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Cellular manufacturing applications in MRO operations

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Abstract

Cellular manufacturing delivers improvements in productivity, lead time and quality. Maintenance Repair and Overhaul (MRO) customers require shorter turn-around-times and reductions in price. The application of cellular manufacturing concepts offers the potential to deliver Original Equipment manufacturing levels of productivity improvement and lead time reductions to MRO operations. Six businesses that practice MRO operations were evaluated to establish the extent and benefits of the application of cell manufacturing techniques to MRO operations. They all reported benefits in turn-around-time and operational performance. All businesses also noted that the difficulties associated with implementation and management of cellular MRO systems related to the variability of input conditions.

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Keywords: MRO; maintenance; repair; overhaul; cell; cellular; productivity

1. Introduction

This paper describes the outcome of a feasibility research project to determine the extent of adoption of cellular manufacturing concepts to Maintenance, Repair and Overhaul (MRO) operations; as a means to drive productivity improvements and the potential for further application. To identify the extent of application of cellular manufacturing concepts to MRO, six companies practising MRO operations participated in the project. Each company agreed to an interview where an unstructured approach, using an issue focus [1], was used to identify aspects that enabled or hindered the adoption of cellular concepts to their MRO operations and benefits resulting from the implementation. The interviews were recorded and notes made about aspects relating to cellular concepts in MRO were made. Key points relating to cellular concepts applied in MRO operations were identified and tabulated. Rigour in this research was ensured by following the guidelines suggested by Coghlan [2], by engaging in steps of multiple cycles to reflect a true representation of what took place, and by challenging and testing assumptions and interpretations of what was happening. The findings are discussed in light of the literature and a number of research areas proposed to further develop the research in this area.

2. Maintenance Repair and Overhaul

Maintenance repair and overhaul is a broad term that includes actions necessary to ensure operability of equipment. The European Federation of National Maintenance Societies defines maintenance as the combination of all technical, administrative and managerial actions during the lifecycle of an item intended to retain or restore it to a state in which it can perform its required function [3]. Overhaul is where equipment is checked for wear and failure and returned to an acceptable level of operation that may be less than, equal to or greater than the Original Equipment (OE) build standard.

3. Cellular manufacturing

Lean manufacturing can be described as production initiated by customer demand (pull production) using systems that minimize waste. Cellular manufacturing takes this

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principle and applies group technology concepts to create a system that takes advantage of similarities in the components, processes or products to deliver benefits which include setup time, reduced work-in-progress and inventory, reduced throughput time, reduced material handling costs, improved product quality and simplified scheduling [4].

Cell manufacturing is defined as 'a group of closely located workstations where multiple, sequential operations are performed on one or more families of similar raw materials, parts, components, products, or information carriers. The cell is a distinctive organizational unit within the firm, staffed by one or more employees, accountable for output performance, and delegated the responsibility of one or more planning, control, support, and improvement tasks' [5].

Cellular manufacturing is well established in production with significant improvements in productivity, lead time and quality being achieved [6]. Improvements in material movement, work-in-progress, cycle times, space utilization, and productivity have been achieved [7]; some delivering multi-million dollar gains over a two year period [8]. Early adoption of cellular systems using group technology ignored the human aspect of cell design and implementation, and consequently did not achieve significant gains [9]. A sociotechnical systems approach to cell design and implementation extends Wemmerlov and Hyer's part family / machine group model [10] to include social dimensions of cell design and implementation. A sociotechnical approach ensures a sound framework for effective and sustainable cell systems [11]. A complementary match between technical and social systems is needed to ensure optimization of cellular manufacturing systems. Planning, job analysis, selection, training, reward structures and employee relations may influence the success of a cell implementation [12]. With increasing product complexity and requirement to drive manufacturing flexibility, scheduling in cell based layouts can be optimized to further improve performance [13]. Cellular manufacturing has been widely applied to deliver significant productivity improvements in industry [14]. Many companies successfully compete through cellular manufacturing [5].

4. Manufacturing and MRO

In MRO operations, cell systems are beginning to be adopted but numbers of implementations are low and the extent of application is much less than in the area of OE manufacturing. There are a number of significant differences between the two areas that inhibit a simple transfer of cellular manufacturing approaches to a cellular MRO operation.

