INCLUDING DESIGN IN E-MANUFACTURING

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ABSTRACT

This paper reviews major issues in the implementation of e-manufacturing, particularly the design aspects. It will examine recent progress, drawing out particular issues that are being addressed. Use will be made of the work by the author and colleagues to devise rule-based design and Internet-based control of machines to illustrate how these developments affect the integrated e-manufacturing environment. A dynamic Simulink™ model of the way e-manufacture is affected by overall design delays is used to evaluate general solutions for partial and complete e-based companies. These models show how changing to improved designs reduces WIP.

Keywords: E-Manufacture, Vendor Managed Inventory, Lean Manufacturing, Simulink™, Input-Output Models, Design

1. INTRODUCTION

What is meant by e-manufacture? Although many definitions are available the one that seems best is from Unifi Technology Group Research [21]:
"A responsive manufacturing model that optimizes the use of production assets based on information exchange from shop floor operations, across the enterprise and extended supply chain."

There are three corollaries from this definition; firstly that it is primarily about information, secondly it is about a systems wide approach, while the final important point is that products are built to order not for stock.

The availability of near instant recall of plant and system-wide data is not itself a panacea.

Effective use has to be made of this data. The one thing is certain in a digital age is that data is abundant, so much so that we can drown in it. We can then assert that an important trend should be to develop a degree of intelligence in the software to provide assistance to the plant supervisors.

We must never forget that the purpose of ALL e-business is to satisfy the customer whilst making a reasonable profit!

The current theme of business is 'mass customization'. Joseph Pine II [12] in his book talks about "*mass production of individually customized goods and services.*" This is the biggest challenge that has faced manufacturers since the beginning of the industrial revolution. We have of course moved a long way towards this goal without the Internet.

Why then do we need to change our current practice? The answer is the speed at which modern customers expect to be provided with goods and services; since their loyalty is fickle they change their supplier without hesitation. One of the prime features of e-shock [3] is that the important clients who use Internet ordering at present are amongst the most articulate customers and will be the first to complain about faulty service. As we move over to e-manufacture even businesses that have traditionally used our companies will be more likely to change their sources of goods. How then can we make a virtue of this trend? Pine [12] loc. cit. talks about flexible specialisation for which four ingredients are required:

- Flexibility plus specialisation
- Permanent innovation
- Skilled workers
- Community structure

Sharma and Moody [15] argue that for successful e-business the organisation must be lean. We would argue that it should also be agile.

The work that is described later will emphasise the coupling effects of the first and second ingredients, which are primarily about total process efficiency.

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1.1 Who are the Customers?

Although most of the customers are the same individuals and companies at present, they will behave in new ways as new possibilities open up to them. It will be possible for them to intervene in the supply chain to insist on them getting what they want in a way more satisfactory to them.

- ***Business to business*** (B2B), other Product Creation Companies (PCCs). They understand system processes and delays.
- ***Business to customer*** (B2C) as with Amazon, often former retail companies such as supermarkets. Characterized by rapid supply problems.

Wright [22] expounds the system characteristics of internet-based manufacturing as:

- Lower labour
- Flexibility
- Quality
- Reduced WIP
- Reduced lead times
- Collaborative design, etc.

Many of these have been under development for many years and we have barely made progress in some. For example, rapid response to new design requirements as we shall see is essential and requires some measure of concurrent design. For mechatronic systems it is mandatory.

1.2 What Do Customers Want?

Ayres and Miller [1] state that they want delivery, quality and variety, Wright [22] goes on to jibe that they want pizza, eyeglasses and their vacation photographs in 1 hour or less or their money back! This may be too cynical, but the potential for demand should not be underestimated in an electronic environment as the Dot.com pioneers did. Even Amazon was overwhelmed initially by the demand they generated and have only recently reached a reasonable financial position.

We need to define very closely what is required to achieve a satisfactory overall system for e-supply. For each product [22] we can ask:

- Who is the customer?
- What is the cost to make the product?
- What quality is required?
- What delivery time is acceptable?
- How fast to deliver the next product line to ensure flexibility?
- What management strategy to ensure long term growth?

