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PROCESS IMPROVEMENT IN BAE SYSTEMS AND THE WIDER AEROSPACE SECTOR

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Brief Autobiographical notes:

Dr Stephen Barker is a Research Officer in the School of Engineering, Department of Power Propulsion and Aerospace Engineering at Cranfield University, UK. Dr. Barker holds a BSc. (Hons.) in Computer Studies, and researched Applied Engineering Process Management for his Ph.D. Currently, Dr. Barker is part of the COPE (COmplex Product Environment) research team, which investigates 'Decomposition-Integration' issues within Complex Product Development Programmes. Dr. Barker has previously worked as a lecturer and tutor in the fields of Network Communications and Operations Management.

Dr Linda Hendry is a Senior Lecturer at Lancaster University Management School. She has extensive research experience within the manufacturing sector, with particular interest in Make-to-Order high customisation companies. She has worked with a number of industrial collaborators including Pilkingtons, BAE SYSTEMS, Hazlewood Pizza and a number of local SMEs. The latter includes many high precision sub-contracting companies whose customers include BAE SYSTEMS. She is a member of three professional societies: EUROMA, The Institute of Operations Management and the UK Operational Research Society.

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Structured Abstract:

Research paper

Purpose: To research the change management processes used to implement 'world class' improvements in a major aerospace company, BAE SYSTEMS, and to propose a model for process improvement in the wider aerospace sector.

Design/methodology/approach: The research was undertaken as a longitudinal study over a period of five years. A variety of research methodologies were used at various stages of the research including action research and observation. Semi-structured and unstructured interviews were used to gather qualitative data along with documentary evidence of the processes being used.

Findings: There are three key findings. Firstly, an understanding of the production stages in the aerospace sector: future project; new product; sustain and return to work. Secondly details of a matrix-based approach and the issues regarding its implementation in a large organisation are discussed. Thirdly, a generic set of principles to aid process improvement in the aerospace sector is proposed.

Research limitations/implications: Given that the study is based in one company, there are issues regarding the generalisation of the results. A potential further research project would entail the implementation of the proposed generic principles in another aerospace organisation.

Practical implications: For BAE SYSTEMS, this research project aided their understanding of the issues involved in rolling out a process improvement program in a large organisation.

Originality/value: Until recently, most of the research into process improvement had either been universalistic or aimed at another type of industry, such as the automotive industry. This research helps to address the specific needs of the aerospace industry.

Keywords: Aerospace industry, process improvement, change management.

Introduction

Many attempts have been made to create a central, well-organised method to control process improvement and manage change within manufacturing organisations. Examples include Total Quality Management (TQM), Business Process Re-engineering (BPR), Just-In-Time (JIT), World Class Manufacturing (WCM) and Lean Production. As 'new' ideas emerge, many companies seek to retain their competitive stance by gaining the advantages offered by the implementation of these ideas. However, it is not always obvious as to which precise activities a particular organisation should undertake to achieve such advantages. Thus the research described in this paper was initiated by BAE SYSTEMS, (or British Aerospace as it then was before the merger with Marconi in 1999), as part of their attempt to implement WCM. In particular, they wanted a definition of WCM, which was in vogue at that time, which would be appropriate to their industry.

The project began with a detailed review of the literature to determine the appropriateness of previous WCM definitions, as summarised in the second section of this paper below. This indicated that much of the previous research has tended to be universalistic in nature. Although the automotive industry has received extensive research attention, there was little evidence of similar interest in other manufacturing contexts. Of those who have attempted this, Muda & Hendry (2002a, 2002b) have suggested that existing prescriptive material is not applicable in its entirety to all industrial contexts. Whilst Muda & Hendry's (2002a, 2002b) work is directed largely at the Make-to-Order (MTO) manufacturing sector, it is reasonable to hypothesise that the lack of universality which they encountered is not confined to this sector, but is evident elsewhere within manufacturing industry.

The problem associated with universalistic research is that it ignores the unique characteristics, present in each industrial sector, that need to be addressed if an effective improvement programme is to be initiated. The aerospace sector is characterised by highly advanced and complex operations. These require a highly motivated and skilled workforce, high levels of manufacturing precision, and detailed co-ordination of resources and manufacturing effort. In the case of BAE SYSTEMS, this co-ordination involves many different projects, spread over several sites, and utilising different manufacturing processes, practices and tooling. The historical development of the company that lead to this level of complexity is described further in Barker & Hendry (1999). Thus the research aimed to identify the principles and criteria necessary for world class achievement, and the method by which it can be instituted in such a large and complex organisation. As the research progressed, the WCM label became less fashionable and lean thinking was becoming increasingly widespread. Additionally, the needs of the case study organisation changed as the merger and subsequent organisational restructuring took place. Consequently, the scope of the project changed to become a wider process improvement project, without any specific label. Once the research for BAE SYSTEMS was completed, an attempt was made to generalise the findings to make them applicable to the wider aerospace sector.

After the literature review section below, the research methodology is described. The remainder of the paper is structured around the following stages of the research. Aspects of this research have been previously described in brief in Barker *et al* (2002):

- A study within BAE SYSTEMS to determine what (and how) the organisation was currently using to structure its approach to process improvement. This included further study within the organisation to review the implementation of this method of process improvement;
- The derivation of a set of principles for process improvement thought to be relevant to BAE SYSTEMS;
- The application of industrial type classifications to the existing set of principles devised for BAE SYSTEMS to render them of use within the wider context of the aerospace sector.

Finally, the conclusions are given, along with issues requiring further research.

