Extending the Product Portfolio with 'Devolved Manufacturing': Methodology and Case Studies

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Abstract

Current research by the developers of rapid prototyping systems is generally focused on improvements in cost, speed and materials to create truly economic and practical economic rapid manufacturing machines. In addition to being potentially smarter/faster/cheaper replacements for existing manufacturing technologies, the next generation of these machines will provide opportunities not only for the design and fabrication of products without traditional constraints, but also for organizing manufacturing activities in new, innovative and previously undreamt of ways. This paper outlines a novel *devolved manufacturing* (DM) 'factory-less' approach to e-manufacturing, which integrates Mass Customization (MC) concepts, Rapid Manufacturing (RM) technologies and the communication opportunities of the Internet/WWW, describes two case studies of different DM implementations and discusses the limitations and appropriateness of each, and finally, draws some conclusions about the technical, manufacturing and business challenges involved.

Keywords

1. Introduction

In the last decades of the twentieth century the development of computer numerically controlled (CNC) machinery and robotic manufacturing equipment has led to substantial increases in efficiency of manufacturing. At the same time, the evolution of new manufacturing methods, tools and systems (Figure 1) has led to changes in manufacturing philosophies from straightforward mass production methods to the latest in agile manufacturing [Cheng, 2004].

Figure 1 – Developments in Manufacturing

Although not always the case, key agents for slow change in manufacturing tend to be economic or socio-political factors whilst fast changes are usually driven by new technologies. Technology driven changes in manufacturing can arise from the development of entirely new technologies like say, lasers which enables some completely new manufacturing method or by the development of related systems (like IT) which allows the realisation of a manufacturing methodology which may have been

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around for years waiting for the technology to 'catch up'. If the new technology leads to significant changes in cost reduction or production efficiency then it will generally become the dominant method.

Periodically, the development and availability of some new technology(s) coincides with developments in other areas to give '*synergistic*' opportunities to approach manufacturing in a novel and previously 'unrealizable' manner.

The evolution of the Internet and/or World Wide Web (WWW), the new manufacturing concepts in Mass Customization (MC) and current developments in Rapid Prototyping (RP) technologies have led to such an opportunity to integrate these three areas. (Figure 2)

Figure 2 - Key areas for integration

The authors have previously used the term *devolved manufacture* to describe an innovative 'factory-less' approach to e-manufacturing [Bateman & Cheng, 2002]. This proposed approach would allow organisations to offer their customers the opportunity to more directly design items (in line with the principles of mass customization) using a web-based system and then have their design 'manufactured' at one of a network of local 'high street' *rapid manufacturing* (RM) facilities - which they can then go along to and pick up their 'creation'.

In this concept, the manufacturing is literally '*devolved*' downstream to the customer, dispensing with the need for centralised manufacturing facilities and inherent distribution issues.

2. Literature Review

2.1 The Internet/WWW

The history and continuing development of the Internet from its beginnings in 1957 at the United States Department of Defence Advanced Research Projects Agency through to the present day is well documented in many places as is the later development of the World Wide Web (WWW) [Berners-Lee, 1999].

2.2 Rapid Manufacturing Technology

Movements to speed up the product development cycle have lead to the introduction of a series of technologies (e.g. CAD) aimed specifically at shortening the design phase of the development cycle. Now, a group of technologies collectively known as *Rapid Manufacturing* (RM) have been developed to shorten both the design and production phases, and promise to revolutionise many conventional manufacturing processes.

These technologies are developed from Rapid Prototyping (RP) technologies and are generally categorized into two types – additive and subtractive [Kai, 1997]. The *subtractive* type essentially begins with a lump of material and by some process (milling, spark erosion, laser, etc.) carefully removes small amounts until the end product is revealed.

The *additive* type creates the item by carefully 'assembling' small amounts of material in layer-by-layer fashion into the whole product. The technologies used basically fall into three groups [Grover, 2002]: (i) liquid monomers which are cured (e.g. by laser) layer by layer into solid polymers, (ii) powdered materials that are bonded (e.g. by heat or adhesive) layer by layer, (iii) layers cut from sheet material laminated together to form the solid object.

The process has common key characteristics whichever method is used. - geometric modelling to create a computer model of the object and define its enclosed volume, followed by tessellation of the geometric model where the CAD model is converted into a format that approximates its surfaces by multiple facets (usually triangles or polygons) stored in an STL format file, then the slicing of the model in the STL file into closely spaced horizontal layers - The sliced model is then used by whichever technology to create the object in a layer by layer fashion.

Various methods exist including the sintering (melting together) of powered plastic or metal, solidifying liquid polymers by use of laser or ultra-violet light or adding small amounts of molten material which then solidifies. Various manufacturers like 3D systems, the Z-Corporation and Stratys, etc. produce systems with different materials, machine capacity and accuracies, allowing the creation of functional prototypes, concept models or moulds depending on the users requirements.

Most of these makers would undoubtedly argue that their machines should be regarded as <u>mature</u> technology (at least in the field of prototyping and model making) but the same cannot be said if one views the technologies as mainstream manufacturing technology. Much of the current research and development efforts of rapid prototyping system manufacturers is now focussed on the development of their technologies to create practical and economic rapid <u>manufacturing</u> machines.

Whilst the current generation of machines struggle to overcome problems of cost, speed and materials, the next generation may well tick all the boxes on the wish list of manufacturers the world over. However, in addition to being smarter/faster/cheaper replacements for existing manufacturing technologies, these new machines will provide opportunities for organising manufacturing activities in new, innovative and previously undreamt of ways.