It is necessary to consider how trade-offs between cost, quality and delivery may be achieved. Some products will of necessity be only delivered in small batches but the type of products and their capabilities will vary as technology improves.

The scale of the design/production time problem is outlined in Table 1. Here Ulrich and Eppinger [21] contrast the scale of the problems in different product sectors.

Although most of the products illustrated in the above table were built to stock, aircraft were never built in this way and were always built to order due to the complexity and expense of the product.

Table 1: Product development times for common products

	Stanley Tools Jobmaster Screwdriver	Rollerblade in line Skates	Hewlett Packard DeskJet 500 Printer	Chrysler Concorde Automobile	Boeing 777 Aeroplane
Annual Production Volume	100,000 units/yr	100,000 units/yr	1.5 million units/yr	250,000 units/yr	50 units/yr
Sales Lifetime	40 yrs	3 yrs	3 yrs	6 yrs	30 yrs
Sales Price	$3	$200	$365	$19,000	$130 M
Number of Unique Parts	3	35	200	10,000	130,000
Development Time	1 yr	2 yrs	1.5 yrs	3.5 yrs	4.5 yrs
Internal Development Team	3	5	100	850	6,800
External Development Team	3	10	100	1,400	10,000
Development Cost	$150,000	$750,000	$50 M	$1 B	$3 B
Ratio of Development Cost to Sales Cost	50,000	3,750	136,985	52,632	23
Ratio of Price to Design Person-years	1	20	2.4	6.4	4,248
Production Investment	$150,000	$1 M	$25 M	$600 M	$3 B

From Table 1 it is clear that the price/person year for the screwdriver is far too low and could be improved by e-manufacture. It also shows why it is a good idea to make aircraft. It is quite clear that for these development times it will not be possible to design a product directly in response to e-mail or web access. It may however be possible to modify the design to fit some or all of the customers needs from a basic modular design.

This is where the e-manufacturing successes will come from for this type of product. As the costs of production come down due to lean production and new manufacturing technology the costs of inventory relative to the other costs are a higher proportion. The effects of maintenance scheduling will again represent a higher proportion than hitherto.

A view of the direction that e-manufacturing systems may take is that offered by the UK electricity supply industry. In this system we have a nation-wide control system that directs power to the grid, this company is now private. Each day individual power plants bid to supply electricity and negotiate the price for each kWh. The local plant manager is responsible for this and maintaining a strict maintenance schedule. Staff involved at each plant is minimal for gas fired plants, maybe only half a dozen!

We can propose a similar system for e-manufacturing enterprises. The Product Creation Company (PCC) would contract out all or most of the design, production and logistics to other smaller specialist enterprises. The design could be contracted to design bureaux, including specialist computer companies for CAE, and production design to similar specialist companies.

Local specialist shops, for say, CNC work or plastic mouldings, could bid for production. These companies would be small, owned by local entrepreneurs and could be changed on a day-to-day basis to allow for either planned maintenance or the fact that customers were nearer to another source company. Logistics could also operate on this basis. The PCC product system director operates the entire programme via intelligent web links controlling even down to individual machines. In practice, many of these systems are operated today, but not in concurrent form nor as co-operatively as is needed. This can be facilitated by software but the will to operate in this way has to be derived from a need to survive in the new rapid environment.

2. REVIEW OF E-MANUFACTURING PROGRESS

Much of the hype and actuality of e-manufacturing has been driven by software vendors who see vast amounts of money to be made from the implementation of e-systems of all types. However much of the research to find what is practicable and what can be of value has been taking place over many years. There are three review papers that describe the current state of the art very well. A review of agile manufacturing systems was undertaken by Sanchez and Nagi [14], for one-of-a-kind product development over the Internet by Xie, Tu, Fung and Zhous [23] and an evaluation of virtual production by Qui, Wysk and Xu [13].

It should be clear to all in Europe and the USA that we need to be very active in this area if we are not to be squeezed out completely!