In manufacturing operations, the product is created and subsequently consumed at some point after the manufacturing operation. In MRO creation and consumption are mainly concurrent in that the product is the MRO service activity. There is not the same opportunity to store product unless a service exchange approach is adopted. In OE manufacturing there is generally a higher specification required than for a repair operation. In some cases, an MRO operation cannot maintain OE build tolerances, but operates to an "acceptable" level that may have external accreditation. The manufacturing process is repeatable and generally process based. The MRO process has variable work content and may require different processes at different times to deliver the same result.

Manufacturing uses specific materials and a specified process that delivers defined and repeatable outputs. With MRO the output condition is known, but the start conditions are unknown until the task commences. One MRO manager described managing this issue as making MRO operations "a bit sporting at times". The key differences between OE manufacturing and MRO operations are outlined in Table 1.

Table 1 Key differences between OE manufacturing and MRO

Characteristic	Production	MRO
Process	Multiple component input to the process and one product output	One main input that is also the output from the process
Input requirements	Clearly defined. Repeatable.	Variable. Defined at the outset of the process
Process	Clearly defined with little variation	Variable depending on input conditions
Work content	Fixed for each repetition Clearly defined as SOP	Variable depending on input conditions
Tacit knowledge	Less relevant as SOP defines process requirements	Applied depending on input conditions
Output Tolerances	Defined by design requirements	Defined by operational requirements
Product	Able to be stored against future demand	Consumed as it is created
Output	Clearly defined tangible product created from components	Output requires end product as input
Work systems	Standardized and clearly defined	Variable depending on condition of input

5. Research activity in cellular MRO

Lean is beginning to be adopted in MRO [15]. Lean has been applied to remanufacturing previously by Amezquita and Bras [16], but they did not specify cellular applications. Talukder and Knapp [17] modelled and analysed grouping of preventative maintenance equipment into overhaul blocks using group technology (GT) principles. The authors claimed that these concepts had not been applied in this manner to date. Mathaisel [18] developed a lean enterprise architecture (LEA) specifically for enterprise-wide transformation in the MRO industry. Mathaisel suggests that cellular design manufacture is described as 'very useful to the transformation of an industrial enterprise' [18]. The LEA concept was originally created for the United States' military aerospace industry [19]. Military readiness is dependent on its ability to operate and maintain systems requiring a flexible, responsive and robust organic depot maintenance repair and overhaul (MRO) capability. One of the major areas that was key during a lean transformation was an infrastructure that supported lean/cellular operation. The use of cellular design was typically applied to these applications. Ford and Gadkari [20] reported a lean/cellular implementation in the form of portable equipment for maintenance painting in military

aircraft with significant labour cost savings in the order of $140k per year. Benefits in cost, throughput speed and reliability have been reported by applying lean engineering practice through cellular units in commercial MRO environments [21]. Benefits reported included a turn-around-time (TAT) improvement of up to 5 times, reducing from 150 to 30 days. Another lean implementation in an MRO enterprise using product family cells, reports sustained 39% labour productivity improvement, an 85% reduction in work in progress, 91% reduction in overhaul lead time, 68% reduction in floor space and a 74% throughput improvement [22]. Srinivasan et al [23] described the case of Warner Robins Air Logistics Center (WR-ALC), an MRO specialist, streamlining their operations. The WR-ALC had already implemented some lean initiatives, including cell teams to improve their TAT. Further work delivered critical chain project management for MRO scheduling and achieving a further reduction in WR-ALC TAT. Specialist automated inspection and repair cells for aircraft composite structural parts have been developed [24] to optimise operations and reduce labour costs by 30%. Development of cells for engine machining repair operations involving lasers and CNC machinery have been also reported [25]. Hunter and Black [26] described the implementation of manufacturing and remanufacturing cells at a large overhaul facility serving naval helicopters. The extant system was a typical job shop with batch and queue production methodology. Annual demand was around 12,000 different components, with demand difficult to predict. A cell for remanufacturing was implemented. It took nine months from start of cell design to steady state production. TAT dropped from 79 days to 11 days; a 77% improvement. Inventory reduction of 37 days represented a saving of $550k. In addition floor space was saved and productivity improved from 48 to 23 hours required per component. The use of a cell within aircraft repair that used Operations Research to improve supply chain management at the U&S Coast Guard Aircraft Repair and Supply Centre delivered inventory reductions of 20-70%, cost savings of 10% and 50% increase in throughput time [27].