Literature Review

The literature review identified five principle approaches, which had previously been taken to developing process improvement strategy, focussing initially on WCM research:

1. the ***practice-oriented*** approach, which consisted of the Japanese approach to manufacturing (Womack *et al*., 1990, 1996; Schonberger, 1986, 1996) and the concept of ‘culture excellence’ (Kanter, 1989, 1992, 1995). This approach includes the JIT concept and Schonberger’s (1996) WCM principles, which prescribe actions such as reducing set-up times, adopting a cellular layout and involving the workforce in strategic decision making.

2. the ***practice-performance*** approach, which suggested that the identification of good practice depended on the measurement of how well it performed (Oliver *et al*. 1994, 1996; Harrison, 1998). Studies in this category typically compare performance of factories, providing valuable data regarding sectors of industry and the standards attained within them. However, they have been criticised by New & Swejczewski (1995) for concentrating on the process sector at the expense of more sophisticated manufacturing organisations. Additionally, these studies tend to offer little in the way of an indication as to how poor performance can be improved, and are an unrealistic guide to improvement for companies that are already high achievers.
3. the ***management 'fad'*** concept (Pascale, 1990), which suggested that all such improvement initiatives are transitory and likely to be replaced in short order by the 'next big thing'.
4. the ***human intuition*** approach (Morton, 1994), which suggested that good practice is dependant upon the ability of humans to identify and control it. Research in this category focuses primarily on issues such as empowerment of the workforce; the concept of human esteem and the consequent need for a change in management skills/attitudes.
5. ***Lean Aerospace*** (Graves *et al*., 1999; Ward *et al*., 2000; Ward & Graves, 2001a, 2001b), distinguishable from the first category above as it includes early work addressed specifically at the aerospace sector.

Much of the literature described, for example Womack's (1990) description of Toyota's manufacturing approaches, or Schonberger's (1996) set of World Class Manufacturing (WCM) principles, does not specify industry type but tends to concentrate on the specification of practice mainly for mass production or make to stock (MTS) operations. Other approaches - Hanson and Voss (1993, 1995) or Oliver *et al*. (1994, 1996) - concentrate on a survey approach which samples a wide variety of different organisations, but does not tackle the individual issues of any particular one in depth. Therefore, even though a few aerospace organisations (or their suppliers) have been studied, it has seldom been in sufficient depth to assist in the provision of a comprehensive approach to process improvement. Although the Lean Aerospace Initiative (LAI) may achieve this in time, it has not done so to date (James-Moore and Gibbons, 1997). It has been implemented in the US with varying degrees of success (Graves *et al*., 1999; Murman *et al*, 2002), and study is still progressing in the UK. At present, the focus is on performance measurement in costing and accounting systems (Ward and Graves, 2004).

Further details of the literature review summarised above are given in Barker (2003). It was concluded that the aerospace sector has not received much attention in the process improvement literature prior to the commencement of the research resulting from the LAI. The research described below was carried out in parallel to that research initiative.

Methodology

The research within BAE SYSTEMS was undertaken as a longitudinal study (Saunders *et al* 2000) over a period of five years, studying the changes and development within the organisation. The nature of the research methodology evolved over the duration of the study. Initially, an action research approach was undertaken. As described by Marsick & Watkins (1997), this approach is set apart from other forms of applied research by its focus on action, with particular regard to promoting change within the subject of the study. At this stage, a researcher was actively taking part in the change process to develop and implement a matrix-based improvement approach. The matrix, described in detail below, included a definition of World Class Manufacturing. The project involved the population of that part of the matrix as well as active participation in the implementation of the matrix. Semi-structured interviews were used at an early stage in the development process to determine the perceived organisational needs and how the manufacturing processes had developed. In addition, much documentary evidence was gathered, including various versions of the matrices used.

However, as the needs of the organisation changed, the research evolved into more of a participant-observer (Gill & Johnson, 1997) and finally an observation research project in which the direct involvement of the researcher in the change process lessened. This was largely as a result of the merger and a change in management priorities, which meant that the achievement of WCM became less of an urgent goal. Thus the research became more focussed on insights that could be gained by observing the organisational changes taking place. Semi-structured interviews were again used to gather qualitative data on the effects of organisational change on the implementation of the process improvement matrices. Further justification and description of the research methodologies employed is given in Barker (2003).

Assessing the existing BAE SYSTEMS matrix-based approach

In order to address the need for a process improvement model within the aerospace sector, it was necessary to determine what had been attempted before by the organisation, how it had been implemented, and how the potential users perceived it. Accordingly, the initial action research period involved working on manufacturing process improvement initiatives within the Military Aircraft division of BAE SYSTEMS. The findings showed that BAE SYSTEMS had approached the problem by devising a matrix-based categorisation, sorted into six main areas of practice: Technology, People (dealing with human resource issues), Process, Organisational Development, Customer Satisfaction, and Performance Indicators. These areas of practice were graded on an incrementally improving scale of achievement, rising from 'Learner' level to 'World Class' standard. This latter nomenclature led to the initial use of World Class Manufacturing (Keegan, 1997) as a basis for the research. This is shown in figure 1.

Take in Figure 1

For each of the key criteria, each stage of the matrix was populated with targets intended to attain a progressively greater level of practice and performance. For example, Technology may include a paperless office and IT standardization in the short term, with the "virtual office" as the long term "World Class" target, whilst for People, full personal development plans (P.D.P.s) may be the short term goal with fully empowered employees as the long term target. Over time, the factors affecting the process will change and hence the content of the matrices would need to be up-dated and revised accordingly.

