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LEAN THINKING CONSTRAINTS IN TRADITIONAL BATCH MANUFACTURING ENVIRONMENTS

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Abstract:
Innovation through the use of improved technology and methodology is becoming increasingly essential for repetitive manufacturers and lean production methodology encompasses the organisational structure, systematic education and training, and the use of sound manufacturing principles. This research paper describes scenarios where demand at traditional batch oriented manufacturing plants is increasing rapidly and they must look for ways of improving capacity and throughput, minimising inventory and reducing set up and lead times. This case study based research has applied the techniques of observation, participation and interviewing to appreciate the constraints of traditional batch manufacturing in the present day manufacturing environment. Results show that attempts to apply certain manufacturing ideals were in conflict with existing traditional, batch oriented practice associated with production of a large variety of product mix and components. Critical aspects of production studied processed product types in batches using the same machines, with resultant increase in bottlenecks and queuing in downstream operations and consequently affecting set operational targets and customer due date for delivery

Key Words: Lean thinking, Batch Manufacture, Single Piece Flow, Engine Blades

1. INTRODUCTION

To remain sustainable and rapidly respond to increasing demand, organisations must continually look at ways of improving capacity while reducing lead times. As 'lean manufacturing' has become the minimum requirement for competitiveness in industry, there has been a surge of interest in control policies for manufacturing systems that combine high service levels with low inventories. This is highly desirable even if a system is unreliable and its demand erratic [1].

Today's operations management environment is very different from what it was just a few years ago. Customers demand better quality, greater speed, and lower costs. In order to succeed, companies have to be masters of the basics of operations management. To achieve this many companies are implementing a concept called lean systems. Lean systems take a total system approach to creating an efficient operation and pull together best practices concepts. This includes concepts such as Just in time (JIT), total quality management (TQM), continuous improvement, resource planning, and supply chain management. The need for increasing efficiency has also led many companies to implement large information systems called enterprise resource planning (ERP). ERP systems are large sophisticated software programs used for identifying and planning the enterprise wide resources needed to coordinate all activities involved in producing and delivering products to customers.

Traditional batch manufacturing environments focus on a production philosophy, which runs as large a batch as it is economically feasible on one equipment or group of equipment in order to achieve maximum cost, labour and time efficiency. This manufacturing philosophy seems to foster process departmentalization in that similar processes are grouped into departments to maximize common process capabilities [2] (Brown, Collins and McCombs, 2006). Unfortunately, poor quality, rework, out of specification variation and scrap are inherent characteristics of traditional batch manufacturing detectable only at downstream departments.

This case study based research was industry led with a major objective to introduce lean thinking ideal to a multinational enterprise that is still producing large volume and variety of jet aircraft and industrial gas turbine engine blades and vanes by traditional batch manufacturing techniques.

The objectives of the investigation, therefore, are to;

- study the flow and pattern of manufacture of a variety of large engine components
- maximise process throughput and therefore eliminate bottlenecks in production
- optimise energy, conversion and inventory costs as well as meet customer requirements by recommending either batch or single piece flow or a mixture of both in manufacturing operations
- optimise inventory levels

1.1. Scheduling and Planning in a Batch Manufacturing Environment

In a typical multiple batch processing situation several different types of items are to be processed on one set of facilities. The advantages of this approach are cost minimisation, equalisation of runout time, increase in production rate and optimisation of processing time. However, situations may arise when items, which must be processed on a facility require a different type of set up. In this scenario, more than one output is competing for the same facilities, inventories of the various outputs are used up and produced at different rates creating differences in economic lot sizes. Uzsoy (1994) [3] and Azizoglu and Webster (2000) [4] have studied scheduling of batch processing machines with non identical job sizes to minimise total completion time and makespan. In another paper Uzsoy (1995) [5] has described the scheduling of batch processing machines with incompatible job families developing efficient optimal algorithms to minimise makespan, maximum lateness, and total weighted completion time. However, these approaches to batch processing fail to tie up production with demand leading to excess inventory, and associated costs. Processing a variety of product mix in a batch oriented environment increases waiting time and prevents the attainment of set operational targets.