What are the prime conclusions from these reviews? In 2001 Sanchez and Nagi [14] complained that few solutions to enable agile production were described in the literature. Most papers were about information systems, this is the area that IT companies know best and it is not surprising that these are the first products to be proposed. Xie et al [23]. in 2003 found a much improved picture but a completely chaotic world view with many competing ideas and no fully proven solutions. There are however particular approaches given in their paper which rank as important steps in the following areas:

- *WWW based applications* - Ho et al. [9] proposed a multimedia communication framework for selecting partners in global manufacturing using as a basis CIM-OSA (open architecture for CIM).
- *Overall system process control* - there are two basic approaches that have been and are being pursued to devise distributed scheduling planning and control. One uses agents Tharmarajah and Wells [19], Gyires and Muthuswamy [7] and the other approach uses an information management system. While Singh [16] has developed a CORBA based architecture system for enabling any mechatronic machine to be operated remotely in real time.
- *Design links with manufacturing* - DFM is now accepted as a desirable goal and many workers have reported progress in an improved data model based on the STEP (Standard for Exchange of Product Model data) [11][6].
- *Modular design* - here the approach of Marshall and Leaney [10] offers a systematic way to achieve a solution but not necessarily a complete solution to the customer's requirements.
- *Design collaboration* - this work started many years ago with Sriram et al. [17] being one of the first, Hartley [8] reported considerable time reduction in development time at DEC and Xerox for example.
- *Scheduling and production management* - Yang and Pei [24] illustrated how a CAD system could be used with MRP using a STEP protocol reducing material usage.
- *Cost control* - one of the most important problems is that of costing software not being integrated with design functions. The latest techniques for doing this using Neural Networks, Bode [2] and activity based costing, Tamas et al.

[18] have given promising results but are still limited in options, for example not allowing the automatic generation of alternatives.

The conclusions that can be reached by examining this now quite substantial literature base is that a lot of basic research has been done with much still to do before we have a workable integrated environment for designers and manufacturing engineers to work via the web. The real crux of all the areas surveyed is the lack of methods to help decide the critical choices. Should we leave it to the engineers and designers? Will they make substantial errors if they are pushed to make decisions in a short time-scale or will they opt for ‘safe’ designs that will not push the boundaries or yield large enough profits to justify the expenses incurred in e-manufacture?

The other major worry is that of project management. Although we have tools for helping and serious training for project managers, failures are large and often, particularly in IT [25].

3. THE EFFECT OF DESIGN ON THE MANUFACTURING PROCESS

From Table 1 the development time for fairly common objects is seen to be very long compared to the likely time-scale that customers would want. The real problem is how to reduce it.

We have seen above that concurrent system design in Mechatronics is one approach. Certainly since the introduction of CAD/CAE/DFM the design time has been significantly reduced. There is still the problem of testing and development, which can be protracted. This is proportional to the complexity of the design and the number of parts required.

The overall approach to design illustrates the fact that feedback and an iterative approach are necessary for successful design. Once the design is completed however, the effect is a time delay before manufacturing is commenced, even in an e-manufacturing environment.

Design by experts has been found to have a number of characteristics that can be reinforced by co-operative teams [5]. One particular aspect of importance in the e-manufacturing debate is the systems approach taken by experts compared to novice designers. As in the case of software production the experts are much faster than their weaker colleagues when producing concepts. This should lead to a number of techniques for software aids producing an expert system to prompt designers.

The design process is heavily dependent on the interaction with outside agencies. These cannot be modelled properly with the model shown here in Figure 2, but could be evaluated with a Vensim System Dynamics model if we could measure a number of interactions with suppliers, a very non-linear system would result and probably would not be capable of generalisation.