The matrix-based categorisation was structured in a hierarchical manner, so that a 'generic' matrix would control overall practice progression and performance, and under this would be individual matrices for each of the projects – e.g. Tornado, Eurofighter/Typhoon, Joint Strike Fighter (JSF), and Future Offensive Avionics System (FOAS). In addition, links between the different projects were sought so as to determine how one project could learn from another. This was achieved through the identification of a "project life cycle", which consisted of four distinct phases of work that was being undertaken by the organisation. These were as follows:

Future Project: The stage at which concepts are investigated, matched to a customer need, and demonstrated to the customer. This involves planning and design of the "demonstrator" platform, and possibly initial manufacture of pre-production aircraft (after an order has been secured)
Examples: JSF, FOAS (Future Offensive Avionics System)

New Product: The production phase of a new aircraft. Pre-production aircraft are built and tested, and the final production specification is agreed, at which point the aircraft goes into full production. This stages ends after the final batch of aircraft is delivered
Example: Eurofighter/Typhoon

Sustaining: The business of maintaining existing aircraft in operational service. Depending on the length of the production run, this stage may commence before New Product ends. This is the organisation's largest source of business
Example: Harrier II, Hawk 2000

Legacy/RTW: This stage deals with older aircraft, which, whilst still in service, rely on older technologies, and require 'traditional skills' to maintain them. Return To Work (RTW) deals with a mid-life update, re-equipping the airframe for an extended service life, or to perform a different function
Examples: (Legacy) Canberra, Tornado, Harrier I (RTW) Nimrod

These phases were formed into a process cycle, which charts how each phase links with the next, thus linking the life cycle for each project, and creating a cycle through the four central engineering businesses as shown in figure 2. Thus, one project might develop skills and processes which can be fed forward incrementally into the next project. Furthermore, lessons learned at, say, New Product stage of one product could be input into the same stage of future projects to prevent the same problems from reoccurring. Using this device, the case could be made for greater co-operation as it could be seen that if managed properly, newer projects would benefit directly from the experience gained on older projects.

Take in Figure 2

The impact of the matrix-based method of controlling process improvement

The matrix-based model provided an interesting insight into the managerial issues behind developing and implementing such an approach, especially with regard to managing the changeover from a largely unregulated ‘ad hoc’ system to a new consolidated method. The matrices had originally been devised by a single manager, and then revised and enhanced by a committee of departmental engineering managers. This was done in collaboration with a central core engineering group, which was responsible for its introduction and upkeep in use.

Initially, the matrices were piloted across a single site, addressing the sustaining phase of the product life cycle only. A short while after implementation, interviews were carried out with several of the engineering managers responsible for its origination, and also with some of the senior engineers who came into contact with it. This was to gauge the reaction to the new approach, to understand any problems with the method, and to see if hindsight provided views on how the implementation could have been better managed. The results of this survey were largely positive, and tended to concentrate on necessary improvements to the matrices. These centred on the clarity and usefulness of the improvement criteria. The main objections from the engineering work force (who had been introduced to the matrices by the departmental managers) were that the criteria was largely vague and ambiguous (i.e. too generic – for example, the legend ‘Benchmark results are considered to be best in class’ on the technology matrix failed to define what was to be benchmarked, or how it was to measured, and against what), and that it was poorly explained. This was partly to do with the fact that there had been no consultation period during the matrices’ origination, and consequently some of the terminology was phrased in ‘buzz-words’ (e.g. STL PDQ, meaning ‘Support Team Leader Personal Development Questionnaire), which meant little to the engineering population. Furthermore, there were many acronyms which were not sufficiently explained. The most significant problem however was that the criteria were not broken down into greater detail, which meant that difficulties could be encountered when trying to apply them to individual jobs and tasks.

In addition to these faults, there were also various structural problems with the matrices. Some information appeared at advanced stages of the matrices without anything earlier in the development cycle to substantiate it. There were instances where criteria at a higher level matrix failed to appear on the relevant lower level ‘detailed’ version, and also instances where criteria appeared on the wrong matrix. These faults were corrected through a series of seminars and meetings attended by senior and departmental managers, and when the revised matrices were released back to site, there was general approval and opinion that this approach would be beneficial to improve manufacturing practice.

At this point, the matrices were populated out across the other sites belonging to the Military Aircraft division, and here further problems were encountered. These stemmed largely from the fact that the organisational structure of the division placed individual projects (aircraft development programmes) at different sites. Each project required often quite different practices and techniques (so, for example, a modern state-of-the-art Typhoon would have one set of practices, whilst an older Harrier would have another). These frequently failed to relate to one another, and consequently (in addition to many of the issues raised at the pilot site) the managers at the different sites claimed that one set of improvement criteria could not be universally applied across all projects and that consequently the matrices were of little use.

Evolving the matrix-based method

One of the chief causes of issues being raised both during the pilot and also at wider site level was the ambiguity of the process improvement criteria. Although they had been designed to be sufficiently broad in scope so that it could be applied across the board, the matrices now possessed insufficient detail to be widely applied. Practices in Electrical sub-systems and Major component assembly, for instance, were likely to be significantly different, yet the matrices prescribed one standard set of criteria.

In an effort to combat this, the matrices were redesigned. The resultant set bore very little resemblance to their predecessors. Whereas the original set possessed a generic matrix connecting to a set of detailed matrices (one for each of the practice streams identified on the generic matrix), the revised matrices possessed an entirely flat organisational structure. There was no generic matrix, and the practice streams of Organisational Development, Customer Satisfaction and Performance Indicators were either incorporated into the remaining practice streams, or dispensed with and dealt with by other initiatives within the organisation. This left Technology, People, and Process as the streams deemed central to practice improvement. Additionally, the nature of the criteria used to populate the three new matrices was altered. Whereas previously matrix criteria had been of the 'umbrella' type 'this is the aim which our practices should achieve', now they were more tightly constrained, and stated 'this is the list of things which need to be done to achieve this standard'. Thus 'Identification and application of leading edge technology' became 'A highly capable, high performance, single pass machining process'. Moreover, the emphasis of the criteria was much more heavily biased towards technology and technological matters. As such, engineering systems were broken down into the various technologies (i.e. Airframe, Composites, Advanced Metallics, Tooling etc.), which were used to drive forward improvement. This highlighted that a significant issue in process of matrix evolution was the difficulty in attaining the right level of descriptiveness and detail.

