AGILE MANUFACTURING PROCESSES

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Abstract

Agility is the next buzz-word for the aerospace industry. Agility literally means: Quick in movement; nimble. If we expand on this meaning further then it may look something like; speed of reaction, responsive to change, rapid processing.

Agility goes much further than the realms of manufacturing and extends through the product development processes and into the entire organisation and affects the role of the customer.

The key corner stone of agility is to completely and explicitly understand the customer requirement. The challenge then lies in translating these requirements into customer value, quicker and cheaper then anyone else.

The manufacturing agility is a key enabler, but willl be constrained by the agility of the whole enterprise.

This paper explores these ideas and draws upon the recent experienced gained during the launch of the Series Production activities in Eurofighter Typhoon, within BAE Systems.

1 General Introduction

This paper is going to explore the steps that are required for a manufacturing process to become agile. To build on these steps then we are going to take the concepts beyond the boundaries of the manufacturing process and look at the inputs to the manufacturing process and then into the organisation as a whole.

Particular emphasis is going to be directed at the product development processes that supply the manufacturing operations, with the key focus being on the need for customer focus.

This will be concluded with the challenges that the aerospace industry will face if it is to take the ideas of agility onwards. With an ever more expectant customer their demands are going to become increasingly difficult to fulfil. This demand will only be satisfied if agility is embraced by the whole organisation.

2 Agility?

2.1 Why do we need it

The word agility is one that is rapidly entering the realms of industry as the next ‘buzzword‘, but what does it mean. The dictionary definition: Quick in movement; nimble. If we expand on this meaning further then it may look something like:

- Speed of reaction
- Responsive to change
- Rapid processing

In essence the whole reason for this desire of agility is to supply exactly what the customer wants, when they want it and at the right cost (see fig.1). This could be verging on a market desire for custom-made products. This expectation is also getting harder to achieve as the customer is becoming more used to having greater choice with a rapid turnaround. Take for example being able to get to your cash in seconds, buy food of your choice in under a minute.

This is coupled with an ever-increasing rate of change in technology, which can only be truly harnessed if you get the idea to the market place as quickly as possible.

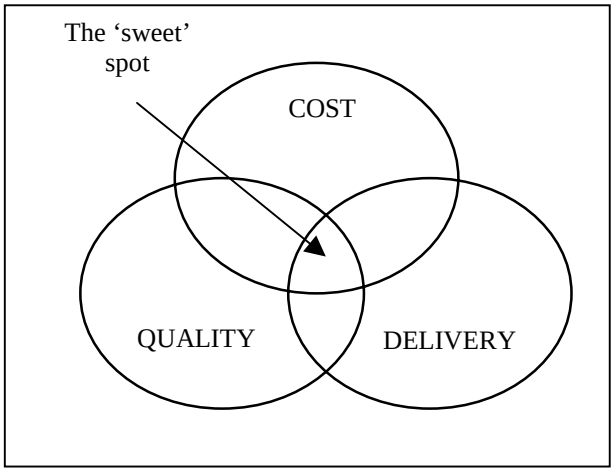

Fig 1, The customer sweet spot

If we don't become more agile then the opportunities that exist can never be fully envisaged. The customer will look elsewhere for their desires to be met in a market where the choice of products is large in comparison to the sales opportunities.

Agility should be the company and product strategy that satisfies customer requirements, improves the profitability and share-holder return since these are the reason for the businesses existence. If we don't take this strategy on board then it can only be a matter of time before the competition embraces it and leaves us behind.

2.2 Agile Manufacturing

Manufacturing has gone through a transition over the past century from mass production of Henry Ford to Lean, based around the Toyota Production System. In between these two poles have been numerous ideas such as cellular manufacturing and continuous improvement. The basic elements of each of these have been to improve the responsiveness and effectiveness of the operation with the ultimate goals being to reduce lead times and inventory levels while improving the quality.

To enable the manufacturing process to be agile then you really want it to become lean. The lean philosophy will provide the customer focus and short processing lead-times with rapid changeovers that are required to become agile. The following steps are a good place to start this journey.

- Understand exactly what the customer wants. What do they value?
- Align the production so that it is customer focussed. Arrange the production process by value stream
- Make the product move through the process as rapidly as possible by removing all blockages. For example, reduce set-up times on machines so that change over can be done in minutes as opposed to hours.
- Reduce the batch sizes down to a minimum (aim for ONE!), by doing this you will not have mountains of inventory clogging up the flow of a customer responsive order.
- Continuously remove anything that isn't needed from the value stream – Waste.