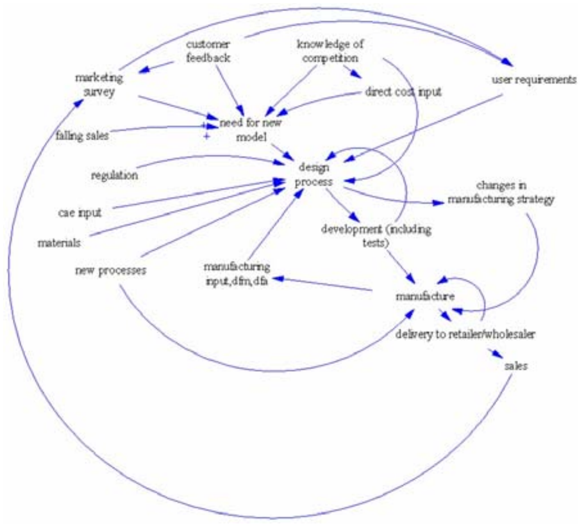

Figure 1: Qualitative design model

Figure 1 shows the qualitative version of such a model. The addition of these interactions makes the model highly non-linear. This is not covered in the following input-output model.

The model used here is based on that derived by Disney and Towill for a Vendor Managed Inventory system [4]. Their model, VMI-APIOBPCS Vendor Managed Inventory, Automatic Pipeline Inventory and Order Based Production Control System is shown in figure 4 as a sub-model for our purposes with the virtual order prediction term predicted by the agent.

The current inventory, AINV, and the WIP are controlled by proportional ordering terms to keep the inventory and WIP to a minimum. The demand smoothing as used by Disney is an exponential term.

This delay is modelled with an exponential term; since this is often how designs get closer to finishing, but is never quite finished. The marketing/tooling delay is a fixed quantity dictated by cost.

This is shown as a separate production line since it was involving different facilities, leaving the original machine available for other secret jobs.

The objective here is to introduce design delays into the vendor managed system. This work is based on a Teaching Company programme that we undertook with a medical instrument company in London. We introduced a concurrent engineering design system. Products were made to order with little stock, but all the existing products were old designs. The company embarked on an ambitious programme of new designs. Design times were reduced dramatically. However the sales of the old products were reducing slowly and the forecast was that sales would fall to zero before the new production could be produced, this was not what transpired. The model reflects as accurately as possible the decision and timing of the situation.