In repetitive batch manufacturing, queue time is generally the longest element and often represents a high percentage of the total throughput time (Bauer et al 1995) [6]. Queues occur because jobs wait before being processed and queue time is proportional to the amount of the work in progress. To reduce the queue it becomes necessary to reduce the work in progress. The key to manufacturing flexibility is in reducing the batch sizes. However, while smaller batches minimise inventory and make planning easier through reducing the unpredictability of capacity bottlenecks and allowing for the use of simple production control techniques they increase the number of set ups. While frequent set ups are necessary to produce a variety of goods in small lots, this advantage can only be fully appreciated through minimising of set up and changeover times (Shingo, 1985) [7]. These conflicts in a batch manufacturing environments need to be explored to optimize on lean approach to manufacturing.

Brown, Collins and McCombs (2006) [2] have researched on the performance issues associated with transformation from batch to lean manufacturing using the Leansigma transformation methodology. As a result of the transformation they reported increased productivity, lower set up times and less space required for manufacturing. Leansigma is thought to combine several leading edge manufacturing management philosophies producing a comprehensive methodology that can be used to achieve a lean enterprise. Amongst Leansigma philosophies are value stream mapping, kaizen, layout redesign for lean, just in time manufacturing (JIT), total productive maintenance (TPM) and six sigma. Doolen et al (2006) [8] has developed scorecards for supplier performance improvement suitable for application in a lean manufacturing organization. The scorecards would provide engineering managers with information to appraise the performance of suppliers in a lean enterprise.

1.2. Lean Thinking and World Class Manufacturing

Lean thinking is a manufacturing ideal that was pioneered by the Japanese Toyota Company and. lean production was coined to describe the concept called the Toyota production system. It was called lean because it used less when compared to mass production techniques - half the labour hours, half the factory space, half the tooling investment, and developed new products in half the time using half the engineering hours, while requiring under half the on site delivery, producing fewer defects, and a greater variety of products. The main concept of a lean approach is the elimination of " Muda ", a Japanese word which means waste; specifically any human activity which absorbs resources but creates no value. The definition of waste in the lean thinking approach can be written as any activity that does not specifically add value to a product in the eyes of a customer. Examples of this can be: the creation of mistakes that require rectification, production of items not required by a consumer, movement of employees and transportation of goods without specific purpose, workers in downstream operations waiting for parts to process, production of goods and services which do not meet the requirements of the customer.

The achievement of lean thinking ideal incorporates five key concepts; value to the customer, value stream operations, flow of value creating operations with minimal waiting time for batching and constant machine utilisation, pull concept and perfection aimed at waste minimisation. Wrapped up in this approach are manufacturing ideals such as Just in time production and Total quality management. The concept of lean thinking has been examined by Womack, and Jones (1997) [9] and again by Womack, Jones and Roos (1990) [10].

Brown et al (2006) [2] believe that a major obstacle faced in building a lean process is in the communication and response to the needs of the internal downstream customer and the practicality of one-piece flow. Communication and flows between downstream customer and upstream suppliers are critical.

Many enterprises have pursued the lean thinking paradigm to improve the efficiency of their business processes, however, more recently, the agile manufacturing paradigm has been highlighted as an alternative to, or an improvement on, leanness. It is thought that agile manufacturing is adopted where demand is volatile, and lean manufacturing adopted where there is a stable demand. Mason-James et al (2000) [11] and Naylor et al (1999) [12] have advocated the utilisation of a different paradigm on either side of the material flow decoupling point to enable a total supply chain strategy, the leagile paradigm.

World class manufacturing essentially means having the right production capability to make money from totally satisfying the customer, with high quality services and products at the right price delivered at the right time. Just in time, manufacturing resource planning, and total quality management are all techniques, which help to achieve world-class manufacturing. Burcher, Dupernex and Relph (1996) [13] have researched on the road to lean repetitive batch manufacturing, modelling and planning system performance. They described a methodology most relevant to manufacturers of repetitive batches to assist them in their journey to world-class manufacturing. They concluded that while lean production can be applied universally within manufacturing, the tools used to enable the philosophy need to be applied in a context sensitive manner. For instance in Toyota Production System there is increasing emphasis placed on worker awareness of, involvement in, and responsibility for the production processes. Team leaders are expected to participate actively in process improvements by identifying and eradicating non-value-adding activities. Each worker is expected to perform more than one task, each of which will be clearly defined and structured via standard working sheets and achieving the following objectives:

(a) Integrated single-piece production flow, with low inventories, and small batches made just in time
(b) Defect prevention instead of rectification
(c) Production pulled by the customer, employing level scheduling, rather than pushed to suit machine loading
(d) Team based work organisation with flexible multiskilled operators and few indirect staff
(e) Active involvement in root cause problem solving to eliminate all non value adding steps, interruptions and variability.
(f) Close integration of the whole value stream from raw material to finished product, through partnerships with suppliers and customers

Recently Abdulmalek, Rajgopal and Needy (2006) [14] have developed a classification scheme for the process industry to guide the implementation of lean. Parry and Turner (2006) [15] have applied lean visual process management tools in aerospace companies to facilitate performance measurement and communication in different engineering processes. They believe that visual control boards act as an extension to metrics and may be considered as a dynamic measurement system provide instant feedback and predict probable outcomes.

1.3. The Lean Temple Concept

Fig.1 shows the lean temple clearly demonstrating the concept of standardisation of working practice broken down into two major components - cost and quality principles, which constitute the two major pillars of the Lean production system reinforcing Kaizen principles.

2. RESEARCH METHODOLOGY

Data collection for this empirical research was conducted using five different techniques.
(a) Observation - This method was exploratory in order to appreciate the use of human, time and material resources and also to appreciate the process layout in this manufacturing environment
(b) Questionnaire - Enabled the collection of broad based data quantified for analysis
(c) Participation / Observation - This method was useful to validate and explain findings
(d) Interview - This method enabled the collection of in-depth data on critical operations
(e) Documentation - This method was essential for both data and information validation and clarification from the various sources

Based on the different methodologies adopted, data and information triangulation became feasible and therefore was useful for information substantiation and validation. The categories of personnel studied and interviewed were - machine operators and shop floor workers, production and quality engineers, supervisors as line managers for the different manufacturing departments and two top members of the executive

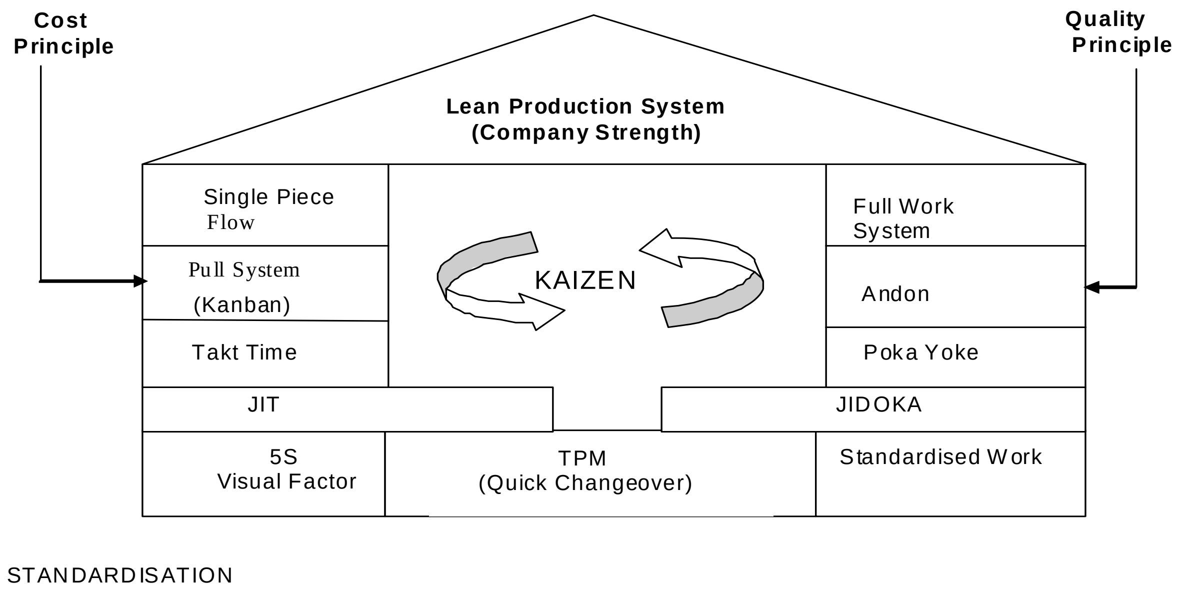

Figure 1: Lean temple concept.

