield tangible cash benefits to the company. Figure 6 illustrates the way in which the business strategy should drive the systems-integration strategy, which in turn will determine the CAE policy. Similarly, the business goals should drive the technical goals, which then determine the requirements for the design system.

6.2 The Move to World-Class Manufacturing

In seeking to re-engineer business processes an approach incorporating appropriate elements of world-class manufacturing should be the stance adopted by all organisations. It may also have particular relevance as a maxim for those SMEs seeking to reposition themselves with regard to their customers within the supply chain. Case-study assessment and other literature on the subject clearly shows that attempting to realise dramatic improvements in critical measures of business performance – such as cost, quality and delivery – a move to concurrent and collaborative engineering using VP tools provides the scope for considerable competitive advantage.

Figure 6 The relationship between business strategy and CAD requirements



(Bennett 1997)

Typically, product development has been seen as consisting of a number of discrete stages. However, competitive pressures and time-to-market requirements are forcing companies large and small to adopt concurrent processes that necessarily integrate and reduce the development stages between initial product concept and full-volume manufacture. Table 4 shows how traditional product-development cycles have been reduced in the face of competitive pressures, to engender a world-class product-development cycle. Within larger organisations, typically structured around individual departments responsible for various aspects of product design and manufacture, concurrent processes raise many cross-departmental communication and trust issues. Within smaller organisations, different barriers to concurrent processes present themselves, such as lack of resources and time. There is no one simple solution to this thorny issue for smaller enterprises. However, what is clear is that issues such as customisation, concurrent processes and new product-development capabilities are areas of extreme challenge and promise for a wide range of enterprises.

Table 4 Traditional versus world-class new product development

Traditional versus World-Class New Product Development	
Traditional	World-Class
• marketing • product design • prototyping hardware and testing • pilot product and testing • full production	• marketing • product design, virtual prototyping and manufacturing development • full production

(Caldwell *et al.* 1995)

6.3 System Selection: What to look for

In selecting suitable VP tools, companies should seek to apply the lessons learned during the purchase and procurement of their CAD and associated design technologies. The sales routes, major procurement steps and hardware requirements are identical to purchasing today's mid- to high-end CAD systems. However, given the evolutionary nature of VP tools, key consideration should be given to the following system elements (Tuikka & Samela 1998).

- *The system should be easy to use.* Where possible it should provide an open menu structure with customisable commands for developing a custom interface, enabling repetitive tasks to be undertaken as macros. Ease of use is a general requirement for the success of VP tools. Integration using open protocols such as the World Wide Web should be sought and the question of how the system can be integrated to support the company's major business processes should be raised.
- *The computer system should be smoothly integrated with design work.* Designers' work is very complex and requires many skills, ranging from understanding of the characteristics of materials, such as plastic or steel, to the usage of computers. A number of systems are commonly used as an aid in industrial, mechanical and electronics design for the specification and development of a product. The VP tool must integrate with these other systems to be able to import and export data efficiently.
- *The concept should be visualized well.* In any VP tool a major feature will be the quality, interactivity and responsiveness of the graphics. Excellent visualization is necessary, not only for communication purposes, but also to sell the idea of a new product. Thus, it is necessary to have photographic quality when rendering the model. Seek a system that has model optimisation, either heuristic or automatic, which gives it the capability to balance the trade-off between displaying top-quality images and the demands of interactivity for dynamic analysis.

- *Files should be easily transferable.* It should be easy to receive or transfer model and design data. Ensure that the system meets the major current communications protocols and that in importing and exporting files major data transfer standards such as STEP and IGES are supported. Challenge the vendor to demonstrate the exact nature of the transfer, as any difficulties in data transfer will greatly impair system performance and can ultimately prove to be time consuming to correct, often requiring a highly skilled design operative. It is also important to ensure that the system has integral data-security features.
- *3D models should be synchronized.* VP tools should incorporate or be interfaced with a system to ensure the integrity and currency of the design model. The relationship between designers, engineers and customers entails a need for synchronization of the product data. This synchronization should be applied to the shared object of design, i.e. the virtual prototype both parties see on their screens. Synchronization allows viewing the virtual prototype from different viewpoints. Similarly, there should also be features that support collaborative sessions in which multiple parties comment on the design on-screen and ideally features to track model versions and keep records on who participated in specific design sessions.
- *The design rationale should be tracked.* Given the often complex nature of new product development, involving input from several different parties, it is important to keep a track of what changes have taken place within the model and the rationale behind them. Retaining records of these process steps is one means of facilitating the capture of product knowledge, which if stored accordingly can be reused for more efficient product development in the future.