These steps will make you more agile and have been well documented over the past decade and some further sources of information can been found in the references section. Many factories have even started to do many of these things even if they didn't know that it would make them more 'agile'.

At BAE Systems we have taken some large steps towards becoming an agile manufacturer, particularly within the Eurofighter project.

The entire architecture for the assembly of major units has been designed around agility. The organisation has been arranged into IPT's (Integrated Product Teams) which gives the manufacturing a product focus (ref. section 3.3). This has been coupled with a system that exploits some of the latest digital technologies in product assembly that allow for changes to feed into production rapidly but also permit for improved process control (see fig.2)

To enable the benefits of virtual agilty to be fully realised then the physical infrastructure has been designed to enhance the overall agility. This has involved a flexible flooring for the assembly area that has had dramatic effects on the way we do some things. For example, all

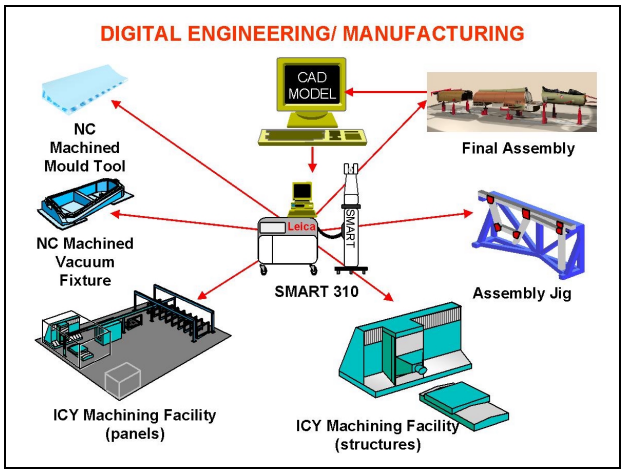

Fig.2 Agility in the manufacturing systems

of the tooling has been made to place anywhere on the flooring but this has meant that the tooling has had to be extremely rigid. The advantage of this is that we can reconfigure the layout of the entire flow-line in a couple of days rather than weeks or even months (see fig. 3).

This flexibility will allow for changes in the customer demand to be made in a very short time-span but with the minimum disruption.

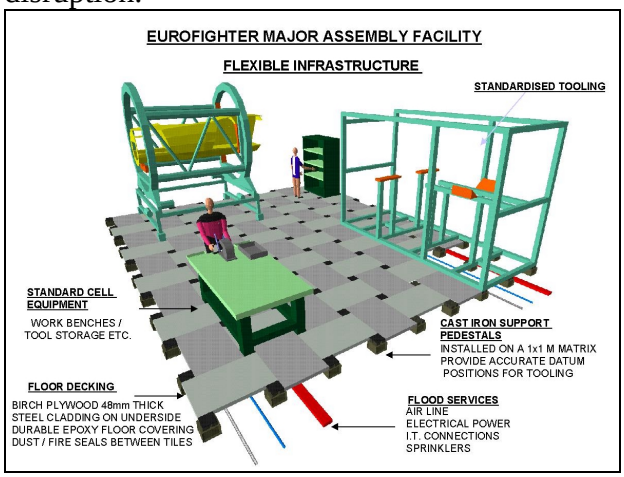

Fig.3 The flexible infrastructure

Despite our best attempts, the factory will become strangled if it doesn't get the supporting inputs it needs. Any attempt to become agile would be futile if the entire organisation doesn't have the same strategy. Any manufacturing process will only be as agile as the inputs that it receives.

3 The Agile Enterprise

3.1 The 'Time-line'

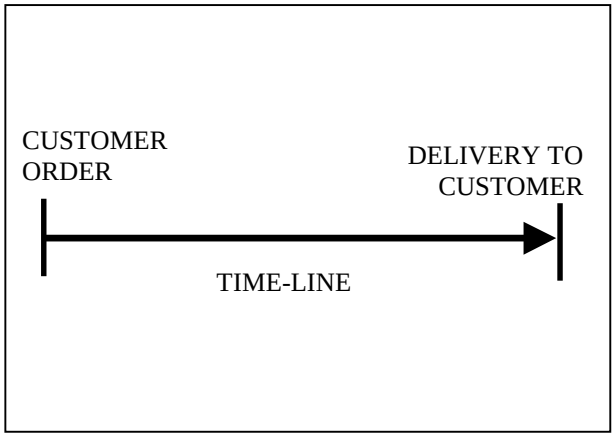

Fig.4 The Time-Line

As discussed in the previous section, the manufacturing element of the business will only be as agile as the support that it receives. The business has to look at the entire operation, the placement of customer order through to the hands of the customer. The time it takes to deliver the order to the customer is known as the 'time-line' (see fig. 4).