2.3 Mass Customisation

Whilst the drivers for manufacturing processes to become leaner, more efficient and more agile may well be economic and competitive forces, such developments may also provide new opportunities. The *mass customisation* (MC) approach - first used by Davis in 1987 [Davis, 1987] and then expanded by Pine in his 1993 book [Pine, 1993] and then further developed by others [Anderson, 1998] - gives such an opportunity.

An exact definition of what Mass Customization is (or is not) has yet to be agreed, with some researchers [Duray et al, 2001] maintaining that *"extant literature has not established good conceptual boundaries for mass customisation",* but the definition proposed by Tseng and Jiao [Tseng, 2001] of mass customization as *" ... the*

technologies and systems to deliver goods and services that meet <u>individual</u> customers needs with <u>near</u> mass production efficiency ..." is often used.

At its simplest, mass customisation allows the customer to effectively 'design' their own product by selecting from a range of pre-defined sub-units which are then combined into the customised product. This approach effectively integrates the customer into the design process (in fact some writers on mass customisation sometimes call the customer the 'co-designer').

To be economically viable, the manufacturing systems used need to be configured to allow the greater range of possible outcomes to be produced as close in efficiency to dedicated mass production techniques and machinery.

Researchers like Davis and Pine prophesied the adoption of the mass customization approach into general manufacturing with the advent of new manufacturing technologies like CIM and flexible manufacturing systems, but to date the (successful) take-up has lagged behind these early predictions.

Research based on 250 'mass customizing' companies [Piller and Sotko, 2001] suggests that this time lag is due to the lack of appropriate technologies to handle the large amounts of information flows connected with mass customization, and that new Internet based technologies will go some way to enable the successful implementation of mass customization in more and more consumer markets.

From this research they generate two conclusions: (i) Every interaction between the customer and the supplier generates a high level of data (when compared to traditional mass production) making the value added <u>directly</u> related to this customer data - therefore mass customization should be seen as more closely related to e-business and the new possibilities connected with the Internet economy, (ii) Mass customization cannot be based <u>solely</u> on flexible manufacturing technologies, but must also include developments of material products and customized services into customized '*bundles*'.

To support the identification of potential mass customization bundles, MacCarthy et al. [MacCarthy, 2002] distinguish between a number of types of customization including; dimensional fit/size, hardware functionality, software functionality, property of the whole product, quality grade, quality level, aesthetics and style, identification and personalisation, literature, packaging and service customization. They highlight the crucial need to identify product areas where customers really value choice and differentiation and thus where the mass customization approach is <u>really</u> appropriate by the use of Key Value Attributes (KVAs).

Although the undoubted benefits of cheap, fast two way communication via the Internet/WWW has revolutionised business by providing access to world wide markets previously inaccessible to all but the largest companies, it then brings with it problems of order fulfilment – i.e. however quickly the product can be manufactured, it still has to be delivered to the customer. Research by MIT [Crespo de Carvalho, 2000] and the University of Westminster [Allen et al, 2000] suggests that despite the improvements in logistics systems, increases in congestion and associated transport costs could negate gains made in the design and production phases of manufacturing.

In an attempt to overcome some of these problems, but still maintain gains from mass customization, Reichwald et al [Reichwald, 2003] have developed an innovative concept of 'mini-plants' (Figure 3).

The basic principle of this concept is that the manufacturers production facilities are split into a network of small, scalable production units which are geographically close to the customer, but contain all the necessary equipment, personnel, etc. to for 'manufacturing', sales, distribution and customer service.

Crucial features of this approach are that research and development activities take place within the network of mini-plants, rather than being centralised, and information is actively exchanged between the mini-plant 'nodes' within the network.

Figure 3 - Customer integration in the creation of product / service bundles

3. Methodology

Many researchers are currently working on many mass customization based projects in a wide range of manufacturing and service industries and mass customization is a growing area of research.

It is generally accepted that today's customers are 'smarter', more demanding and are seeking more individualized and personalized products [Glazer, 1999]. Mass customization is one approach which may provide manufacturers with the 'tools' and methods to meet these changing consumer demands.

The authors concept of devolved manufacturing, in which manufacturing is literally 'devolved' downstream to the customer, dispenses with the need for centralised manufacturing facilities (and inherent distribution issues) or even 'mini-plants' - which although they will go some way to moderate distribution problems by being physically closer to the customer, still require the same personnel, premises, manufacturing and storage facilities 'in miniature'.

Devolved manufacturing (Figure 4) should be thought of as a 'factory-less' approach to e-manufacturing, which at the moment is probably not feasible due to internet and rapid manufacturing technology limitations. However, the point of this research is to demonstrate that the concept is valid - despite needing to wait until the technology 'catches up'!

Figure 4 – Devolved Manufacturing in the Agile Manufacturing Spectrum

The next section describes two case studies how the devolved manufacturing concept might be implemented either as (i) an 'internal' extension to an existing small company system, or (ii) as a web-based 'virtual organisation' allowing the customer almost total creative design control over the product.

4. Example Application Cases

4.1 Case Study One - Clutch Ability Limited (CAL)

Case Study One describes the extension of an 'in-house' system for an existing small (semi-fictitious) company Clutch Ability Limited (CAL) which specialises in the development and provision of specialist high performance clutches for race and rally cars. The range of clutches offered by the company is defined by the size of the market and only those models which fit engine/gearbox combinations commonly used in the race/rally arena are economically viable for sale since these items are relatively high-value (£300-750) and therefore represent a large investment for stockholding for such a small company.

The function of an automotive clutch is to allow the transfer of the rotation developed by the crankshaft of the engine through to the gearbox input shaft. The clutch allows a smooth engagement of a spinning engine to a non-spinning transmission by controlling the slippage between them. A typical racing clutch is an assembly of several distinct parts (Figure 5) each with a specific function and can have between one and four friction plates.