Unfortunately, these new matrices were never used to great effect. This was because at the time of their introduction, the organisation merged with Marconi Electrical Systems (MES) to form BAE SYSTEMS. As a result of this there was wholesale reorganisation and restructuring of the aircraft manufacturing business, which led to a concentration on issues that were non-matrix related. Furthermore, an initiative (Project Axis) was introduced immediately prior to the merger, which changed the structure of the Military Aircraft division. Prior to this, manufacturing had been organised on a site basis, with individual projects being based at, and using the resources assigned to, that site. Henceforth however, resources were assigned to the projects, which were based at whatever site was deemed to be appropriate. This shift of emphasis from site to project focus meant that the resources at each site that would be needed to maintain the matrices over a period of time were no longer in place, and thus the matrices ceased to be used as a matter of policy across the entire Military division.

Despite this, when a second period of field work was done within BAE SYSTEMS, a surprising consensus of opinion was reached amongst the managers and engineers who were interviewed. The merger seemed to have created a vacuum of centralised control. The new matrices were found to still be in use by individual teams within engineering departments to structure workload, monitor progress, and set performance targets. Although, according to managers the matrices had ceased to be used and were being replaced by an end-to-end 'cradle to grave' lifecycle, the engineers stated that there was no sign of this happening. Furthermore, there was now a lack of centralised support, which meant that all teams were effectively acting in isolation. This would, according to the engineers, provide a significant barrier to the reinstatement of a widespread process improvement approach.

Developing process improvement principles for BAE SYSTEMS

Despite the fact that the revised set of BAE SYSTEMS matrices ceased to be used in their intended manner, they provided a great deal of information with regard to what would be required of a process improvement approach for the organisation. The matrices provided a wealth of detail relating to the needs of the organisation at the Sustaining phase of BAE SYSTEMS' manufacturing operation. It was possible to use this information in conjunction with various approaches for manufacturing improvement (see for example Schonberger (1986,1996), Morton (1994), Kanter (1992), and Bolden *et al*. (1997)) to identify a set of principles for this area of operations. This was achieved by taking an interactive approach to relating the existing details to the BAE SYSTEMS matrices. Information was sought from engineers and managers as to the meaning and application of the criteria, which could then be mapped against the details in the literature approaches to form suitable principles. The research uncovered a number of instances where there appeared to be a mismatch or lack of commonality between the matrix-based approach and the literature. Where this was the case, the following questions were considered:

- What was meant by each item of matrix information (where that information did not correspond to anything within the literature)
    - Was it correctly worded (it might actually be in agreement with material from the literature whilst appearing not to be)?
    - Why was it included – what was it intended to achieve?
    - Why was it necessary – was it actually needed?
- Was information presented by the literature, but not present in the matrix, relevant to the aerospace sector?

These issues were raised informally with the engineers and managers who had originally devised the matrix. In this way, it was possible to assess how the information within the matrices had been originally devised, and whether on reflection (of those within the organisation) it was *actually* relevant to practice improvement strategy. The second point allowed an evaluation of how complete the matrices had been – the amount of information deemed relevant to process improvement but not present within the matrices could be used as a measure of the completeness of the matrices, and of how effective they were as a process improvement method (notwithstanding the structural, technical and usage issues outlined earlier). The process of discussion eventually produced a set of concepts that was both largely common to the matrix and the literature, and deemed relevant to the aerospace sector (by the engineers and managers). By following this process, it was possible to assemble a set of process improvement principles for the Sustaining phase of the BAE SYSTEMS lifecycle, by combining the matrices' content with information from literature. This was subsequently approved by the organisation.

In addition to producing information for the Sustaining phase of the operation, it was also helpful to attempt to identify principles for the other three phases of BAE SYSTEMS' manufacturing cycle: Future Project, New Product, and Return to Work. A potential issue, however, was that the matrices had been piloted for the Sustaining phase only. Therefore a period of observation and general unstructured discussion with manufacturing 'facilitators' (i.e. managers and team leaders) was undertaken to gain an understanding of the activities and needs of the other three phases. Once this was achieved, it was then possible to map out a set of principles for each of the remaining three phases. These principles were grouped under the following six general headings: customer relations; use of technology; work force relations; quality assurance; process and supplier relations. The process of devising them is detailed in Barker (2003). The principles are described in full in figure 3. This new set of principles reflected a need for highly skilled knowledge and practice at the earliest stage of the life cycle (Future Project), at which point the design and flight of the demonstrator takes place, and relations with the potential customers are initiated. This places a heavy reliance upon the levels of technology and technological expertise possessed by the organisation. Once the project moves into the New Product – that is to say aircraft production – phase, the emphasis moves toward process management and enhancement. This is complimented by stressing the integration and realisation of worth of the employee. As the project moves into the final two stages, Sustaining and Return to Work, the emphasis moves still further onto the importance of the engineer. At this point the aircraft being worked upon are often from a previous generation of manufacture. As a result, it may often prove uneconomical to redesign the processes to enable modern manufacturing techniques to be employed, both in terms of extreme cost, and also the variable level of business conducted. As a result it is imperative that a high level of engineering skill is maintained in the organisation to cope with the contingencies of the older 'legacy' projects in addition to the high degree of specialisation required at the onset of project development.