This diagram is very simple in format but powerful in concept. Everything that you do in the organisation to bring the product to the customer is part of this time line. This time will be made up of things that add value for the customer and things that do not. Anything that doesn't add value is waste (1).

$$\textit{Time-line} = \textit{value adding activity} + \textit{waste} \quad (1)$$

The first part of becoming agile is to take as much waste out of the time line as possible. But this can only happen once you have a clear and explicit definition of customer value. To get this definition then every part of the organisation needs a clear customer focus.

Despite the recognition that the entire organisation needs to become agile then there appears to be a continued quest to make manufacturing, assembly and other key recurring process elements; slicker, leaner and faster, focussing yet more effort and resource for ever diminishing returns. Whilst by comparison, the same focus has perhaps not

been given to the non-recurring engineering activities. The focus has been placed on the technology and hardware rather than the actual processes and organisation through which the engineering activities work.

3.2 Customer Focus

A clear customer focus is a key element to creating agility in the business. All of the operations within the business require a clear definition of what the customer values. This goes further than simply looking at the end customer, but treating the next station as customer, The person who you deliver your product or service to.

This is made more difficult to achieve within the aerospace market since the customer does not always know what they want or what they can have, and for this reason then even more emphasis has to be applied. The relationship with the customer has to be become a partnership with a high degree of trust in each other being the critical feature. Within BAE Systems the promotion of the company's' 5 values supports this need for a deep understanding of the customer, in particular the 'customer' and 'partnering' values. The BAE Systems 5 Values:

- **Customers** - *our top priority.*
  We will delight all our customers, both internal and external, by understanding and exceeding their expectations

- **People** - *our greatest strength.*
  All our people will be encouraged to realise their full potential as valued members of the team

- **Performance** - *our key to winning.*
  We will set targets to be the best, continually challenging and improving the way we do things, both as individuals and as members of our teams.

- **Partnering** - *our future.*
  We will strive to be the partner of choice, respected by everyone for our co-operation and openness.

- **Innovation and Technology** - *our competitive edge.*
  We will encourage a hunger for new ideas, new technologies and new ways of working, to secure sustained competitive advantage for our company

The phrases ' exceeding their expectations' and 'delight our customers' emphasise the need for a real customer focus. This can only be achieved with 'co-operation' and 'openness', which will follow on to a massive involvement of the customer in the development of the product. There is a warning that has to be heeded here in managing the customers' expectations. Through their involvement they will gain a greater understanding of what current technology can produce in the form of performance. If they do not understand these limitations then their expectations could be artificially inflated to an extent that would be impossible to achieve.

Once you have this vision of what the customer requires, the real challenge comes when you have to communicate this desire to the whole organisation. The communication can only take place by developing the mechanics of the process that captures, with absolute clarity, the tangible requirements driven out at the customer interface. Then decompose these into explicit key product objectives.

The customer focus cannot be underestimated, as this will focus the technical perfection that may otherwise be sought. Take for example, the Lightning. Due to technical brilliance it was one of the fastest production aircraft available in its time, but because of this excellence then some other key factors were not given the same attention. The aircraft was expensive and difficult to maintain and this was one feature that the customer found disappointing.

3.3 Company and product strategy

When you look at the need for customer focus then it quickly becomes apparent that agility cannot be something that is done in isolation within manufacturing. It has to be done

throughout the organisation, from concept through to delivery into the hands of the customer.

This would include every element of the time-line. The true benefits of agility can only be fulfilled when the whole product stream is aiming for the same goal of agility. If this goal is then looked at as a company wide strategy, then the company can only be as agile as the weakest link or the least agile element of the time-line.

Historically, the time line would have been arranged in a series of functional departments; i.e. design, stress, tooling, production engineering, etc. This has caused a culture of 'over the wall' attitudes and massive defences of these functions. This defence has led to protection of information that has not allowed appropriately informed decisions regarding the product to be made. As in the example of the Lightning.