Figure 5 – Component Parts of a Typical Competition Clutch

The key factor in determining whether the clutch assembly will fit any particular engine/gearbox configuration is 'shape of the central hole' (Figure 6) where the splined end of the main input shaft of the gearbox runs through the hub of the friction plate(s). This is the key *interface* between the gearbox and the clutch.

Figure 6 – Example Splines at Centre of Friction Plate Hub

Splines are essentially integral keys spaced uniformly around the outside of the shaft and the inside of the hub and are used in cases where there would be too much torque for single key to handle. Splines may be either *straight sided* or *involute*. Straight sided splines should conform to the Society of Automotive Engineers (SAE) standard for straight tooth splines and involute spline dimensions and tolerances have been standardised with American National Standards Institute (ANSI) standards ANSI B92.1-1970 (R1982) for involute splines and ANSI B92.2-1980 for metric module involute splines. Different manufacturers use different spline arrangements but almost all modern gearbox input shafts have involute splines since they are typically stronger, more self-centering and are easier to cut and fit. The teeth have a profile similar to standard gear teeth with around 50% of the depth.

Whilst the use of a modern Computer Aided Design (CAD) system allows design of the different spline patterns with 'relative' ease, the operation of such a system requires a fair bit of expertise and a small company which deals primarily with the selection and supply of pre-manufactured solutions could not justify the employment of a CAD specialist for the small number of customers who need a solution different from those normally stocked by the company.

However the standardisation of the shape and positioning of the required spline pattern means that relatively straightforward algorithms can be developed to manipulate the

central features of a standardised CAD model of the friction plate hub. Only a few key dimensions are required to correctly create an 'appropriate shaped hole' (Figure 7) in the existing CAD model - since all other dimensions relating to how the hub fits to a standard friction plate (external diameter, thickness, rivet hole size and number, 'level of fit' of splines, etc.) remain fixed - to ensure the hub can be assembled into the final product.

Figure 7 - Key dimensions for friction plate hub (straight splined only shown)

Use of appropriate modification algorithms mean that these few dimensions could be input to via a simple data entry screen and used to drive a specially written computer programme which will modify a base CAD model of the friction plate hub changing only the centre spline pattern to create a new CAD model of the required hub. This can then be inspected using a simple 3D browser and if fit for use sent off *electronically* to be manufactured. This scenario has two advantages for the company – first it does not suffer the relatively high costs (for a small company) of CAD programmes and second requires no specialist CAD knowledge of the normal staff at the company.

4.1.2 Manufacturing Issues
The usual method of manufacture for a component like the friction plate hub with internal splines is by 'broaching'. This is a well-known method of machining using a specialist broaching machine which moves a stepped multiple tooth cutting tool in a linear motion relative to the part. The tool is passed repeatedly through the centre hole when more and more material is removed until the splines become sufficiently well defined. This process produces good surface finish and close tolerances but has the disadvantage that for each different spline pattern a different (and generally very expensive to manufacture) broach is required. This means that manufacture of individual items or small batches is prohibitively expensive.

4.1.3 The Sequence of Events in the System.
The standard part of the Clutch Ability Limited (CAL) system is an access based database system used to facilitate the day-to-day running of the company and contains the type of functions one would expect of this type of system – e.g. storage and searching of product, stock and customer details, business transactions and invoice creation and printing, stores and re-order management, etc. as well as the usual housekeeping backup and data security functions.

The additional 'customization' part of the system is designed to allow salespeople to input the few necessary parameters into a simple data entry screen. This then triggers a computer programme which modifies a standardised base CAD model of a friction plate hub with the appropriate dimensions of the required internal spline pattern. The model can then be viewed by the operator using a 3D browser. When the operator is satisfied that the model is correct, it can be emailed directly to the chosen local 'rapid manufacturing' company for manufacture. Once made, the hub is freighted back to CAL for attachment (riveting) to the friction plate. The entire assembly can then be delivered to the customer.

Figure 8 shows the sequence of events in the Clutch Ability Limited (CAL) system which is followed to create a customized friction plate hub unit in accordance with customer requirements.

Figure 8 – Using the customization function of the CAL system

4.1.4 Evaluation of the CAL system

Evaluation of a system is normally performed in two different ways. First is the process of *functional testing* where the system is tested against a formal test plan and the second part of system evaluation usually takes the form of *user testing*. The CAL system was subjected to both these testing regimes with many different sets of spline dimensions being input and the resulting CAD model being examined for 'correctness'. As a final test, a small sample of the resulting output CAD files were used to create a physical part. For reasons of cost and convenience the CAD models were processed using the facilities available at the School of Technology at *Leeds Metropolitan University*.

Figure 9 - Pre-processing of CAD model - calculating machining path

Figure 9(a) shows pre-processing of the model using *DeskProto V4.0* software prior to the model being CNC machined. Figure 9(b) the University's Roland CAMM-3 PNC-3100 machine in use and Figure 9(c) show the finished part (after being given a coat of bronze paint). In the case of a real manufacturing outlet, this would now be sent back to Clutch Ability Limited for final assembly onto the friction plate and subsequent dispatch to the customer.

4.1.5 Discussion

The 'customization' function of the system has some validation processes built into the programmes which modify the initial blank CAD model into the required CAD model for the specific customer requirements. However, the final inspection and validation of the CAD model created requires the eye of an experienced operator who would make the final decision on whether model is fit to be sent to manufacturing facility. This process is rather more difficult to test than the normal data handling functions of the simpler parts of the system. The only really effective testing process for the creation of effective parts by a particular rapid manufacturing technology is to use the system to design and then have fully manufactured a representative range of parts which are then inspected and measured and tested for fit on the relevant gearbox input shaft.