6.3.1 IMPLEMENTATION TIPS

The wide variety available means that selecting VP tools can be difficult. Several requirements bear consideration in the selection of a suitable tool:

- Visit user sites where systems under your consideration have been installed to see what role the equipment and software perform at those sites. VP tool suppliers are all too keen to quote happy customers and systems users. It is worth exploring the uses to which the system is being applied as larger organisations may be using VP as a research tool and not in a design capacity. The opinions and experiences of such an organisation may therefore not apply to a system intended for design.
- Establish clearly at the outset who within your organisation is going to take ownership and responsibility for the system. Try to establish cross-department responsibility to prevent the problem of the system becoming a single department's hobbyhorse.
- Ensure that there is an established, cost effective and readily available migration path to the vendor's proposed future products. Obtain comments from

customers that have undergone upgrades regarding any issues or hidden costs. Scalability of VR tools is in line with that of CAD.

- VR tools are by their very nature inclusive systems. Before starting down the path of system selection, build credibility and support within the organisation by involving the affected departments. Establish a cross-discipline VP team if necessary (including members from marketing, production and design) to promote and drive system selection.
- Do not expect to revolutionise or abandon your current prototyping methods immediately. Physical mock-ups will still be required. Whilst the design department and production engineers should be capable of familiarising themselves with the technology, additional time may be required before other departments such as sales and marketing come to an appreciation of the approach and become able to comment effectively on it.

7.0 VR Tools

Computer-Aided Industrial Design (CAID)
Alias Studio Tools Combines advanced design tools for precision surfacing, with powerful conceptual modelling and rendering capabilities. StudioTools is a powerful suite of award winning 2D/3D software, used for design and styling in the automotive, marine, aircraft, sporting-equipment, electronic-enclosure, children's-toy and fashion-accessory markets. StudioTools 9.7 software (June 2001) features a family of tools – DesignStudio™, Studio™, AutoStudio™ and SurfaceStudio™, with prices starting at $7,500. The software runs on Windows NT®, Windows® 2000, SGITM Irix®, Sun™ Solaris™ and Hewlett-Packard® HP-UX®. Alias Waveform, 210 King Street East, Toronto, Ontario, M5A 1J7, Canada Tel: 001 416 362 9181 Fax: 001 416 369 6140 Email: info@aw.sgi.com Web: www.aliaswavefront.com
VisConcept VisConcept, originally introduced last year, replaces physical prototypes with realistic, interactive, one-to-one-scale virtual prototypes in such immersive environments as visualization rooms, visualization wall displays and desks. A scalable virtual prototyping solution, it enables manufacturing teams to experience, evaluate and explore product designs for formal or ad hoc reviews, dramatically reducing product design time and the need for physical prototypes. VisConcept features three key modules. Layout is a graphical-user-interface-based tool for creating interactive virtual prototypes on desktop workstations that can be viewed on the desktop or at a 1:1 immersive scale. Presenter provides immersive interfaces for scene interaction and supports complex environments with multiple pipes and processors, stereoscopic displays, interaction devices and head tracking. And Conference enables collaborative interaction with multiple VisConcept sites, so geographically dispersed sites can participate and interact with VisConcept virtual prototypes. Engineering Animation, Inc., 2321 North Loop Drive, Ames, Iowa 50010-8615, USA Tel: 001 800 324 7760 Fax: 001 515 296 7025 Email: uginfo@ugsolutions.com Web: www.ugs.com/products/colsol/
Opus Realizer Opticore's Opus Realizer was developed expressly for use by designers and modellers, using extensive input from the global design community. Opus Realizer works the way designers work – intuitively, interactively, and in real-time. Product features include a simple graphic user interface and parametric data preservation. CAD-import formats include Catia v4, Pro/E, IGES, STL and DXF.There is easy handling of multiple models, Visual Effects and Multipass rendering; a customisable material library for material editing. For texture editing, there is editing in 3D, Planar and cubic texture mapping features; model optimisation in combined and spatialise geometry. Opticore Inc, 3250 W. Big Beaver, Suite 327 Troy MI 48084, USA Tel: 001 248 649-2514 Fax: 001 248 649-2542 Web: www.opticore.com