Take in Figure 3

Generalising the Process Improvement Principles

As was indicated earlier, one of the main aims of the research was to provide a more general set of process improvement principles, which could be used not only in BAE SYSTEMS, but also within the wider aerospace industry. In order to do this, it was necessary to study the different types of manufacturing to gauge what effect these would have upon the principles devised for BAE SYSTEMS. There have been various attempts to define the nature of manufacturing. Hill (1993) and Amaro *et al*. (1999) have provided categorisations by manufacturing type. Hill (1993) provides a description for the various types, Design to Order, Engineer to Order, Make to Order, Assemble to Order and Make to Stock. These definitions are somewhat at variance with the traditional descriptions of ETO, MTO, ATO, and MTS. This is a point highlighted by Amaro *et al*. (1999), who go on to provide a much more detailed taxonomy of manufacturing classes. In this paper, the terms ETO, MTO, ATO, and MTS are defined as follows:

- Engineer-to-Order (ETO): The product is individually tailored to a specification provided by the customer. The design and engineering of the product is primarily the responsibility of the manufacturer;
- Make-to-Order (MTO): The majority of the operations required to manufacture the product is performed after receipt of the customer's order. The product is customised to the customer's requirements;
- Assemble-to-Order (ATO): Although customised to a certain extent, this involves mainly standardised manufacture and the provision of a finite number of ways in which the product can be assembled;
- Make-to-Stock (MTS): Parts and components are manufactured prior to receipt of order

and stored in readiness for use.

These definitions, in addition to that provided by Muda and Hendry (2003) were used to identify how BAE SYSTEMS' manufacturing life cycle could be categorised by manufacturing type. This is shown in figure 4. It was found that the initial stage of the project, Future Project, was largely ETO in nature, whilst the next stage, New Product, was predominantly MTO. This was because the high level design was achieved at the first stage, and when passed to New Product phase, the operation became the manufacture of a highly complex product to an existing design and set of requirements. Further through the life cycle, the manufacturing operation became largely ATO at Sustaining phase, where the maintenance undertaken consisted of the manufacture and assembly of relatively standardised parts. This standardisation was also evident at the Return to Work stage, where the operation was largely MTS, being the routine maintenance of older aircraft. This final phase also possesses an element of ETO however. This occurs where the customer requires an aircraft redesigned to perform a different purpose (an example being the transformation of Nimrod from Air-Sea Rescue to Airborne Early Warning). In this instance, the manufacturing process iterates through the design and development cycle. Therefore there exists an entirely new manufacturing lifecycle, albeit in microcosm within the Return to Works phase.

Take in Figure 4

The information provided by this analysis enabled the existing process improvement principles to be reassessed. As before the new principles were grouped under six general headings. To illustrate the types of change that occurred, the new versions are shown in figure 5 (using the same format as for the original principles described in figure 3). Of much use at this point was Muda and Hendry's (2003, 2002a, 2002b) work, which relates specifically to the specification of process improvement principles for small manufacturing enterprises within the MTO field. This provided a direct comparison with the MTO areas of the manufacturing lifecycle (New Product phase). It was found that many of Muda and Hendry's principles were relevant albeit not always directly. This was primarily because of the nature of the aerospace industry. For example, whilst it is necessary to promote business and technical ability, this must be done in a very general manner so as to avoid infringing customer technology and to prevent industrial espionage and theft of concept. So whilst it is possible to highlight the ability to manufacture to within thousandths of an inch, it is not possible to describe in any depth the work that has been done for previous customers. Largely, however, Muda and Hendry's set of MTO principles verified those devised for BAE SYSTEMS'.

Take in Figure 5

There was comparatively little existing work on establishing principles for each of the other manufacturing types. A degree of reliance was therefore placed upon descriptions from Hill (1993) and Amaro *et al*. (1999) on the essential characteristics of the various manufacturing types. In this way, it proved possible to judge whether criteria from the BAE SYSTEMS' principles would be suitable for use within operations characterised by other manufacturing types. When this analysis was carried out, existing principles were found to be reasonably accurate for ETO, although a greater emphasis was required on reinforcing people's engineering skill sets, which need to be integrated into the design and manufacturing process. The training of the employees is vital given the high levels of complexity often involved in design and manufacture. Finally, the transfer of skills from project to project can dramatically improve design capability throughout the organisation. The need for research into the nature and the use of advanced and cutting edge technology was also recognised as key to a continually evolving engineering design process. Furthermore, whereas the original principles (figure 3) had focused on understanding the needs of the customer, the analysis of the ETO approach at 'Future Projects' phase revealed the need to promote the skill sets to advertise capability was of great importance. It was recognised that by involving the customers in design decision making, these capabilities could be shown, whilst increasing customer satisfaction, and reducing lead times for design and concept generation.

The 'Sustaining' and 'Return to Work' phases of manufacture have the maintenance of older aircraft in common, and the line defining when a sustaining project becomes return to work can often be subjective and blurred. In these phases, ATO and MTS respectively, it was found that notable changes were required from the earlier MTO stage. Principally, these centred on the integration of key skills to enable the organisation to maintain 'traditional' practices needed whilst working on older airframes, whilst removing any lesser skilled or repetitive task out to sub-contract. This requires a focus on training of traditional as well as current engineering methods, and a close relationship with sub-contract and material suppliers to ensure the sourcing of older components and the quality of sub-contract work. Technology was found to be less of a driver, with human skills and abilities, and maintenance of the engineering process being the central facets of strategy. The principles for these final two phases were closely linked to the principles of the original classification (figure 3).