For example, if the manufacturing capability is fully agile and can make a whole range of products in a very short lead-time, and the engineering definition takes years to materialise for any customer change. Then the agility will be rendered useless. However, if the product has been designed with interchangeability and modularity in mind, then any customer requests should be very simple to embody and make in market leading time. But again, this will only happen if the process they are passing through is configured for agility.

The modular strategy will only be effective if the definition of customer value has been explicitly understood at the start of the requirement definition, and the foresight of customer desires have been designed into the modularity. For example, a generic platform for radar to plug-in and play taken from an ever developing range of radar.

To aid with this customer focus BAE Systems has taken a number of large steps that have given the company a much greater customer focus. Project Axis was implemented with the aim of assigning the right number of skills to a particular project. This reduced the conflict for resource that occurred in a functional organisation and allowed people to focus in on one product (see fig.5).

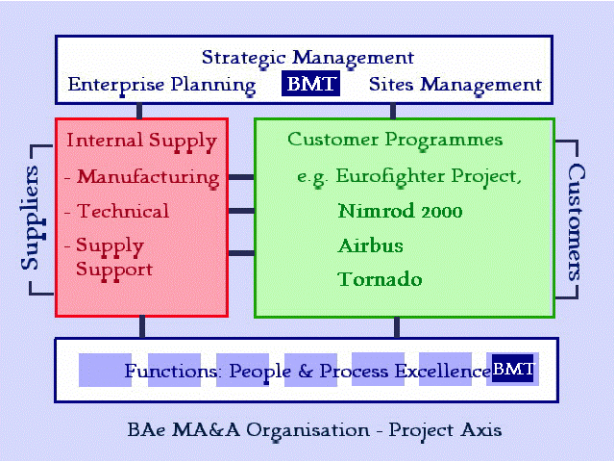

Fig.5 Project axis

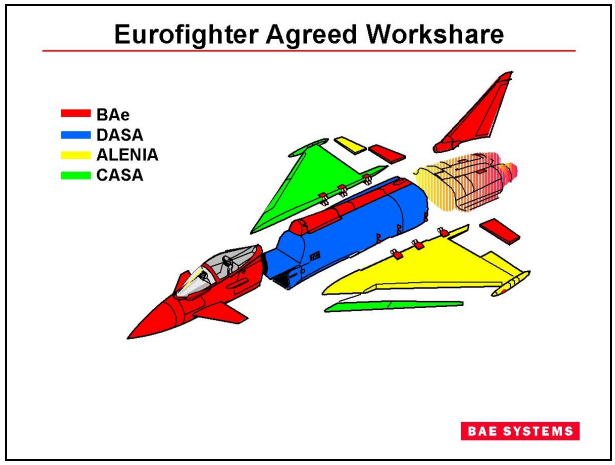

Fig.6 Eurofighter work-share breakdown

The other major step has been to organise the projects into IPT's. This takes the form a multi-disciplined team, responsible for the total product life cycle, with a single point of leadership and a single product/ customer focus. This has had the effect of focusing the functions on the customer, but also has breaken down many of the inter-function barriers.

Within the Eurofighter project, IPT's have been established focussing on the key areas of the aircraft that we build (Front fuselage, center fuselage, rear fuselage), figure 6 shows the parts of the aircraft of BAE Systems interest.

4 Agility in product development

4.1 The difference between recurring and non-recurring activities

The terms recurring and non-recurring explain the types of environment that we are looking at. The manufacturing environment has a lot of physical recurring activity, where as the product development world tends to only perform an activity once, thus the term non-recurring.

Historically, these two parts of the same value stream have been regarded as entirely separate entities, or functions. This has led to each having their very own cultures and measures of success. They both have good and bad points, but they also have had a skewed and somewhat self-centered perception of success, without really focussing on customer value. Also, due to their different strategies, then agility has never been allowed to prosper. They are both part of the same value stream so should have the same goals, strategies and share success as a whole rather than functionally. Unfortunately, this has rarely happened.

Similarly, the behaviours also show some massive differences. Evidence of this is apparent if you analyse the outputs of each environment. The schedule adherence for completed orders varies dramatically, fig. 7 shows a picture of this variation.

The output of a manufacturing environment tends to follow the pattern of a normal distribution. There is an equal amount of product completed before the required due date as well as after. Also, the average finish time equals the required due date. This does not mean that all orders are on time but there is a balance centered on the due date.