Outside aircraft MRO, ship repair and maintenance using “virtual clusters” as a cellular layout has been suggested [28]. Unlike the classical cell approach, virtual cells relax the co-location requirements for machines that are grouped into physical cells. The adoption of lean principles in the form of maintenance work cells is suggested for the plastic moulding tooling industry [29]. Design and implementation of a lean remanufacturing cell is described by Hunter and Black [30]. The authors describe the implementation of manufacturing and remanufacturing cells at a large overhaul facility serving naval helicopters, where significant improvements were realized in turn-around time, inventory, floor space and productivity. Application and analysis of group technology principles have been also reported in the mining industry to effectively plan and conduct complex preventive maintenance routines [31]. The benefits of this approach are optimized inventories and the creation of standard unit work guides.

5.1. Application of cellular concepts to MRO

There is a general acceptance that lean alone is insufficient to achieve company goals and that it must be combined with other tools. The ‘newness’ of this paradigm to the MRO sector means many practitioners are still experimenting with lean principles [15]. Implementation of an MRO cell, although outwardly similar to a regular cell, is considered to be an order of magnitude more difficult to implement than traditional manufacturing implementations [30].

There is relatively little in the academic literature relating to the application of cellular concepts to MRO operations. The application of cellular concepts in MRO operations remains relatively unexplored although practitioner developments indicate that the concepts are beginning to be exploited.

6. Application of cellular concepts to MRO operations in practice

A number of companies already adopt some aspects of cellular concepts to their MRO operations. This is more prevalent in aerospace. Standard Aero, organizes workflow in its Cincinnati facility in 13 integrated teams and cells. This facility is set up to provide each cell with the appropriate tools, processes and expertise to ensure efficiency and to minimize time for completion and transition between functions. Standard Aero markets this capability as a competitive advantage [32]. Zone (cell) based maintenance is adopted by some static facilities as a means to improve maintenance efficiency [33,34].

Within the UK, a number of MRO operations participated in a research project to determine the extent and benefits of applying cellular concepts to MRO operations. The companies participating in this research project are noted below.

6.1. Company A

Company A is an international engineering company manufacturing and supporting components and sub-systems for aerospace, defence and energy. The UK facility operates MRO operations on wheel / tyre assemblies and brake systems for aircraft. The organization has adopted cellular concepts in the tyre and wheel overhaul. The MRO operation on brake systems has been prepared but has not yet been implemented. The company had previous experience of delivering these benefits from adopting cellular manufacturing concepts for their production facilities. Within the MRO side of the business reliability in meeting delivery times is a key competitive advantage.

6.2. Company B

Company B is a global engineering company specializing in high performance components and sub-systems for aerospace, defence and energy. Company B’s Singapore facility is a low volume MRO provider. It is a small scale version of the UK operations but has a broader product range;

wheels, brakes, engine valves, engine heat exchangers, sensors and electronics. The company recently moved into a new facility to accommodate growth in demand, and this was used as an opportunity to re-evaluate the MRO operations. The processes were mapped to determine the wastes and it became clear that in the majority of cases a cellular approach was able to deliver a more reliable and effective system. The facility was set up with 10 cells. MRO operators move between the cells to flex the capacity in each cell. Lean techniques were applied to support the cellular implementation. Shadow boards and a visual factory support the cell operations.

6.3. Company C

Company C is an international airline operator whose core business activity is operation of a fleet of long-haul aircraft. The MRO operation is a supporting function for this business. The MRO facility is based in the UK and provides support up to a "C" check. The activity is mainly "A" check and casualty work.

The Business Improvement Manager applied line maintenance techniques to the hanger maintenance. Zones (or cells) was created on the shop floor. Technicians are allocated to tasks in each of the zones; undercarriage, engines etc. Unnecessary movement, such as walking up and down stairs to collect documentation, tools, materials, etc, was removed by clustering these in the physical location of the zone. All necessary approved data is held on the shop floor. Visual management was adopted through the use of easily seen indicators. Each cell team is allocated defined packages of work, with defined completion times. The Manager was able to observe the Boeing 737 build system whilst in the USA. The zone/cell concept was developed based on this system.

6.4. Company D

Company D designs, manufactures and supports fuel pumps and electronic control systems for aerospace applications. There are around 350 people employed at the UK facility in total, with 100 to 150 in fuel pump repair and overhaul, and 150 in electronic control systems repair and overhaul. The remainder work in support functions.