ICEM Surf

World leading photo-realistic rendering in real time with rapid visualisation and streamlined modelling functionality. ICEM Surf provides breakthrough technology enabling users to produce world-class products in today's competitive, global markets. Acknowledged as the premier system for the creation and development of Class A surfaces, ICEM Surf bridges the demands of aesthetic designers and production engineers right up to tool and die designers.

PTC	Tel: 001 781 370 5000
140 Kendrick Street	Fax: 001 781 370 6000
Needham, MA 02494, USA	Web: www.ptc.com

Design Review and Motion Simulation

MSC.visualNastran & Working Model

Merge motion simulation, FEA and animation into a power functional modelling system that enables integrated motion and FEA simulation of assemblies in one environment. Working Model is the world's most popular CAE tool. Working Model 2D is a conceptual design tool that allows the creation of simulations that replace vague, time consuming, inaccurate 'back of the envelope' calculations. Working Model 2D has been adopted by thousands of professional engineers to create and analyse real-life mechanical systems. It has been designed from the ground up to optimise performance on the Windows 95 and Windows NT operating systems. Working Model 2D includes automatic collision detection and responses for NURBS geometry. The latest release also includes such popular scripts as Flexbeam, Shear and Bending Moment, and Pin Friction. These scripts have been customised to expand the use of Working Model 2D.

MSC. Working Knowledge	Tel: +44 (0)1276 601900
MSC House	Fax: +44 (0)1276 601909
Lyon Way	Web: www.workingmodel.com
Frimley	
Camberley	
Surrey GU16 5ER	

InCAD DesignPak

Range of extensions to existing CAD systems covering FEA, mechanical event simulation, material analysis and specialist areas such as fluid-dynamics analysis. Algor's InCAD DesignPak seamlessly captures CAD solid parts or assemblies from popular CAD solid modellers regardless of the location of the CAD and Algor software. DesignPak lets engineers control mesh quality through an easy-to-use sliding control and optional advanced meshing controls. DesignPak's solid mesh engine automatically generates a tetrahedral mesh from the high-quality surface mesh, comprised of nearly equilateral surface triangles, for a highly accurate solid FEA mesh. InCAD DesignPak enables engineers to get started with a minimal investment of $975.

ALGOR Inc.	Tel: 001 412 967 2700
150 Beta Drive	Tel: +44 (0)1784 442246 (UK)
Pittsburgh	Fax: 001 412 967 2781 (US)
PA 15238-2932	Email: info@ALGOR.com
USA	Web: www.algor.com

VisMockup

Real-time digital prototyping solution that provides interactive advanced 2D and 3D visualisation and analysis of products with robust analysis of large product assemblies.

Engineering Animation, Inc.	Tel: 001 800 324 7760
2321 North Loop Drive	Fax: 001 515 296 7025
Ames, Iowa 50010-8615	Email: uginfo@ugsolutions.com
USA	Web: www.ugs.com/products/colsol/

DADS

Allows for assembly, analysis, optimisation of dynamics and mechanics. Also verifies fit, function and reliability of your designs. DADS is a computer simulation tool for predicting the behaviour of single or multimode mechanical systems. To improve efficiency in creating your DADS model, you can collect model data and geometry from most CAD programs. For some of the most popular CAD packages, interfaces have been developed which automate the process. Furthermore, a complete library of controls and hydraulic elements is available within DADS