2.1. Case Study

The case study reported here was industry led and supported by top management of this multinational manufacturing enterprise (Thompson et al 2000) [18]. The case company studied is a world leader in the production of super-alloys and titanium components for jet aircraft and industrial gas turbine engine blades and vanes. It specialises in the castings of solid single crystal, directionally solidified and equiax airfoils using the lost wax investment casting process. The castings are used for several applications, from military, helicopter and civil jet engines through to the largest industrial gas turbines currently manufactured. The company is growing rapidly and has more than doubled its volume in the past ten years. Customer demand at the vendor's manufacturing site has increased by 50% in two years. Unable to expand physically due to available space, the company is continually attempting to improve flow and production capacity, minimise waste, reduce cost and minimise lead times for customer orders. The company therefore, has attempted to veer away from the concept of mass production and introduce a lean approach to manufacturing at the factory. The production process itself, however, is in part highly capital intensive and technologically advanced, and for most operations is batch orientated. However, batch operations present major logistical and economic challenges in a one-piece flow environment

2.2. Flow Through the Manufacturing Plant

Turbine blades and vanes produced at the company are manufactured using the lost wax process. The different blades produced have different processing characteristics dependent on their size and structure. The size of the blades and vanes determines the size of the equipment to be used. Consequently, four broad product families are identifiable.

Fig. 2 shows the flow through the plant. Generally, each department deals with the different product families in separate processing cells but the basic principles of the operations are common.

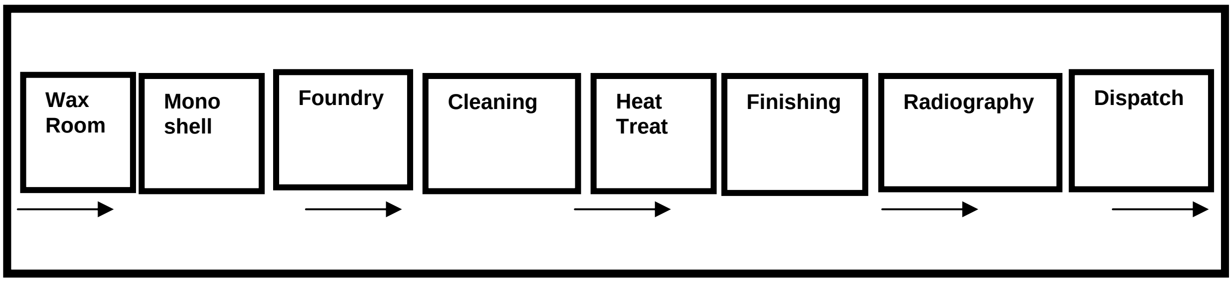

Figure 2: The layout of production departments.

Wax Room – Wax patterns with cores in the models are produced using a wax injection machine. The nature of the lost wax process is that the final product can be no more accurate than the wax pattern
Mono-shell – The clusters are dip coated by robots in up to twenty layers of slurry. Each layer is dried in a controlled environment before the next is applied.
Foundry – The moulds are preheated in a furnace for at least four hours and transferred to a casting machine and the alloy is preheated and poured into the mould under vacuum to avoid contamination.
Cleaning - The first stage involves the destructive removal of the shell, and then for some products batches are soaked in boiling caustic to dissolve the ceramic and then water blasted.
Heat Treat – The blades are loaded on to trays in different batch sizes, depending on the batch size they arrive in, and heat-treated according to customer requirements.
Finishing - The finishing process includes any final grinding that may be required as well as providing an overall finish to the blade. The customer specifies the exact requirements to which the department works.
Radiography – The blades undergo a series of X or Gamma ray inspections to ensure there are no defects. The exact method used and acceptable quality level are determined by customer.
Despatch – The blades are packaged in the number required and dispatched.

2.3. Definition of Sample For Study

This manufacturing environment has a very complicated production process with 250 possible different blade types produced, each with individual requirements, specification and routing. This results in many different permutations of the common activities and as such made scheduling very complicated.

In other to simplify the investigation in line with the set objectives it was decided to focus on samples of six families of blades. The choice of a product family for study was based on volume produced as well as the economic benefits for their manufacture. Table 1 shows the selected samples classified in terms of blade type, engine set size and engine sets produced per month. Thus the blades selected for modelling were the highest volume parts.

Table I: Sample engine blades showing set size and volume of production.