Comparing this to the non-recurring information output, there is a marked difference. There is very little design that exits the process before the due date. You will find that a large amount exit exactly on time, but the

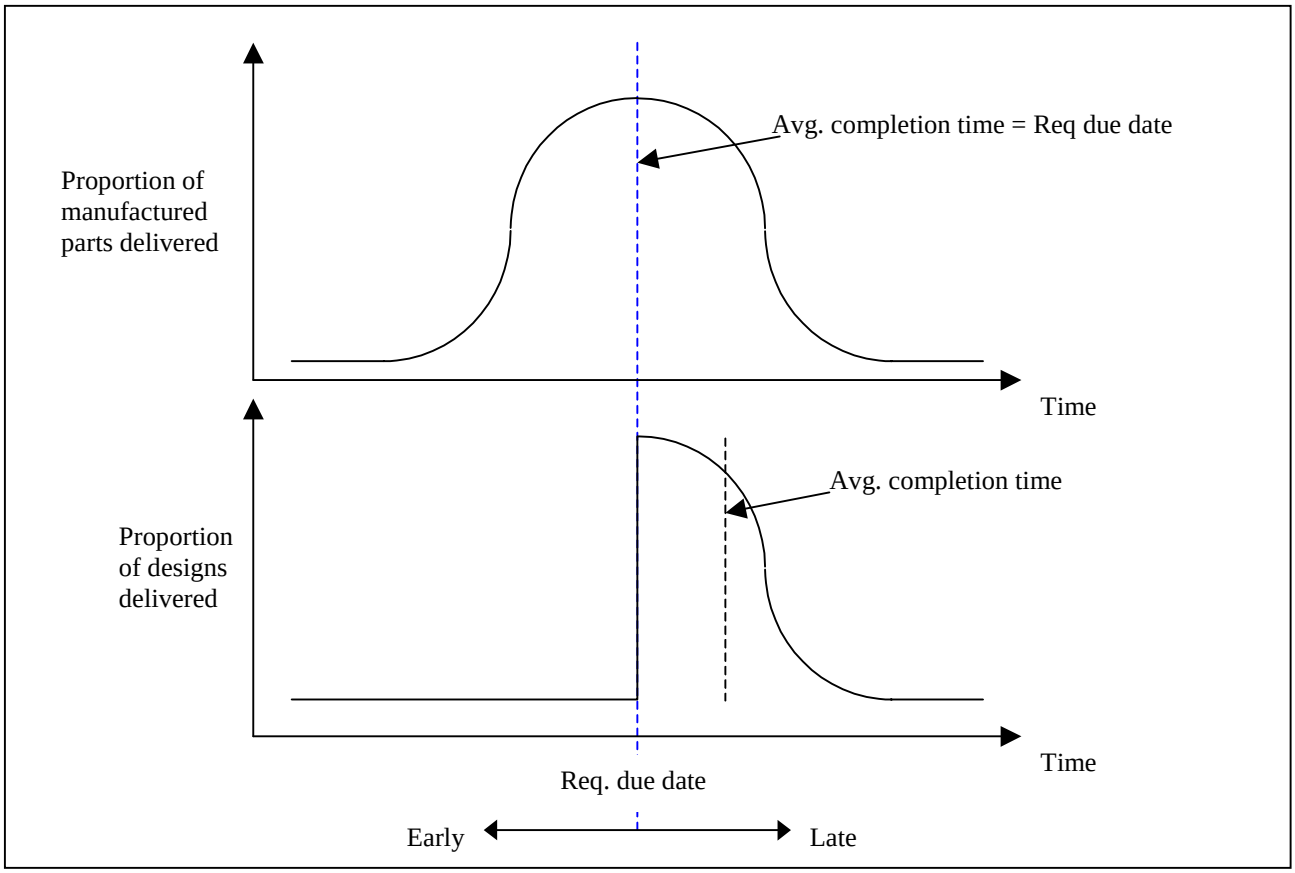

Fig. 7 The comparison of schedule adherence between manufacturing and non-recurring information

majority are completed late. As a result the net average complete time is later than the due date. The distribution is completely skewed to being late. The question has to be what causes this massive difference?

If you reflect back a moment, and remember what agility actually means. Then it is the ability to react quickly, nimbleness. Next, think back to what makes the manufacturing process agile. Then it would be its ability to change between different products, with immediate response to a customer demand, with the absolute minimum of disturbance to the performance of that process. Now take this thought back to the product development world and think how the process would need to be configured?