LMS International	Tel: +32 16 384 200
Researchpark Z1	Fax: +32 16 384 350
Interleuvenlaan 68	Email: info@lms.be
3001 Leuven, Belgium	Web: www.lmsintl.com

ADAMS

ADAMS is the world's most widely used mechanical system simulation software. It lets you build and test virtual prototypes, realistically simulating on your computer, both visually and mathematically, the full-motion behaviour of your complex mechanical system designs. ADAMS can quickly and easily create a complete, parameterised model of mechanical systems, building from scratch or importing parts geometry from a preferred CAD system. The system then enables users to apply forces and motions and run this model through a battery of physically realistic 3D motion tests.

Mechanical Dynamics Inc.	Tel: +44 (0)1926 420230
12 Clarendon Street	Fax: +44 (0)1926 420494
Royal Leamington Spa	Email: mdi_uk@adams.com
Warwickshire CV32 5ST	Web: www.adams.com

ProductView

Displays many types of product-related information from 2D drawings to 3D models in a Web-based framework. Allows for large data sharing capabilities.

PTC	Tel: 001 781 370 5000
140 Kendrick Street	Fax: 001 781 370 6000
Needham, MA 02494, USA	Web: www.ptc.com

Ergonomics, Maintainability and Assembly Sequencing

VAPS

Tool for building data-driven, interactive, visual human-machine interfaces (HMIs).

Virtual Prototypes	Tel: +44 (0)1635 262724
St. Marys House	Fax: +44 (0)1635 528701
40 London Road	Mobile: +44 (0)468 975676
Newbury	Email: leng@VirtualPrototypes.ca
Berkshire RG14 1LA	Web: www.virtualprototypes.ca

Jack

Enables users to position biomechanically accurate digital humans of various sizes in virtual environments, assign them tasks and analyse their performance. Jack has been bought by SCI who have enhanced the product as follows:

- Dynamic module support added.
- Automatic detection of large psurfs
- Support for Digital Image Design's Monkey added.
- Support for Ascension's 3-button mouse.
- Update to Cyberglove interface.
- Texture-mapping updates.
- Motion planning updates.
- Many miscellaneous command additions.

Engineering Animation, Inc.
2321 North Loop Drive
Ames, Iowa 50010-8615
USA

Tel: 001 800 324 7760
Fax: 001 515 296 7025
Email: uginfo@ugsolutions.com
Web: www.ugs.com/products/colsol/

ERGOMan

Takes into account the ergonomic factors in design by the use of virtual humans in design environments.

Delmia Ltd
Victoria Court Bexton Road,
Knutsford
Cheshire WA 16 OPF

Tel : + 44 (0)15 6575 1121
Fax : + 44 (0)15 6575 1123
Web: www.delmia.com

Factory Layout, Simulation and Robotics

e-Factory & VisFactory

e-Factory Solutions include a core infrastructure that provides a common environment for multiple users and a set of best-in-class digital manufacturing applications. Visfactory is an older product that provides a systematic approach to facility design and smart factory object technology enables concurrent engineering of the whole factory.

Engineering Animation, Inc.
2321 North Loop Drive
Ames, Iowa 50010-8615, USA

Tel: 001 800 324 7760
Fax: 001 515 296 7025
Web: www.eai.com

ERGOMAS

Flexible instrument for shop floor layout, production-line planning and work-station design

Delmia Ltd
Victoria Court Bexton Road,
Knutsford
Cheshire WA 16 OPF

Tel : + 44 (0)15 65 75 11 21
Fax : + 44 (0)15 65 75 11 23
Web: www.delmia.com

EMPower

A suite of programs enabling design and analysis of workplaces. Factory layouts, cell designs and single operator movements are covered. Specific modules are as follows.