Blade Name	Engine Set Size	Engine Sets Produced per month	Average number of blades produced per day for a six-day working week
Blade A	96	8	32
Blade B	34	4	5.7
Blade C	55	2	4.6
Blade D	40	4	6.7
Blade E	40	3	5
Blade F	40	3	5

Three critical components of the production process, the foundry, cleaning, and heat treatment areas were chosen for study due to characteristic flow constraints encountered, and, therefore, would be amenable for study, improvement and possible incorporation of lean technologies. The chosen departments were running close to full capacity and therefore, were unable to cope with increasing customer demand.

2.4. System Constraints in Case Organisation

(1) Foundry – Flow within the foundry is a mixture of batch and single piece flow.

- Some of the product types are cast one at a time in dedicated furnaces while others are cast in batches in this department. Consequently single piece flow partly operates in this area.
- The flow of certain products within the foundry is limited by the preheat temperature and the casting weight of the products. This in effect causes single piece flow within batches.
- For a successful casting run with a minimum number of crucible changes (change overs) the largest blades have to be cast first, however if the preheat temperature between two batches of moulds were to increase by over 50 ^{0}C the furnace must be emptied before reloading the next components. This scenario therefore, requires the smallest blades to be cast first.

As a result of this conflict of interest, the flow of work through the foundry needed to be carefully studied, scheduled, and planned.

(2) Cleaning - This department’s capacity is particularly dependent on work mix from upstream operations and has always constituted a major constraint in the factory’s output. The continuously changing work mix has prevented an accurate schedule to be employed and becomes critical especially in a situation of increased demand for the vendor's products. The cleaning department therefore, is a major determinant of on time delivery to final customer.

(3) Heat treat – There are four main types of products that can be treated in this department and currently, such products are heat treated according to the batch size they arrive in while striving to meeting individual end customer requirements. This may sometimes necessitate outsourcing product families to other sites for further processing to achieve the desired specifications while striving to achieve on time delivery.

This study will now focus in detail on the cleaning department because of the critical position it occupies in both the supply and operations chain with a view to identifying individual cleaning processes that have a potential to cause delay to achieving overall target objectives in the factory. It will also examine how the operational problems in this transition department for most product families will affect both upstream and downstream processes as well as the implementation of the desired manufacturing ideals.

2.5. Operations Management in the Cleaning Department

The remit of the cleaning department is to remove the shell and core of components, if in place, remove any of the casting gates and pouring cups and ensure the blades leave the department in a condition suitable for further downstream processing. Generally, the mode of operation in this department is to collect a batch of blades irrespective of product family as delivered from the foundry, work on them individually, and then dispatch them from the department as a batch when the cleaning process is complete. Although they arrive as a batch to the cleaning department, some of the parts follow different processing routes due to their unique cleaning requirements. Consequently, the parts arrive the cleaning department as a batch then disperse to their next unique operations in single pieces.

Overall the mechanisms for cleaning involve the use of manual and pneumatic hammers, applying either a shell leach and water blast or a hanger blast depending on the product, grain etch and check (mainly for specific type of products), canning, core preparation, core removal, fibro scope inspection and quality inspection.

Analysis of the cleaning department was performed using a paper log, which records the component movement within the department. The planned route, planned date of completion (assumed to be realistic), the actual date of completion etc were included in the log. The time taken for the operation was compared with the allowed time and recorded in day units. Table II shows the blade type and sample size used for study.

Analysis was also carried out to determine the time taken to carry out individual operations within the cleaning department and the actual deviation from the planned time. This would enable an identification of the processes that would impede flow within the department. .

Table II: Blade types showing sample sizes used for study.

Blade Name	Engine Set Size	Sample Sizes Used	% Sample Size Used to Engine Set Size
Blade A	96	10	10.4
Blade B	34	5	14.7
Blade C	55	5	9.1
Blade D	40	5	12.5
Blade E	40	5	12.5
Blade F	40	5	12.5