Conclusions and Further Work

The research found that the concept of a matrix-based approach to process improvement was potentially a valid and useful method at a detailed level of operations. However, its success in use was entirely dependant upon the quality of change management processes employed to facilitate it. Several significant issues were identified regarding the provision of support to enable the engineering population to use the matrices. The initial versions of the matrices were developed without consultation with the people who would use them – i.e. the engineers – and subsequently problems were encountered due to areas of poor description, vagueness of practice criteria, and confusing 'buzz word' phrases. Broadly, the initial matrices were too process focused and generic for the task in hand, and this caused significant problems when attempts were made to use it across the entire Military division. One of the major issues here was the lack of user support, for whilst meetings and forums were held, it was then left to the managers and engineers to return to their individual sites and use the matrices relatively unaided. Although the matrices were redesigned in the light of views from across the Military division, the merger brought a premature end to its extensive implementation. The revised matrices were more detailed and focused upon technology. As a consequence, the criteria were clearer and more closely related to the manufacturing engineering activities of the organisation. It is likely that this would have met the needs of the engineering population more successfully than the original versions, a fact proved by the use of the matrices in individual areas of the organisation.

At a higher level, the classification of principles developed by this research has identified four distinct phases of operation for the aerospace sector: future project; new project; sustaining and return to work. It has further devised sets of principles based on a combination of literature, existing organisation methods, and knowledge gained through discussion and observation, which are intended for use in each of the four phases. The four phases and their identification is in itself a useful descriptor of the aerospace industry.

In terms of future research, in order to further validate this approach, there would need to be a further trial of the matrix-based concept in a predominantly stable manufacturing environment. This would focus on the definition of principles and criteria, and the provision of in depth centrally based support for the approach during its use. Additionally, there is a need to trial the principles for manufacturing improvement developed during this research within the matrix structure. In essence, these represent a first attempt at a definition to include, and therefore need to be refined and adjusted over time. Therefore, in order to determine how they can be adapted to fit differing manufacturing environments, and to develop them over a longer duration, a period of involvement with an aerospace organisation is necessary.

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	Learner	Developer	Performer	Contender	World Class
Technology					
People					
Process					
Org. Dev.					
Cust. Sat.					
Perf. Ind.					

Figure 1 : BAE SYSTEMS' original Matrix-based approach to manufacturing process improvement