4.2 Product development with agility

For agility in the development process to happen then there has to be a tool-set that will support the goal. The set-up times need to be minimal and changes to the actual product can be made quickly and effectively.

If you look at the tool set that has been employed to perform these tasks, then you couldn't get anything much more agile. The latest CAD (computer aided design) systems allow for the rapid design of products with an in-built capability to make changes nearly instantly. In other words, they allow for very rapid construction and deconstruction of designs / engineering data. But there has to be a word of warning here, does the technology achieve the objectives that it was implemented for:

- The ability to design a better product
- Reduce the products time to market

When you take into account how successful these objectives have been, then we are producing a better product but the time to market has not always been fully realised. The technology that has been employed in the development process can does help, but can hinder.

This agility can only be exploited if the behaviours of the people using the tools are also trying to be agile. The picture shown in fig.7 suggests that agility is not the key driver. The very agile tool set is being used to allow for many tweaks and changes to be made to the product in the time allotted. This leads to procrastination and a desire to continually strive for perfection in defining the product. Therefore, designers / engineers will keep iterating until it is at the deadline, and then often over step this because of things that they

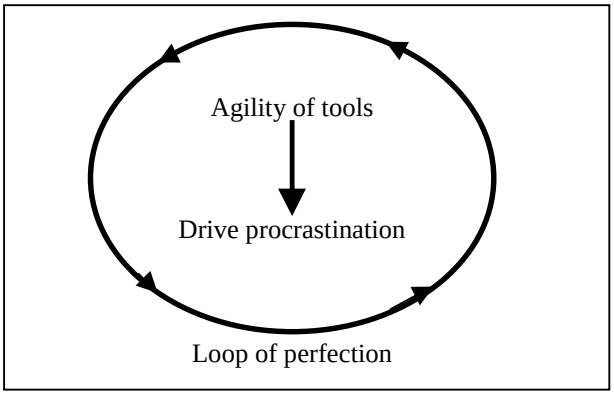

Fig 8 The loop of perfection

hadn't seen. The procrastination and desire for perfection lead into a continuous loop and thus give us the late average completion time (see fig. 8).

This loop of perfection will be the reason why very few designs are completed on time. Agility in product development comes from our ability to make informed decisions about what to design, and what it is going to interface with. This can only happen if a true understanding of customer value (both internal and external).

The result of the procrastination is an ever-increasing amount of information that is queuing at every step through the development process. It is these levels of information that can stop the flow through the process.

If you assess the levels of WIP (Work In Progress) and DIP (Design In Progress) in the value stream. Then the level of DIP can be up to 10 times greater than the level of WIP *(source: Managing the Design Factory)*. Yet in most businesses the levels of the DIP are rarely noticed and measured. This is due to the classical accounting methods that have been employed to measure the business degree of success.

WIP is measured fanatically and is even regarded as a £'s asset on the balance sheet. DIP is not even taken into account even though it has a value that will often be much greater than its physical cousin. This value of DIP comes from the hours of expensive expertise that have been spent on it and the massive risk of obsolescence. This can occur if a change ripples through the product and renders the design incorrect. To compound the DIP problem, then any change that occurs results in re-work that adds to the growing chaos and increases the number of products that are waiting to be processed.

The queues of product information stop the flow of the system. This can be seen when looking at figure 9. The time that anything spends in a queue is dependent on the utilisation of that process. Therefore, as the queue for a process increases then the utilisation also increases and the amount of time that DIP waits also increases. In fact, if a utilisation of 65% is exceeded then you will find rapidly diminishing returns. The end result will be an ever-increasing overall lead-time for the DIP to be completed.

In summary, this will work completely against the goal of agility in the inputs for the manufacturing process. Thus stifling all attempts to become agile in the business.

4.3 Freeing the blockages

As discussed so far, the desire is to produce the ultimate product and the agile tool set they have results in the loop of perfection. Now the challenge lies in finding the barriers that are blocking the goal of agility.