3. RESULTS

Fig. 3 shows a plot of lag in days for the different cleaning processes. The deviation from planned completion time for each blade was averaged to give a batch average and then a blade type average. The time lag for the individual departments was combined to provide the average lag per department irrespective of blade. According to fig 3 the Fibre scope inspection in the cleaning department had greatest average deviation of 2.9 days. This implies that if a part required fibro scope inspection it would likely take 2.9 days more than the planned operation time. The results were subjected to a Parreto analysis which suggested that 80% of the waste was caused by 20 % of the deviations from planned activities. It is therefore thought that solving 20 % of the problems would drastically reduce the waste. According to fig 3 there were four main areas with flow constraints. Fibroscope Inspection, Wet cut off after HIP, Core Removal and Knock Off Hand. Together they accounted for over 55% of the total deviation from mean output. The core removal operation was responsible for an early delivery of 1.42 days, however,

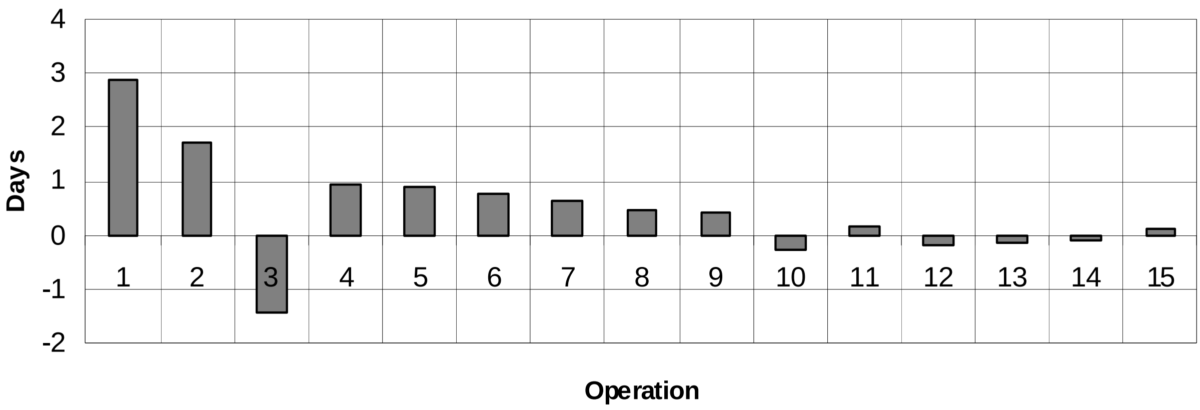

Figure 3: Plot of lag in days for different operations.

there are obvious penalties for any deviation, positive or negative. Naturally, the system would perform more efficiently with a just in time manufacturing ideal.

It is clear that there is a great deal of waiting time through the cleaning department as a whole because of the difference between the planned operation times and the actual times the parts spent in the department. The results showed that very few of the operations actually performed as expected.

Table III shows a listing of the operations in the cleaning department and the time lag associated with the different operations. The core removal process stage is easily the greatest constraint in the factory, which is as a result of frequent change in work mix (demand for both batch and single piece operations). In many cases the level of achievement at the factory is highly dependent on the core removal process. The core removal facility is a pure batching process for all blade families with the associated problems of capacity utilisation, cost and required output. In a lean production environment, it is assumed that batching operations can be tolerated if the change over time is limited to 10% of the processing time. The change over time in terms of downtime between cycles for core removal process is approximately 30 minutes assuming that the correct batch arrives during the processing of the previous batch. The processing times all seem longer than 5 hours with a 30-minute change over time (matching 10 % of the standard processing time). This theoretically means that the core removal process should have the potential to be incorporated into the lean single piece ideal. There is a potential for efficiency improvement if the engine blades were to be processed in batches of single piece flow so that an engine as a set would arrive at core removal at the same time. The fact that the order of the blades produced is not in the required batch size does have efficiency consequences, particularly for heat treatment processes downstream, however these can be measured against the economic benefits of single piece flow if this manufacturing option were considered for adoption.

Table III. Listing of cleaning operations showing the time lag for the various activities.

	Operation	**Lag in Days**
1	Fibroscope Inspection	2.90
2	Wet cut off after Hot isostatic press (HIP)	1.73
3	Core removal	- 1.42
4	O / P Hip	0.93
5	Grain Inspection	0.90
6	Clean inspection	0.79
7	Ferric Etch	0.66
8	Shell Leach	0.46
9	G/Etch Prep	0.42
10	Hanger Blast	- 0.26
11	Cut off Gates	0.18
12	Grind Gates	-0.16
13	Core Prep	-0.15
14	Blast	-0.09
15	Alloy Check	0.11

3.1. Analysis of Results and Recommendations

Study of the activities in the cleaning department showed that specific operations were compulsory for all the blade families notably; the knock off operation, alloy check, the hanger blast, the grain etch, and the inspection areas. Compulsory processing of all manufactured components at these stages would certainly constitute a queuing and backlog constraint. Also movement of the blades through the department in batches severely limits the ability of the department to implement single piece flow despite the fact that several of the machines could be configured to process individual parts.