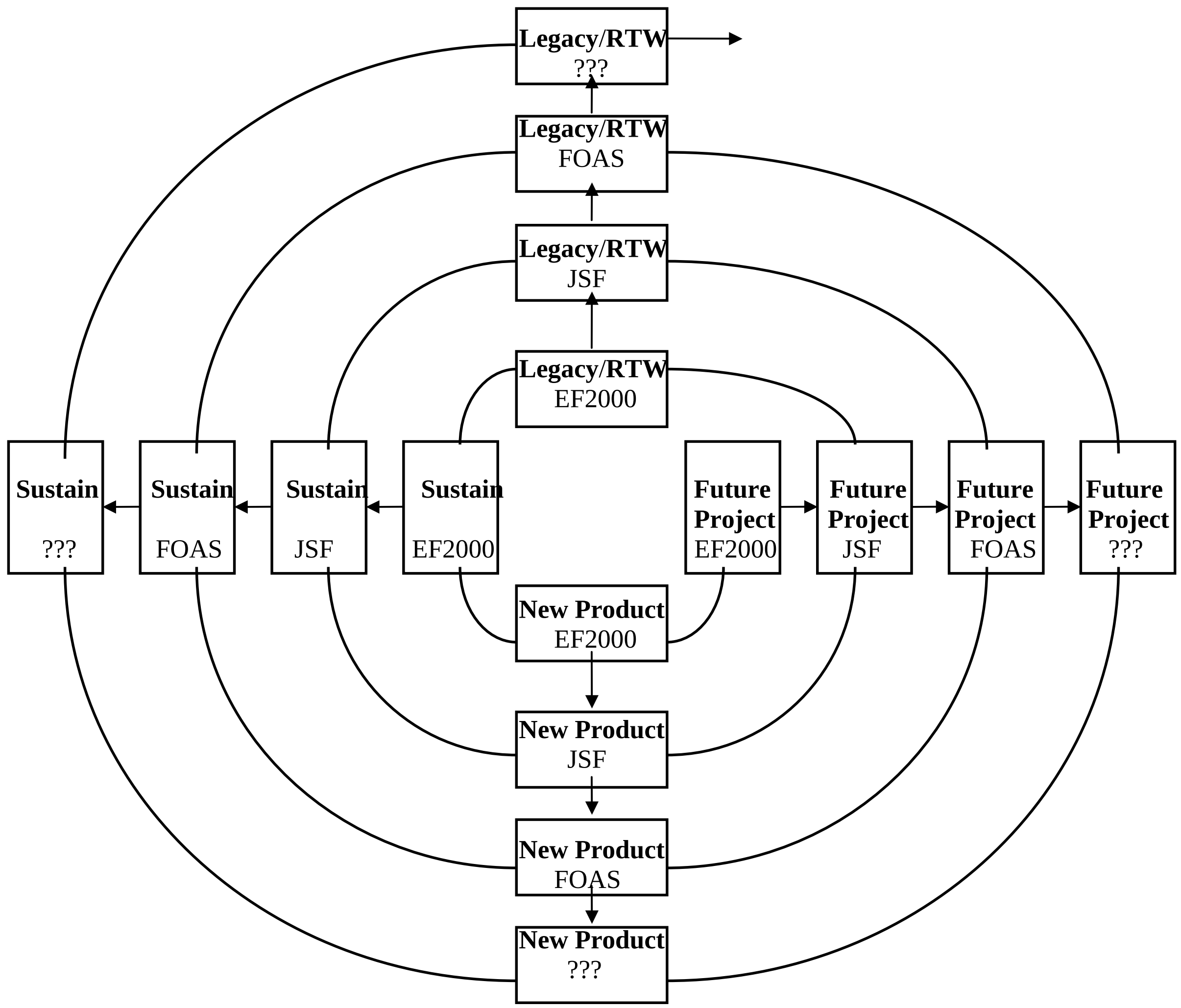

Figure 2: "World Class" Progress Spiral

		Future Project	New Product	Sustaining/Return-to-Work
Customer Relations :		GET TO KNOW THE CUSTOMER	MAKE CUSTOMER A PRIORITY/ ORGANISE BY CUSTOMER	MAKE CUSTOMER A PRIORITY/ ORGANISE BY CUSTOMER
		Conduct market research/ Customer surveys	Get close to customer & involve in design process	Offer after sales support
		Predict customer requirements/ Understand customer needs	Promote customer awareness of improvements	Promote customer awareness of improvements
		Customer involvement in design process	Obtain customer feedback/ communicate, be honest	Obtain customer feedback/ communicate, be honest
		"aggressive selling"		
Use of Technology:		ORGANISATION WIDE TECHNOLOGY STRATEGY	ORGANISATION WIDE TECHNOLOGY STRATEGY	ORGANISATION WIDE TECHNOLOGY STRATEGY
		Group technology knowledge	Process Engineering development	Process Engineering development
		Process Engineering development	ADVANCED TECHNOLOGY	Maintain existing before purchase new
			General automation	
			EDI, computer aided management & comms.	
			CAD/CAM, CAP techniques	
			Rapid Prototyping	
			MRP/MRP II	

Figure 3: Principles for WCM in the aerospace sector

		Future Project	New Product	Sustaining/Return-to-Work
Work Force Relations:		EXPLICIT HRM STRATEGY	EXPLICIT HRM STRATEGY	EXPLICIT HRM STRATEGY
		Clearer leadership structure/ clarify management role	Learning culture /"Invest in people"	Learning culture /"Invest in people"
		Close relations with unions	Continual training & development, Equal opportunity	Continual training & development, Equal opportunity
		Learning culture /"Invest in people"	Empowerment	Empowerment
			Job rotation/multi-skilling/ flexible work force	Job rotation/multi-skilling/ Flexible work force
			Ensure effective communication	Ensure effective communication
			Use of skilled contract labour / secondments	Use of skilled contract labour / secondments
Quality Assurance:		QUALITY STANDARDS & AGREEMENTS	**QUALITY STANDARDS & AGREEMENTS**	QUALITY STANDARDS & AGREEMENTS
		TQM/Kaizen	'Quality Functional Design'/Conformance testing/quality inspections	'Quality Functional Design'/Conformance testing/quality inspections
		'Quality Functional Design'	Agree quality issues with customer	Agree quality issues with customer
		Quality training	Feedback to/from operators on quality/ Quality awards	Feedback to/from operators on quality/ Quality awards

Figure 3 (continued): Principles for WCM in the aerospace sector

		Future Project	New Product	Sustaining/Return-to-Work
Process:		CONCENTRATION ON CORE ACTIVITIES	CONCENTRATION ON CORE ACTIVITIES	CONCENTRATION ON CORE ACTIVITIES
		Analyse, identify, realise, need for change, reinforce & institutionalise change	Work in progress/lead time reduction, shortest throughput	Work in progress/lead time reduction, shortest throughput
		Ensure mission, vision, values and objectives	Engineering techniques (JIT, SPC, etc.)	Engineering techniques (JIT, SPC, etc.)
		Gain political sponsorship	Institute importance based reporting procedure	Institute importance based reporting procedure
		BPR	Retain data at work place	Retain data at work place
			Time/cost based management	Time/cost based management
Supplier Relations:		SINGLE SOURCING/SELECTION OF BEST SUPPLIER(S)	SINGLE SOURCING/SELECTION OF BEST SUPPLIER(S)	SINGLE SOURCING/SELECTION OF BEST SUPPLIER(S)
			Control Inventory	Maintain stock levels [supply as required]