The MRO cellular concepts grew out of the steps the company had taken in implementing cellular systems to their OE manufacturing. The MRO facility is divided into two large cells, one for fuel pumps and one for electronic control systems. The MRO Cell system was started around 10 years ago and the cells have been self-contained since around 2006. As the system developed, support functions, dedicated so support is on tap were added. Improvements are in place to remove waste, eg travel for components, rationalizing processes (aircraft industry standards). TAT, although improved, has not seen 'massive' benefits, as scheduling is still an issue for the system. The cellular structure has contributed to a significant improvement in quality and reliability of the product.

6.5. Company E

Company E is a stand-alone Aircraft MRO and aviation services provider. The Airworthiness & Design Manager and the Director of Commercial & Sales participated in the interview. MRO operations are key to maintaining a competitive advantage for Company E. TAT, quality and delivery performance are key measures of success in this arena. The company is developing a cellular approach to the MRO operation. The company deals with multiple aircraft types, so cells based on aircraft type are not appropriate. TAT is the most critical customer issue. The change programme is part of a strategic initiative that is a business wide response to changing market conditions and aims to create a competitive advantage in the market for Company E.

6.6. Company F

Company F is a specialist aerospace fabricator. It has been established for around 70 years and employs 30 people. Capabilities include hydroforming, sheet metal working and welding. The Managing Director of Company F participated in the interview. Company F operates an MRO cell. The business is essentially a low volume facility. The cell is equipped with all materials and quickly accessible tools and materials. Demand is very erratic, with no steady flow of work. The adoption of a cell based MRO operation was based on pervious knowledge the Managing Director had regarding cellular manufacturing. The business also takes a cellular approach to fabricating MRO parts.

7. Findings

A number of common themes emerge from the analysis of interviews held with each business. All companies, to a greater or lesser extent, indicated that the cellular system had been set up with reference to an OE cellular manufacturing system. For some it was based on prior experience an employee had with other businesses, for others it was the company's own OE manufacturing operations. This indicates that the concept is being applied with an OE manufacturing environment in mind. This variability of input created problems with scheduling of remedial work, variability of cycle times, availability of materials and equipment for remedial work, after the input conditions were identified. As all participants indicated that the issue of variable inputs created problems in subsequent process, it is clear that this problem, where OEM has consistent inputs and MRO has variable input conditions, has yet to be addressed.

All businesses achieved some benefits in TAT and operational performance. For two businesses, Company B and Company D, the cell teams had developed continuous improvement (CI) actions and a culture that supported and encouraged CI activities. Again this resonates with the experience of OEM cellular implementations. For four companies, cellular MRO was perceived as a strategic competitive advantage rather than a tactical operations improvement. For two businesses, Company E and Company

B, the design and development of a cellular approach was a part of a broader strategy to create a competitive advantage by re-designing the business operations. Company B indicated that the cellular layout acted as a showpiece for potential customers to create a favourable impression of the business and its capabilities. These implementations were driven from top management as a strategic action rather than within the operations community as an operational improvement. All companies reported that they foresaw the cellular implementation as a first stage, and that they envisaged further development of their cell system to further drive improvement. For five of the businesses, work scheduling was noted as a problem area, resulting in the main from the variability of input conditions, but also due to the lack of notice received from customers for MRO work. The cell system was described a facilitating a faster response in these cases than for a more traditional system. For two businesses, Company E and Company F, a capability to reconfigure the cell system to facilitate a number of platforms was noted as a potential and desirable improvement. Company E noted that management of the tacit knowledge required to manage the input variability was an issue that required addressing. A summary of key findings from the participating companies is shown in Table 2.