The viability of this scenario assumes the presence of *appropriate* rapid manufacturing machinery, therefore the types of manufacturing issues which might arise will be those which are inherent in conventional manufacturing processes (human error, poor materials, etc.) and the solutions will be the same. One particularly problematic area would be the accurate measurement of the dimensions of the splines – this would probably be best left to staff at the company, rather than allowing customers to provide their own!

The overall benefits of this approach to a small company would be to effectively increase the range of products that the company can offer without the attendant increases in manufacturing and stock holding costs normally associated with increase in product range and also without the need for specialist CAD skills amongst staff.

At the time of writing, (realistically speaking) none of the Rapid Prototyping / Rapid Manufacturing processes available have the capability to directly create a finished part with the necessary dimensional accuracy or physical properties (strength, etc.) without at least some post-manufacture 'attention'. However, the continuing development of the capabilities of the various technologies means that this will not always be the case.

4.2 Case Study Two – WYDIWYG.CO.UK

Case Study Two describes an implementation of a devolved manufacturing virtual organisation and is centred on web-based company WYDIWYG.co.uk (What You Design Is What You Get!).

The purpose of the wydiwyg.co.uk web site is to allow online customers to access a free simple downloadable CAD type design programme and to use this programme to create their own designs from scratch. Once customers have created their finished design, they decide if they wish to have the object made and if so pay (via credit/debit card) to have the object made at a location chosen from a list of *rapid manufacturing outlets* available on the site. Alternatively customers may choose a 'blank' model from a number available on the site and then modify this to their own requirements.

Using this web based system allows the customer to create completely original objects without having to buy any expensive third party CAD software package and importantly, to have that object directly manufactured and then be able to collect the finished object from close to where they live - not having to wait to have the object delivered. This aspect of wydiwyg.co.uk may be thought of as its *unique selling point* (USP) – i.e. the reason why customers would choose this method of getting their objects created over any other method.

This method of working may be regarded as a win-win scenario for all parties concerned:
- the *customer* gets the capability to design and create objects (in their own time and at their own pace) that they might find it difficult to have made by other methods,
- the *manufacturer* makes only to order, and then only when payment has been made (so no capital is tied up in stock and warehousing, etc.)
- *society* in general benefits by zero waste and little or no environmental concerns over transport and delivery.

4.2.2 Technical Issues

As outlined earlier, this case study is developed along the lines of a *virtual organisation*, so following this path, responsibility for any functions which can be performed (in an economically viable manner) by an appropriate third party organisation will be 'distributed' accordingly. Figure 10 shows the required 'components' needed for the wydiwyg web site.

Figure 10 - Components required for the wydiwyg.co.uk web site

Whilst the selection of an ISP host and the gaining of the appropriate domain name are relatively simple tasks, the method used for payment along with all the possible security problems is a critical choice. Since wydiwyg.co.uk is an unknown trust levels by the customers would understandable be low at the beginning of the service. In keeping with the principles of a virtual organisation, the payment system of the services of the third party *PayPal* online payment service organisation provides an ideal solution.

The revenue model for the wydiwyg web site is the so-called *'click-through'* model. The basic principle of this model is that revenue is generated indirectly from levying a

small charge on each transaction – rather like the charge for the use of directory inquiries – between the customer and the manufacturing outlet. Additional revenue can also be generated by advertising or 'sponsored links'.

4.2.3 The Sequence of Events in the wydiwyg.co.uk System.

The are essentially three parts to the wydiwyg.co.uk sequence (i) the initial logon to the home page and downloading of the mini-CAD programme, (ii) the use of the mini-CAD programme (offline) to design the customers desired object, and (iii) logging back onto wydiwyg.co.uk to upload the design file, choose a manufacturing 'outlet' in the customers locale, pay for the manufacture, and confirm. Once this third step has been taken, the uploaded CAD file is sent to the chosen outlet for rapid manufacture with a confirmation email being sent when the object is ready for collection.

Figure 11 – The wydiwyg.co.uk Process

Figure 11 shows the logic flow for the wydiwyg process, and Table 1 the steps through the wydiwyg 'system' screens.

Table 1 Stepping Through Wydiwyg.Co.Uk System Screens

4.2.4 Evaluation of the wydiwyg.co.uk system

The evaluation process for wydiwyg.co.uk system was the same split of functional and user testing used for case study one. Functional testing for the web components included web page type issues like the correct positioning and display of images, text, the correct functioning of hyperlinks, etc. and the download and upload mechanisms for associated files. The mini-CAD programme was tested for self-installation, CAD functions and creation of appropriate files. As a final test (as with case one) a small subset of CAD files were used to create physical objects using the same test facilities. Figure 12 shows a pair of moulds created using the wydiwyg.co.uk system.

Figure 12 – Pair of moulds created via wydiwyg.co.uk

4.2.5 Discussion

The rationale for the wydiwyg web site service was to demonstrate that such service could operate as a virtual organisation. There are of course, a number of missing parts to the jigsaw which would need to exist for the service to be implemented in the real world.

The wydiwyg web system developed for this project demonstrates that the first part of the process of *devolved manufacturing* could be made live without too many problems. The pages of the web site (whilst clearly in need of further development and enhancement) contain the minimum functionality to allow users to download a mini-CAD program from the site and then to use this to create CAD files of their own designs. Subsequent uploading of these files and online payment are already functions widely used by online services. The one necessary function for the completion of the wydiwyg concept which does not currently exist (in an appropriate form) is that of *rapid manufacturing*.