The analysis also shows that there are obvious inefficiency costs associated with additional time spent moving parts to and fro the department in order to achieve occasional single piece flows where batch processing is predominant. Given that core removal is a typical batching process, it makes sense to move the blades into the area in batches in spite of single piece capable operations. It may be more appropriate to allow batching to prevail in the clearing department in spite of single piece flow capability.

- Batching Ethos in the Ceaning Department

Operations management in the cleaning department is fundamentally flawed in its ability to achieve the single piece flow ideal. This is as a result of the general mode of operation throughout the department, interfering with single piece flow by continuously applying batching and debatching operations. This batching ethos has become fundamental in the department and clearly contributes to bottlenecks caused by every operation This can be minimised by improving the standard mode of transportation in the department. It is therefore thought that the implementation of a single piece conveyor system would eliminate the batching related processes.

- Commonality of Machines in the Cleaning Department

Several of the machines in use processed a complete range of products, which caused a high waiting time. To combat the common machining problem there is a potential to right size the machines and implement different machines for separate product families.

- Requirements of Downstream Customer

There seems to be no facility in the cleaning department for determining the exact requirements of the down stream customer. This prevented any pull type operation occurring and therefore served to prohibit the possibility of a single piece flow. The rationale was that it was inefficient to travel the distance with only a small number of blades.

The vendor has a SAP system, which normally should provide real time information about the flow of parts throughout the factory. However, it is not being used to its fullest potential to assess and appreciate the factory's performance and productivity. If used appropriately it could then serve as a mechanism for the communication of downstream requirements. The system could enable the order of flow to be effectively governed by a pull in downstream operations and thereby making requirements available upstream through the other departments.

Uzsoy [5] has studied the problem of scheduling single batch processing machine with compatible job families where jobs of different families cannot be processed together in the same batch. He developed efficient optimal algorithms to minimize makespan, maximum lateness and total weighted completion time and applied the results to problems with parallel identical batch processing machines. It is not certain whether this algorithm can be applied in the traditional batch manufacturing setting with no efficient means of separating and transporting large components. It is also possible that certain production processes are too complicated to be software driven in this manner.

Burcher, Dupernex and Relph (1996) [13] also have developed a model to resolve batching problems identical to the case under study applying the following procedures;

- Bottleneck identification based on actual product mix and volume being planned
- Set up, and changeover times minimisation approach
- Capacity validation against sequenced schedule taking account of set up reductions gained through sequence dependencies
- Batch splitting
- Alternative routings

It is recommended that traditional repetitive batch manufacturers wishing to adopt lean thinking may well consider these concepts.

4. CONCLUSION

The adoption of lean thinking ideal in a repetitive batch-manufacturing environment will systematically pose a problem as a result of constraints and conflicts associated with bottlenecks impeding throughput, increased set up and changeover times, and poor capacity management. On the other hand improved process flow in such manufacturing scenarios can only realistically be achieved by minimising set up times, debottlenecking based on careful bottleneck identification and optimal capacity utilisation.

For instance the achievement of single piece flow and lean manufacturing ideal in the case under study in this paper is flawed due to inherent difficulties associated with compulsory batching processes initiated from upstream operations. This flow arrangement apparently cascades into the cleaning department where machines are used in common to process a large variety of product mix further exacerbating the already accumulated waiting and queuing times. The cleaning department in this instance sometimes therefore, behaves like a kanban with batches of families of components queuing to be processed. This high level of work in progress is due to the use of same machines for processing a large variety of product mixes. A carefully developed pull from the downstream customer could promote process flow. Meanwhile this objective remains partly unachievable without a radical restructuring of the process layout.

This preliminary study in a repetitive batch-manufacturing environment therefore, highlights the conflict associated with implementing lean ideal in a traditional batch manufacturing setting. The conflicts highlighted in this paper are also applicable to other old style manufacturing organisations that are still striving to improve their production efficiency in a fierce, customer focused, competitive business environment

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