Table 2 Key findings from participating companies

Company	Cells set up due to previous knowledge of cellular manufacturing	Gains made in TAT	Gains made in operating costs	Continuous improvement developed from cell system	Cellular MRO seen as a competitive advantage	Further development of cellular MRO required	Scheduling considered an issue	Tactical decision to implement cellular MRO	Strategic decision to implement cellular MRO	Input conditions cause variability of cycle time and operation type	Ability to reconfigure cell for different platforms desirable
A	✓	✓	✓			✓		✓		✓	
B	✓	✓	✓	✓	✓	✓	✓		✓	✓	
C	✓	✓	✓		✓	✓	✓	✓		✓	
D	✓	✓	✓	✓		✓		✓		✓	
E	✓				✓	✓	✓		✓	✓	✓
F	✓		✓			✓	✓	✓		✓	✓

8. Discussion

Variability of input conditions, including areas requiring remedial action and the extent of the remedial action, created subsequent problems with variation of work content required and with corresponding cycle times. In addition, the requirement for materials and equipment to effect the remedial action was not known until completion of the initial exploration of the input conditions. This assessment of input, or level of degradation from the required operating standard, determines subsequent actions and workload.

Implementation of all cell based MRO systems observed was guided by OE cellular manufacturing approaches. In some cases this was based on the company's experience of OE manufacturing using cells, or on individual employees' experience of OE cellular manufacturing. Some aspects of cell design are likely to be common to both OE manufacturing and MRO operations. For example, engaging the workforce and ensuring they participate in the cell design is considered to be a key aspect of a successful implementation for both OE manufacturing and MRO operations. As implementation was based on knowledge or experience of existing cellular manufacturing systems, there was no template for design, implementation or management of a cellular MRO system. At first glance, manufacturing and MRO appear similar enough that cellular manufacturing systems principles can be applied. However, the nature of MRO, the variable input conditions, the relative lack of knowledge about the input conditions until the work commences, the capture and reuse of tacit knowledge, all contribute to making the implementation more complex. This view is supported by research into adoption of cellular MRO systems, where it was stated that although "outwardly similar to a regular cell, the remanufacturing cell may be, in some applications, an order of magnitude more difficult to implement" [26].

There is little literature on the design, implementation and management of cellular MRO systems. The MRO applications observed represent copies of manufacturing operations, using similar application of as applied in OE manufacturing. There is clearly scope to consider radical system re-design as part of an MRO cellular implementation that could deliver significantly more benefit than is realized by simple clustering of like processes and components. One area that could deliver additional benefit is clustering the MRO system based on failure types. OE cellular manufacturing tends to group by product, process of component similarities. MRO operations could be grouped based on failure modes, on input conditions or on work content and type identified when the level of input variability is determined. With this variability of input as compared to OE operations, and the consequent variation in workload, materiel requirements and work content, the cellular concepts would need to be developed to accommodate these.

Realization of OE manufacturing levels of performance improvement is possible by developing cellular concepts that are applicable to the particular environment of MRO operations. The key issue is the identification of the input variables and subsequent structuring of the post-assessment processing to effect the MRO operations. There is a gap in knowledge about the application of cellular techniques to MRO operations. By developing knowledge about the design, implementation and management of cellular MRO systems there will be an opportunity to support the widespread adoption of such systems across MRO operations, through

consultancy, training and applied research. With the potential growth in MRO operations, there is clearly scope to drive productivity improvements that deliver revenue and bottom-line benefits to MRO businesses.

9. Limitations and Future Research

A small number of companies participated in the research and the focus was aerospace. A broader spectrum of MRO operations and larger number of participants would allow the collection of richer data. Data gathering was based on unstructured interviews using an issue focus. The next stage would be to refine and focus on specific aspects of cellular design, for example, clustering type, managing input variability, aligning OE and MRO standards and scheduling improvements, to provide a greater depth of understanding of the implementation and operational issues. The examples cited by the participants as their OE manufacturing template were not evaluated. It is likely that each of the OE cell system may have had some limitations to their effectiveness imposed as part of design or operational constraints, which would have influenced the adoption of the respective cellular MRO system. An evaluation of the exemplar OE cell system would inform the key aspects being used to develop the cellular MRO design. Implementation of cell based MRO systems requires careful design to consider how the input conditions are determined and how subsequent remedial work can be optimized.

10. Conclusion

There is growth potential in the global MRO market. To enable a competitive advantage in MRO operations, the application of cellular manufacturing concepts is beginning to take place. Several MRO operations using cell-based systems were evaluated to determine the issues associated with design and implementation of a cell-based MRO system. Findings indicated that improvements were realized from the adoption of cellular concepts to MRO operations, but that managing the input variability was a critical aspect of effective system design. This input variability influenced, labour, material, equipment, knowledge requirements and influenced the scheduling of post-assessment operations. Input variability is a key difference between MRO and OE cell based operations.

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