Improvements necessary to this area to make the wydiwyg type of service <u>commercially</u> viable include: (i) the development of current generation *rapid prototyping* machines into <u>real</u> manufacturing machines - by increasing the speed and range of materials available but also by enhancing the usability of the machines themselves to require less operator intervention and (ii) a substantial increase in the number and locations of companies using these technologies (to give the kind of national coverage needed).

Until these developments occur, the wydiwyg type of service will remain too limited an offering to attract sufficient customers to make it economically viable. This does not however detract from the value of the concept, but probably means that it should be considered more as an idea 'awaiting its time'.

5. Conclusions

Faced with the possibility of implementing some form of *devolved manufacturing* system, any individual or organisation must always ask the question "Under what circumstances does it make (commercial) sense to do this?" There must be sound economic reasons behind any decisions to start a new business or to move an existing business into a new area and there are many issues to be fully considered.

To fully consider implementing some form of devolved manufacturing many issues need to be considered and major questions answered including:

- how is the implementation to be financed?
- what kind of organisation is most appropriate?
- is the technology available (and sufficiently mature)?
- which strategy is best?
- what are the implications for the design process?
- what are the ethical and legal issues?

The correct strategy, organisation and modus operandi for a new devolved manufacturing implementation is must be determined by the point from which the business is starting. The manner in which a large multi-national organisation would choose to implement a DM approach will almost certainly be different from a brand-new start-up and the capital requirements and available resources will be reflected in this.

There are advantages and disadvantages to adopting a new technology and *adopters of technology* can generally be categorised as one of five types [Rogers, 1995]:
  (i)   *Innovators* – who are willing to take the high risks and high capital investment associated with bringing the idea in;
  (ii) *Early adopters* – who are generally industry leaders and changers of opinion and can serve as role models;
  (iii) *Early majority* – not leaders but move when they think the evidence looks like it may be overwhelming (and may be driven by financial imperatives);
  (iv) *Late majority* – who where and may still be sceptics, and
  (v)   *Laggards* – characterised by traditional ideas and wanting to stick to 'the devil you know'.

Some commentators on rapid prototyping technologies [Kaempher, 2005] [Oakham, 2005] suggest that the speedy pace of development in the past few years indicates that the *breakthrough point* is imminent - however if rapid 'manufacture' technology is to be truly devolved into the High Street, work on the level of automation of current generation rapid prototyping/manufacturing machines will be required to allow either unattended operation or operation by unskilled operator.

The two case studies of this project support the devolved manufacturing concept as 'realizable' – i.e. given the appropriate development in the rapid manufacturing technologies and careful selection of target market place it should be possible to create and implement some form of devolved manufacturing operation.

However, there are numerous strategic, legal and technical issues which must be resolved to ensure a successful outcome. Given the abundance of different possible starting points and subsequent directions for development, each venture will need to proceed on an individual basis to ensure the requisite expertise is found and appropriate questions answered

The high number of strategic, legal and technical issues to be resolved (as outlined in the previous chapter) and the relatively immature nature of current rapid prototyping or rapid manufacturing technologies suggests the difficulty of implementing a *successful* devolved manufacturing venture *at present* will be considerable.

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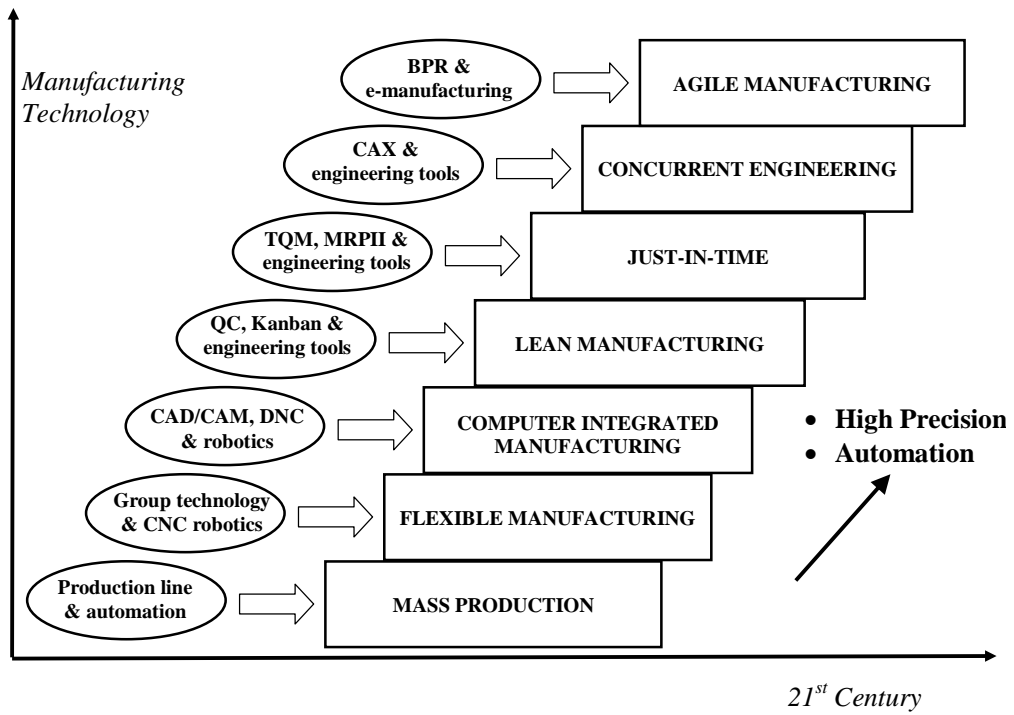
Figure 1 – Developments in Manufacturing
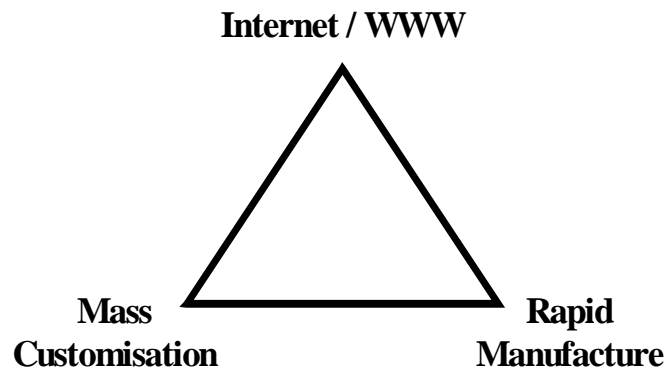
Figure 2 - Key areas for integration