- eMPower CarBody enables developing, communicating and operating optimal body-in-white processes in the automotive industry.
- eMPower Assembly enables developing, communicating and operating optimal assembly processes in the automotive industry.
- eMPower Box Build enables developing, communicating and operating optimal assembly processes in the automotive and electronics industries.
- eMPower Machining enables planning, developing and communicating power-train machining lines for the automotive industry.
- eMPower Quality enables defining, predicting, measuring and analysing dimensional tolerances throughout the industrial process in the automotive, electronics, heavy and aerospace industries.
- eMPower PCB Assembly enables developing, communicating and operating printed circuit board processes in the electronics industries.

Tecnomatix Technologies Ltd.	Tel: +44 (0)121 3231300
5 The Priory	Fax: +44 (0)121 3231333
Old London Road	Email: szajas@us.tecnomatix.com
Canwell	Web: www.tecnomatix.com
Sutton Coldfield B75 5SH	

CAE Visualisation

EnSight

Provides a complete tool for all types of engineering analysis, visualisation and communication.

CEI Inc.	Tel: 001 919 363 0883
2166 N. Salem St., Suite 101	Fax: 001 919 363 0833
Apex	Email: ensight@ceintl.com
North Carolina 27502-8208, USA	Web: www.ceintl.com

ICEM CFD

A family of tools that can be incorporated into CAD systems to improve visualisation of ideas and technical material information. ICEM CFD is used for engineering applications such as computational fluid dynamics and structural analysis. The grid-generation tools offer the capability to parametrically create grids from geometry in multi-block structured, unstructured hexahedral, tetrahedral, hybrid grids consisting of hexahedral, tetrahedral, pyramidal and prismatic cells; and Cartesian grid formats combined with boundary conditions. Over 100 flow solver and structural analysis translators are provided to produce an input file containing mesh and boundary conditions. ICEM CFD also offers tools for post-processing and mesh optimisation.

ICEM CFD Engineering	Tel: +44 (0)1926 623321
Warwick Science Park Innovation Centre	Fax: +44 (0)1926 623322
Warwick Technology Park	Web: www.icemcfd.co.uk
Gallows Hill	Email: info@icemcfd.co.uk
Warwick CV34 6UW	

Fieldview 7

Standalone CFD Post processor.

Intelligent Light
1290 Wall St West
Lyndhurst
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Virtual Training

Creator; Creator Pro; Terrain Pro; GL Studio (3D modelling)
SmartScene; Handscape (immersive tools)

Rage of products featuring immersive 3D virtual training simulator. Allows humans to interact with virtual tools through a two-handed interface. SmartScene™ is the first application to fully exploit real-time 3D technologies to train, certify and maintain efficient workforces and to enable man-in-the-loop virtual prototyping process. SmartScene uniquely fuses MultiGen®'s industry leading real-time technologies with an intuitive two-handed interface, creating the most efficient immersive technology available. GL Studio™ is the newest and most advanced way to create interactive 3D graphics, instrumentation and innovative user interfaces for training, simulation, and virtual prototyping.

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7.0 Summary

Virtual prototyping is a computerised design technology that holds revolutionary promise in improving efficiencies within new product-development processes. The technology has evolved from existing design tools such as CAD and VR, and has now reached a level of maturity to warrant serious consideration as a must have design capability.

It recognition of its maturity, many CAD tools now incorporate VP capabilities as part of their modular construction. Thus the technology has reached mass market audiences.

Many potential users are confused over the applicability of VP to their specific design needs. As commented upon within this report, VP and the next generation of design tools, are increasingly moving away from being seen as luxuries, towards essential elements in any companies design arsenal. Demonstrably, VP tools have enabled companies to address the issues of customisation, developing concurrent processes, and the need for greater design collaboration, by allow them to tackle and reduce the ever critical time-to-market performance measure required to maintain their profit margins. VP helps generate saving through enabling better project coordination, quicker testing, engineering change reduction and process optimisation.

The implications for small companies seeking to adopt VP have moved aware from the cost barrier, as the price of tools has fallen significantly in recent years. What is required is a greater understanding on their part of the potential and usability of VP and the development of a viable business case for adoption. The technology itself, whilst continuing to fall in price, is coalescing around common standards and interface tools such that it ease of use and market acceptance are on the increase.

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