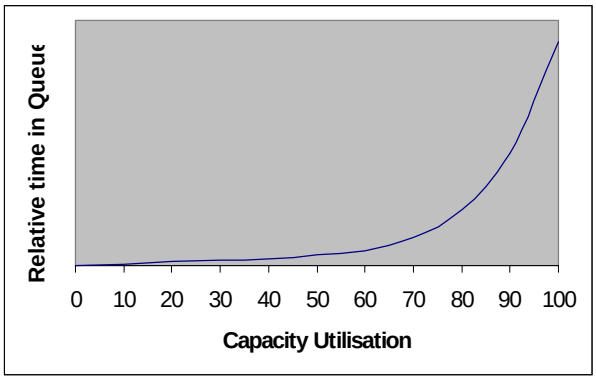

Fig.9 Queue length vs. Utilisation

Starting with the rules for a manufacturing process, then you would aim for a minimum of inventory (ideally one product at a time) that is pulled through at the demand of the customer. This is coupled with process capability that can be changed quickly. There is also one key difference that can easily be overlooked. That is that the product cannot be easily changed once the processing has taken place. It is nearly impossible to add metal back onto a machined item. This means that the decision to change the shape of the metal has been accurately informed since mistakes are usually irreversible. All the relevant information will have been in-place, all focussed on producing what the customer wants. This has the effect of putting tight constraints on the process, due to this customer focus. In the unusual case that something is made that nobody wanted, then the resultant 'useless' lump of metal is a very visual symbol that a mistake has been made.

Transferring this idea back to the realm of product development, then evidence of similar mistakes is almost impossible to find. I would argue that this is because of the agility of the tool set employed, once the change is made then the past guise is lost forever. It does not sit in a pile in the corner of the IPT office, giving out signals as strongly as a lump metal can.

The first step in creating agility will be to create this customer focus in the form of creating an organisation that is aligned with the customer in mind. Coupled with this will be setting up IPT's that will have the singular focus and correct mix of skills and experience that the product requires.

The second step will be to define what the customer really wants and desires. We should seek to develop the supporting process enabling us to pay more of an attentive ear as the initial requirements of the customer are refined. This in turn will help us to understand the engineering implications on a practical level, and ensure we integrate these in the form of explicit product focused objectives at the appropriate level in the right areas. Without these explicit criteria then it is difficult to link these to a top-level customer requirement. This would help to answer some of the current enigmas that exist within the product, e.g. 'What does a 1-point trade-off on the Stealth scale equate to on the Mass scale?'

These explicit requirements will enable the appropriate constraints to be determined; i.e. we need this box to do this job, in this space, for this mass and work with this software. In-turn, the procrastination and number of iterations that are made through the development stages should be greatly reduced. The amount of re-work and change will reduce significantly. Thus, reducing the amount of waste and DIP that is present and overall, shorten the time-line.

5. The effect on the Time-line

There are two key benefits of becoming agile; these are to reduce the time to market for a product (shorten the time-line) and, produce a better product that the customer wants. The things that have been discussed within this paper will help to produce both of these benefits, but through experience on the Eurofighter project then it is not as easy as it first appears.

Within the manufacturing processes we invested a lot of time and money into producing the agility that we sought. This has been done throughout the entire manufacturing process from machines through to the actual assembly of the product. A good example of this is on the assembly of the front fuselage and where a flow-line technique has been employed. This has had the effect of dramatically reducing the amount time it takes to build the aircraft. If the comparison is made with the Tornado project, then it took 41 weeks to assemble the Tornado front fuselage and the planned time for Eurofighter is only 9 weeks.

This massive reduction in lead-time has been produced through IPT's and the use of better design and simulation tools. These tools have resulted in a reduction of parts for assembly and an improvement in the methods of assembly due to the improvements in simulation techniques and a multi-displined approach to product development.

The reduction in lead-time has produced minimal levels of WIP in the system. When coupled with the flexible infrastructure and tooling, then this will have the effect of making any changes to the product much quicker, easier and cheaper to implement. The net gain being increased agility.

The same agility and reduction in lead-time has not been found in the product development process though. The learning curve associated with the tool set has contributed, but the struggle to gain and cascade explicit customer requirements to enable informed and timely decisions to be made has been a greater problem. The syndrome of aiming for perfection in the product development has kept the time taken at this stage to be the same.

Procrastination has been prevalent, and in conjunction with the latest computer aided and simulation tools, the result has been to produce a much better product. The number of right first time parts has increased massively, the result of which has been for the first assembly parts to fit together better than anything previously experienced. This will lead to an overall improvement in the build quality of the aircraft.