Mini Plant
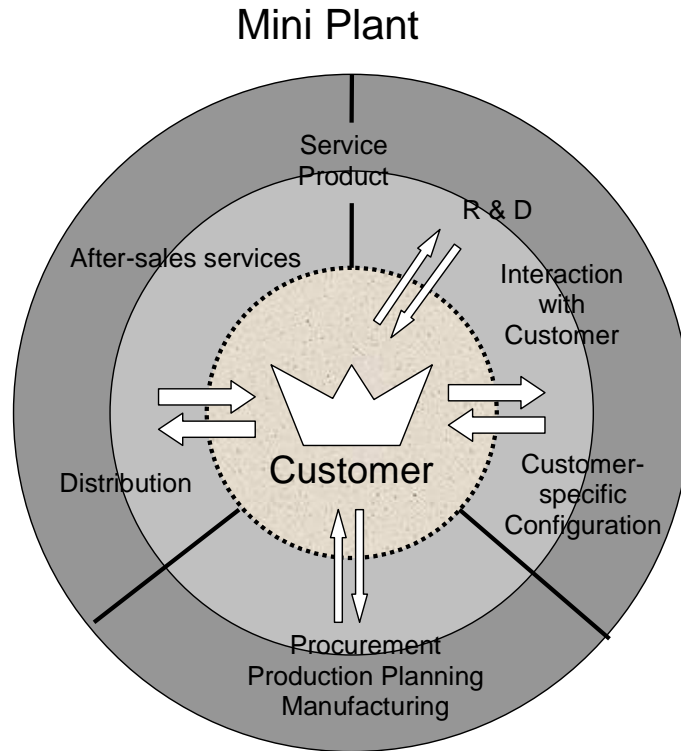
Figure 3 - Customer integration in the creation of product / service bundles
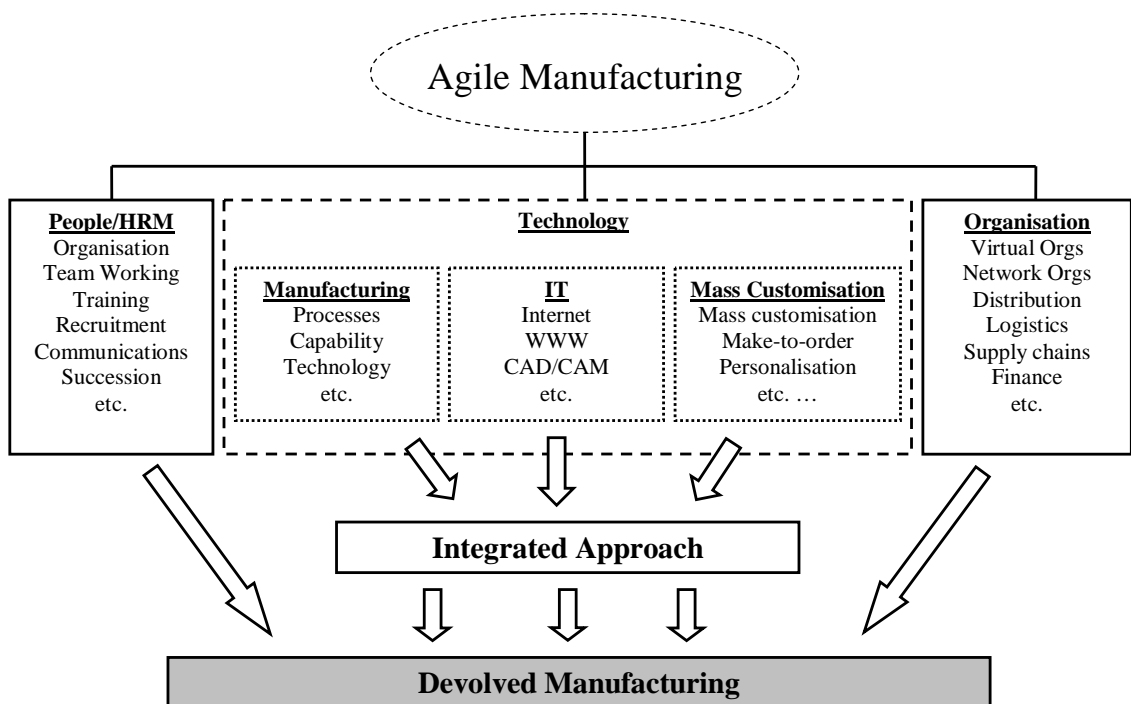
Figure 4 – Devolved Manufacturing in the Agile Manufacturing Spectrum
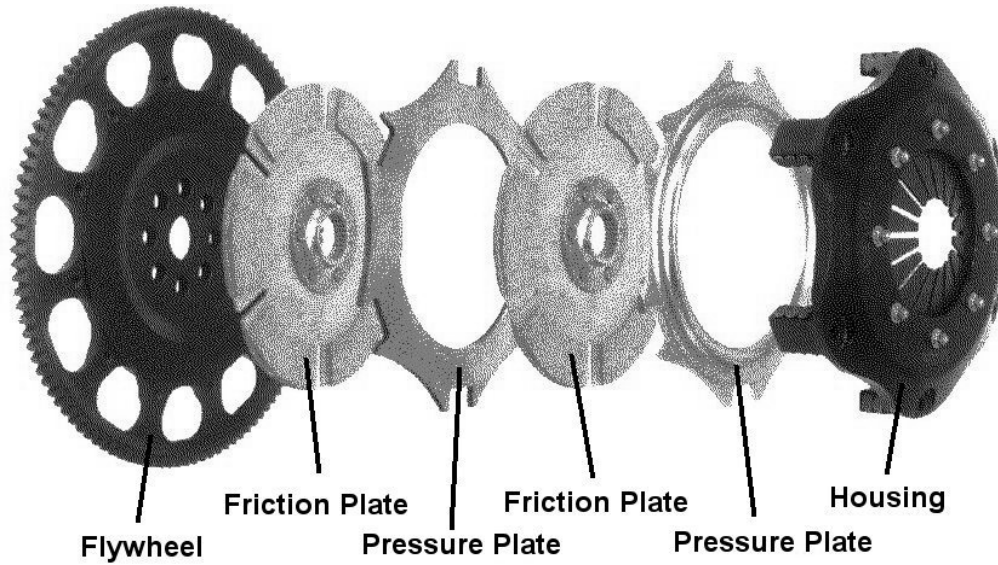
Figure 5 – Component Parts of a Typical Competition Clutch
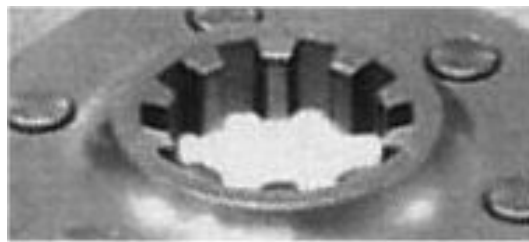
Figure 6 – Example Splines at Centre of Friction Plate Hub