Figure 3 (continued): Principles for WCM in the aerospace sector

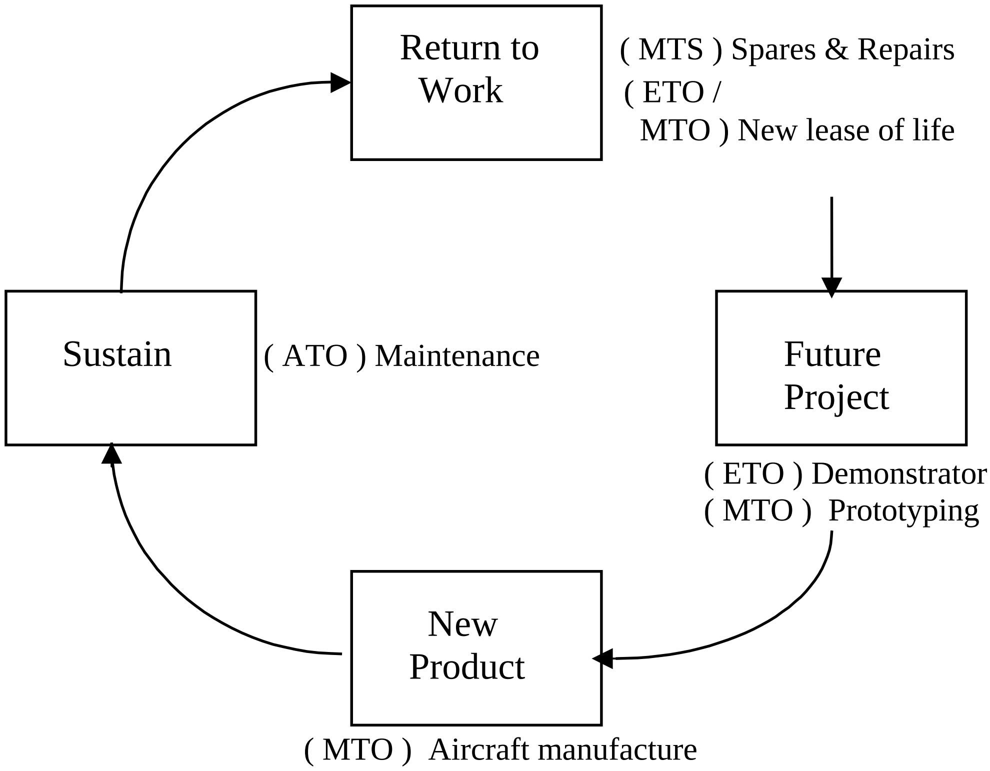

Figure 4: BAE SYSTEMS' manufacturing life cycle

		Future Project (ETO)	New Product (MTO)	Sustaining/Return-to-Work (ATO)
Customer Relations :		GET TO KNOW THE CUSTOMER:	COLLABORATE WITH THE CUSTOMER:	COLLABORATE WITH THE CUSTOMER:
		Conduct market research/ Customer surveys - gain feedback	Make customer a priority/ Organise by customer	Make customer a priority/ organise by customer
		Predict customer requirements/ Understand customer needs	Get close to customer & involve in design process	Offer after sales support
		COLLABORATE WITH THE CUSTOMER:	PROMOTE IMPROVEMENT AWARENESS:	PROMOTE IMPROVEMENT AWARENESS:
		Customer involvement in design process	Promote customer awareness of improvements	Promote customer awareness of improvements
		Customer contact at all design/manufacturing levels	Obtain customer feedback/ communicate, be honest	Obtain customer feedback/ communicate, be honest
		Benchmark against customer needs		
		ENSURE VISIBILITY OF COMPETENCIES		
		Promote key skills and abilities		
Use of Technology:		PROCESS ENGINEERING DEVELOPMENT	ORGANISATION WIDE TECHNOLOGY STRATEGY	ORGANISATION WIDE TECHNOLOGY STRATEGY
		Develop technology for function	Process Engineering development	Process Engineering development
		Place emphasis on development for future capability	EVALUATE TECHNOLOGY NEED:	Maintain existing before purchase new
		Continually research new concepts/levels of technology	General automation	
		Propagate technology and liaise continually	EDI, computer aided management & comms.	
			CAD/CAM, CAP techniques	
			Rapid Prototyping	
			MRP/MRP II	

Figure 5: The revised principles for WCM in the aerospace sector

		Future Project (ETO)	New Product (MTO)	Sustaining/Return-to-Work (ATO)
Work Force Relations:		EXPLICIT HRM STRATEGY	EXPLICIT HRM STRATEGY	EXPLICIT HRM STRATEGY
		Clearer leadership structure/ clarify management role	Learning culture /“Invest in people”	Learning culture /“Invest in people”
		Definition of task and function	Continual training & development, Equal opportunity	Continual training & development, Equal opportunity
		Communication and collaboration amongst projects	Empowerment	Empowerment
		Learning culture /“Invest in people”/Involvement schemes	Job rotation/multi-skilling/ flexible work force	Job rotation/multi-skilling/ Flexible work force
		Integration with process and technology issues	Ensure effective communication	Ensure effective communication
			Use of skilled contract labour / secondments	Use of skilled contract labour / secondments
Quality Assurance:		QUALITY STANDARDS & AGREEMENTS	QUALITY STANDARDS & AGREEMENTS	QUALITY STANDARDS & AGREEMENTS
		‘Quality Functional Design’/TQM/Kaizen concepts	‘Quality Functional Design’/Conformance testing/quality inspections	‘Quality Functional Design’/Conformance testing/quality inspections
		Integration of quality with technology and processes	Agree quality issues with customer	Agree quality issues with customer
		Quality training	Feedback to/from operators on quality/ Quality awards	Feedback to/from operators on quality/ Quality awards
				EXPLICIT HRM STRATEGY

Figure 5 (continued): The revised principles for WCM in the aerospace sector

		Future Project (ETO)	New Product (MTO)	Sustaining/Return-to-Work (ATO)
Process:		CONCENTRATION ON CORE ACTIVITIES	CONCENTRATION ON CORE ACTIVITIES	CONCENTRATION ON CORE ACTIVITIES
		Analyse, identify, realise, need for change, reinforce & institutionalise change	Work in progress/lead time reduction, shortest throughput	Maintain existing practices and methods
		Ensure mission, vision, values and objectives	Concurrent engineering techniques (JIT, SPC, etc.)	Work in progress/lead time reduction, shortest throughput
		BPR - Integrate customer & business requirements	Integrate customer & business requirements	Concurrent engineering techniques (JIT, SPC, etc.)
		Identify & institute performance measures	REDUCE FLOW OF INFORMATION	Institute importance based reporting procedure, Retain data at work place
		Gain political sponsorship	Institute importance based reporting procedure	Time/cost based management
			Simplify the work area/ Retain data at work place	
			Time/cost based management	
Supplier Relations:		SELECTION OF BEST SUPPLIER(S)	SELECTION OF BEST SUPPLIER(S)	SELECTION OF BEST SUPPLIER(S)
		Share product development concepts	Communicate and trade ideas	Focus on improving and maintaining supplier relations
		Co-operate as much as possible	Focus on improving supplier relations	Single source where appropriate
				Maintain stock levels [supply as req.]

Figure 5 (continued): The revised principles for WCM in the aerospace sector