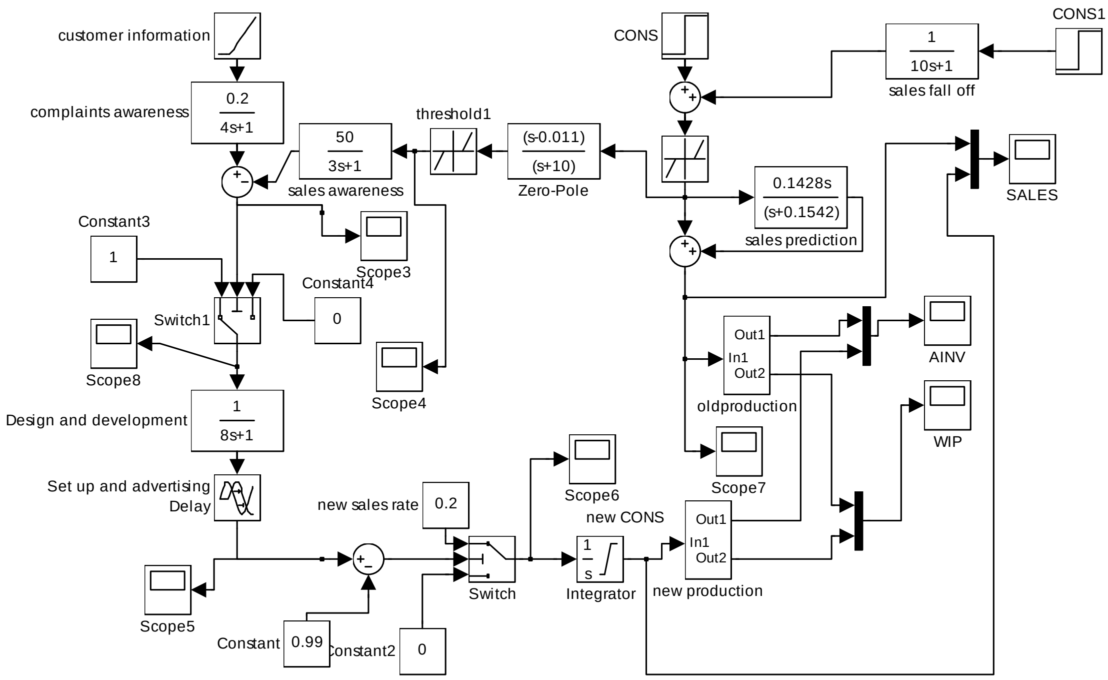

Figure 2: Schematic Simulink™ diagram of design modified VMI model

The product chosen for the model here was a cauterising tool, which was almost wholly machined from plastic. The new design was moulded and much more ergonomic. It could easily be produced in several sizes. The old design took four weeks to make, whereas the new design could be made at the rate of two per week.

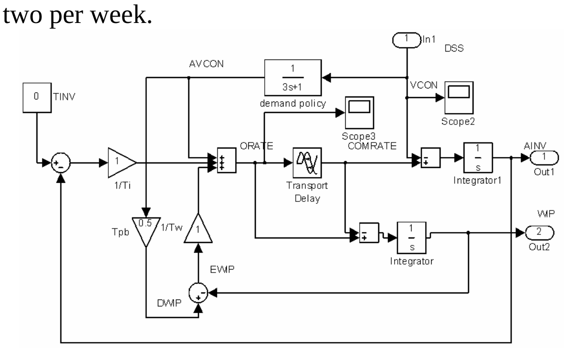

Figure 3: The Simulink™ model

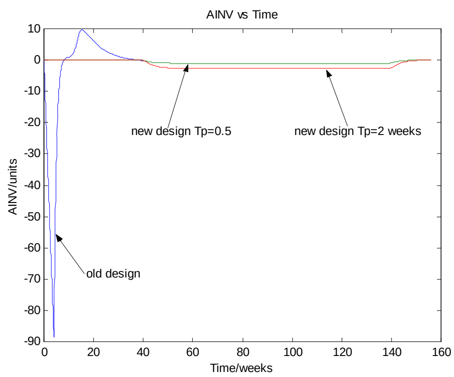

Figure 4: Inventory for different design and production times

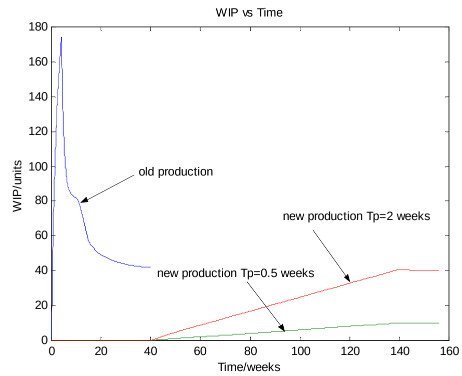

Figure 5: WIP for different production times

The new design produced orders at an increasing rate. These did not start until after the design and development had been completed after nearly three months. The sales of the old product did not fall to zero but levelled off. Figure 4 shows the effect of the new design on the real inventory and Figure 5 shows the WIP reduction using the new design with even better results after the production time was.

The overall model of the Design Modified Vendor Managed Inventory system yielded some interesting results. The first is that the effect of production time is made very clear comparing the two processes in Figure 4 & 5. The reduced production time lowers both inventory deficit and WIP. The time delay due to the design + marketing/set up time is critical here it was only just sufficient to prevent bankruptcy.

The real problem was not in the design, although this item was the first re-engineered by the CE team, but in the attention given to the customers' comments and the recognition that the loss of sales was due to the product itself.

5. CONCLUSION

- Complete electronic integration of the order to manufacturing in e-manufacturing has not yet been achieved.
- The main areas of deficiency are not in data management but in aids to decision making.
- In the Design Managed Vendor Managed Inventory System modelled here the crucial delays in recognising that there were problems with the design and that this was causing loss of sales was a critical factor.
- Reducing production time with new processes and designs was clearly seen to be reducing WIP and inventory.
- Overall reducing design time and design problem recognition was very important.
- Producing software to help with these two areas would be very beneficial.

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