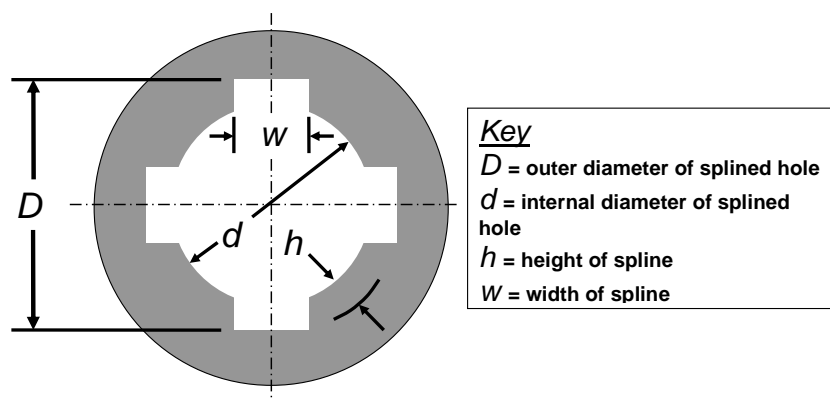Figure 7 - Key dimensions for friction plate hub (straight splined only shown)

Step One
Entry to the system is through the Main Menu.

Step Two
Customer part is searched for on the part database. If it exists ordinary sales proceeds, if not 'customized service' is offered/explained.

Manual process for receiving dimension details from customer

Step Three
Requisite dimensions requested and received either direct from customer or by staff measurement of gearbox input shaft.

Step Four
Dimensions are entered into the hub parameter input screen and validated. If OK, then 3D model is viewed

Step Five
3D CAD model of clutch hub is displayed for viewing and visual inspection (using browser).