6. The challenges for our industry

In our complex industry, with complex products, we can anticipate that we will find continued difficulty in thoroughly understanding the detailed requirements of our customer(s). Especially with due consideration given to the overall project time-line, from

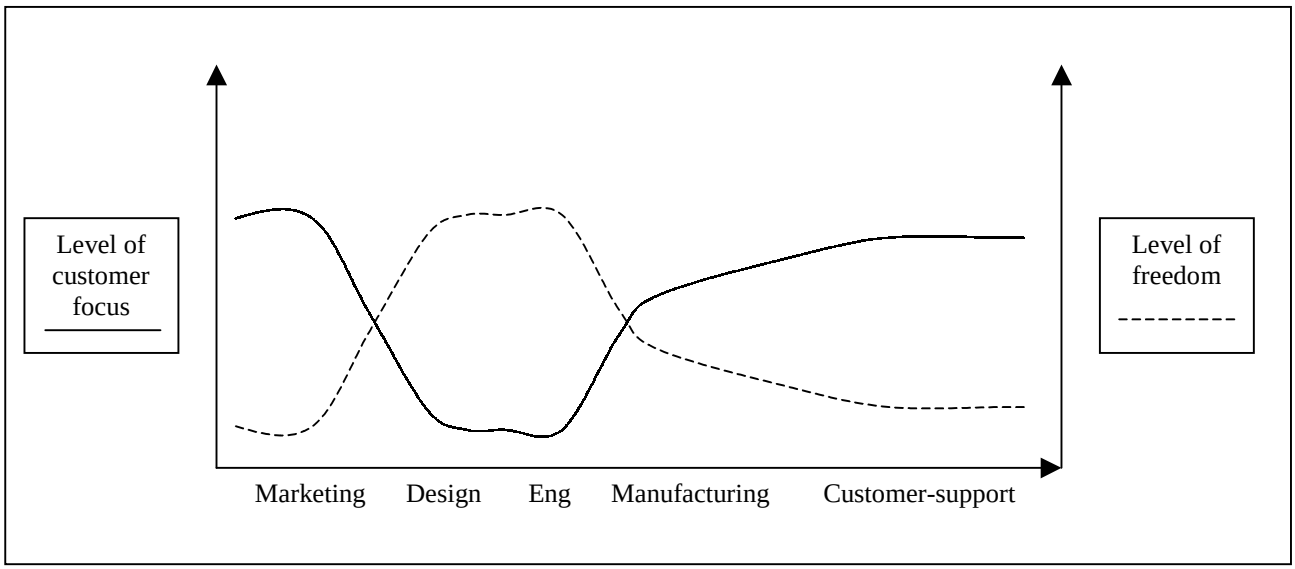

Fig.10 Customer focus and constraints through the time line

formulating initial Weapon System Requirements to delivering and supporting a Series Production aircraft. Ironically, it is the lack of clarity and fundamental understanding of what the customer actually needed (back fifteen or twenty years ago) that constricts us most in the daily evolution of defining the product solution today. It is unrealistic to expect to walk away from closed negotiations with the customer, armed with absolute lucidity a vision of their real needs. We need to achieve this clarity of requirements and then the challenge lies in spreading the needs across the entire time-line in the form of explicit objectives.

When assessing the project time line then the level of customer focus appears to vary considerably (see fig. 10). It also shows that while the level of customer focus varies, then the degree of constraint conversely fluctuates. Therefore, where there is a high level of customer focus, then freedom in which choices can be made are more limited. Where the customer focus is low, then the freedom is high and it could be this freedom that leads to degree of perfection and procrastination that is sought. Ideally, if agility is the strategy for the project then the degree of customer focus should be equal across the entire project. By disseminating the requirements in the form of explicit objectives to all parts of the project then the decision processes should be made quicker and easier to fulfill. Subsequently, the amount of procrastination will reduce and the degree of agility will increase not only in manufacturing, but also in product development.

We have learned on our most recent projects (Eurofighter included) some hard lessons, whilst at the same time realising some significant positive gain. The gain has been in the transition from the serial ‘discipline’ based approach employed on yesterday’s products, to an integrated engineering and product development taking ownership for the full product life cycle. It is also clear that the scope of the new and evolving engineering philosophy must now be extended to embrace both upstream and downstream elements of the time-line if we are to develop our ability to be agile. Extending our agile engineering approach to understand and acknowledge the voice of the customer explicitly and at the earliest point in the time line is where the greatest business advantage can be gained. This is the next major hurdle in becoming agile in our industry.

Only when we have done this can agility in the entire product time-line be achieved, in turn release the full potential of our agile manufacturing processes.

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