Step Six
If model and dimensions are valid, then outlet (manufacturer) is selected and details and CAD model e-mailed out.
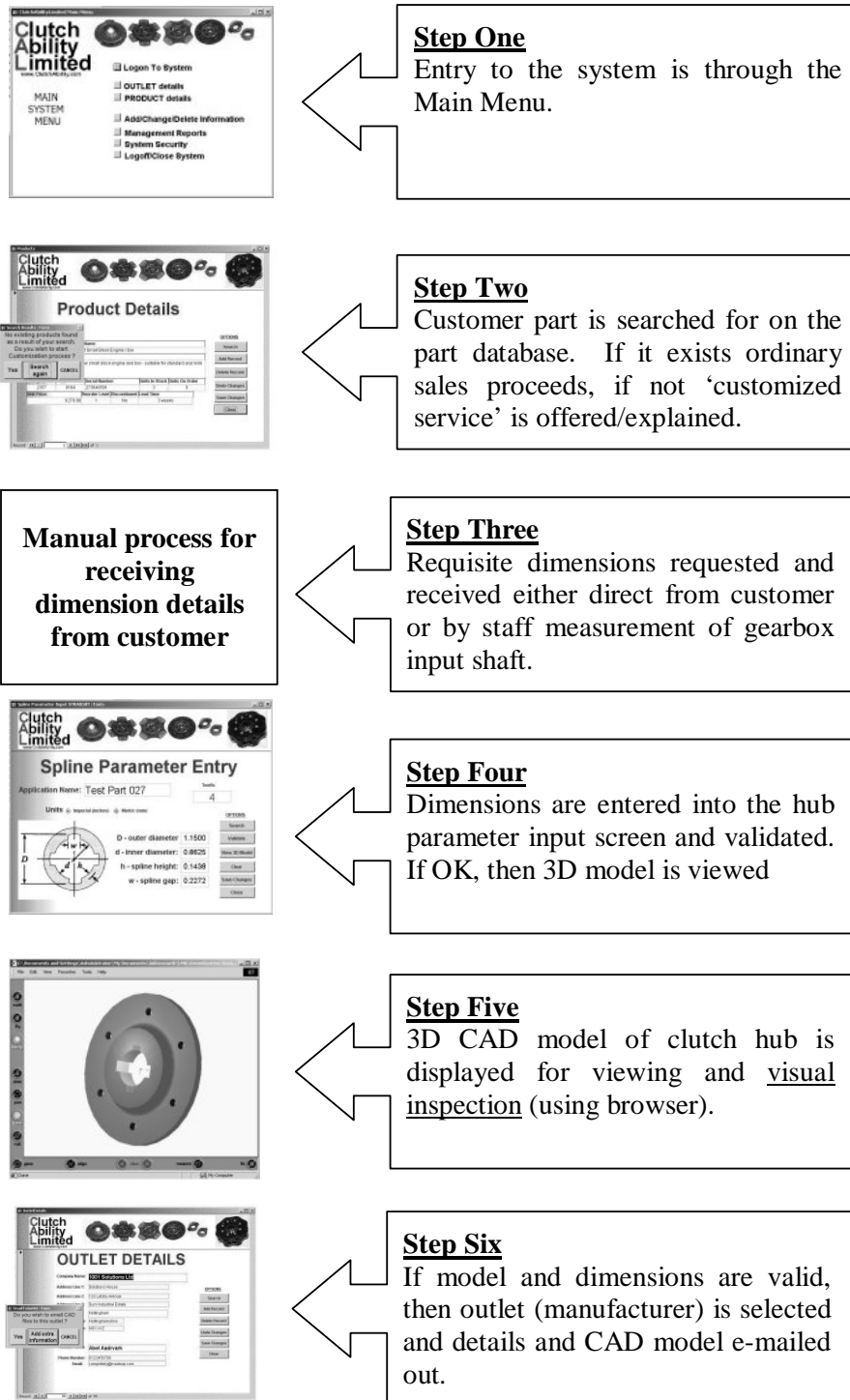
Figure 8 – Using the customization function of the CAL system
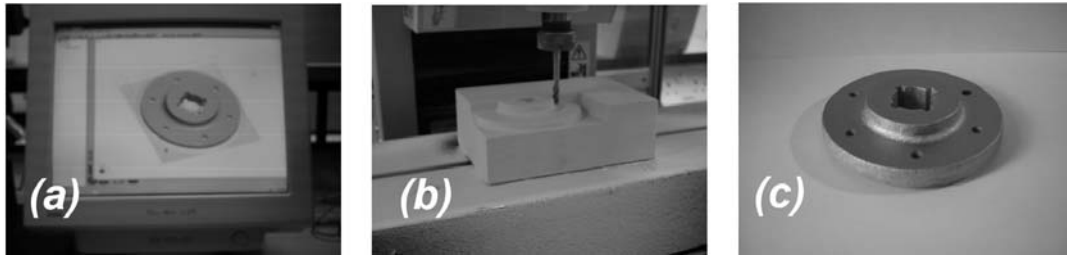
Figure 9 - Pre-processing of CAD model - calculating machining path
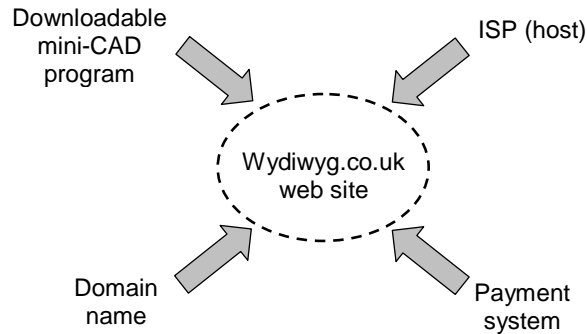
Figure 10 - Components required for the wydiwyg.co.uk web site

Figure 11 – The wydiwyg.co.uk Process
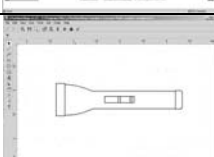
Figure 12 – Pair of moulds created via wydiwyg.co.uk

TABLES

	Step One **Entry to the web site is through the WYDIWYG.CO.UK home page which also has other links to various information pages like *About Us*, etc.**
	Step Two **New users are directed to information on the WYDIWYG concept and given option of downloading mini-CAD program. Existing users can log-in to system directly**
	Step Three **New users download the WYDIWYG mini-CAD design program. At this point they go *off-line* and begin to design.**
	Step Four **User designs their object using the mini-CAD program. In-built training scheme can be used by completely new users.**
	Step Five **Mini-CAD model of users design is displayed for viewing and inspection using 3D viewer facility.**
	Step Seven **Entry to the web site is through the WYDIWYG.CO.UK home page. Existing users can log-in directly using the 'sign-in' facility.**
	Step Eight **New users register themselves by entering their contact details. These details are then stored in the wydiwyg database and an email confirming registration sent.**
	Step Nine **The user then finds an appropriate outlet – either by searching the clickable map or closest to postcode dialog box.**
	Step Ten **Next the user uploads their CAD model and the order is constructed. Payment is requested (via Pay Pal services).**
	Step Eleven **The user confirms the order details and on clicking 'OK' the data and CAD model is sent to the chosen outlet which emails to confirm.**

	Final Step
	The user is given an acknowledgement of the order with a unique identifier number and asked to print for future reference

Table 1- Stepping Through Wydiwyg.Co.Uk System Screens

WORD COUNT = 5,975