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Implementing Cellular Manufacturing in a Make-to-order Manufacturing System: A South African Case Study

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***Abstract*--Make-to-order was formerly the single most utilised approach to produce high variety, low volume products. The result was that only the affluent buyer could afford the products. Mass production played a part in the accessibility to products but contributed to the loss of uniqueness of the products. With the introduction of mass customization uniqueness and accessibility were addressed. South African manufacturers are facing growing international competition from low labour cost countries. Lean manufacturing is seen as an instrument to increase competitiveness through continuous improvement. According to numerous research papers less than 0, 5% of an organisation's process operations are value adding. The majority of operations could be classified as waste. The paper addresses smaller production lot sizes and pioneering manufacturing approaches to increase competitiveness. The paper studies the design of a lean manufacturing approach in a make-to-order production system subjected to a considerable range of product types and with high-level of demand uncertainty. A production system utilising cellular manufacturing and line balancing were developed. Cellular manufacturing with a supermarket of parts is well suited for application in make to order manufacturing systems. A number of the seven wastes identified will be addressed.**

I. INTRODUCTION

South African organisations function in a highly unionised milieu which induces excessive labour costs. As an emerging economy, the South African currency is unstable and result in fluctuating productions costs. Cost escalation occurs because South African manufacturers must import raw materials and components. Import erodes the competitiveness of local manufacturers. South African manufacturers turn to Lean Manufacturing in increasing numbers in an attempt to become more competitive. The worldwide economic downturn makes it ever more important that South African manufacturers are able to compete internationally.

According to [3, 4, 6, 9, 10, 12, 14, 16, 17, 23 and 25] owing to an increase in worldwide competition, gaps were identified for diminished life cycles for goods, time to market and new consumers. As a result, modifications in fabrication techniques were assessed in enhancing response flexibility and efficiency of fabrication techniques. A number of fabrication techniques are in existence. They are mass production also known as flow production, batch production and job shop production. The job shop fabrication technique is characterised by a notable flexibility and low volumes. The fabrication technique is restricted in the manner fluctuations in demand and fabrication quantities are controlled. Fabrication techniques must regularly reconfigure before reacting to product design modifications, new product launches as well as product and demand volume fluctuations.

Corporations are loath in contemplating the original process options during conversion to lean. While numerous concerns stick to the mass production viewpoint, several adhere to the craft or job shop doctrine. Job shop businesses normally expect numerous impromptu changes to order rates. Process control is exercised at shop floor level to unequivocally execute essential operations. Made-to-order goods are habitually manufactured according to the job shop doctrine.

Various case studies were conducted; investigating suitability of the lean methodology in high variety, low volume businesses. It is postulated that the Lean Manufacturing methodologies accentuated, depend on the particular conditions in the business. The conditions embrace volume deliberations and variety provisos. A fundamental relationship linking inputs and outcomes have to be recognized for a successful conversion to lean. The fundamental processes of a production concern whether a job shop, make-to-order or mass producer, serve the role as the input variable.

Irrespective of the industry sphere, it is mandatory for manufacturing organisations to satisfy customer demand, enhance quality and reduce cost due to the incessant adjustments in the marketplace. The environment in which organisations operates at present is at best unpredictable. Regularly unparalleled and unexpected events transpire. Consequently, it has become obligatory for business executives to incessantly redefine operational performance and tactics.

Delivery of goods has to transpire at the right time, place, quantity and cost. A failing in any of these measures would seriously impede the competitiveness of organisations. Manufacturing abilities create the competitiveness of an organisation and conditions such as service, quality and cost are assessed. The conventional foundations of competitive advantages, high quality and low costs, have turn out to be deficient and organisations began to seek out new expertise to expand their primary capabilities.

The execution of a Lean Manufacturing approach permits the reinforcement of processes resulting in operational excellence and continuous improvement. Additionally, it contributes towards waste reduction in processes. Lean procedures contribute significantly to the functional management of the enterprise. The Lean ideology has facilitated the attainment of noteworthy monetary advantages while improving quality, cost and time imperatives. The Lean methodology is resolute in its recognition and eradication of waste in the manufacturing, product development and service environment.

Lean has developed into an extensively acclaimed perspective. The methodology aspires to diminish waste and non value adding actions enhancing performance in cost efficiency, compliance quality, efficiency, decreased inventory and process times. Lean is harnessed to enhance the flow of information and material. Waste originates principally from needless stoppages, tasks, costs and mistakes. The seven wastes of Lean include overproduction, transportation, inventory, processing, waiting, movement and rework. The principal pivot of Lean is the consumer. Consumers are willing to pay for value adding operations but not for non value adding operations.

II. BACKGROUND

Company A is an engineering organisation manufacturing an extensive range of products. The organisation is located in an industrial area in Johannesburg, Gauteng Province of South Africa. Company A is a subsidiary of an international manufacturing organisation. The organisation devotes organisational endeavours fulfilling the wants of clients continuously. The organisation distributes a catalogue, electronically on their website, listing the full range of pin-tumbler locks fabricated. In certain instances, products do not appear in the catalogue. It is as a result of special requests from customers.

For the purpose of the paper the research were restricted to the Pin-Tumbler lock department. The Pin-Tumbler Department assembles 9 different types of cylinders namely Expanda Cylinder, 2x18 Master Key Cylinder, 2x18 Standard Cylinder, 2x6 Standard Oval, 2x6 Master Key Oval Cylinder, 2x8 Master Key Oval, 2x20 Master Key ½ Profile, 2x19 Knob Master Key and 462 Cylinder Locks. The Cylinder section manufactures one basic model. From the basic model, different barrel pitches are inserted into the basic cylinder to meet customer demand. The pitch refers to the key cut for a specific key to open the lock it was fabricated for. Company A utilises the job shop fabrication technique and the make-to-order philosophy. Execution of a customer order commences with the receipt of an internal sales order (ISO) by the cell leader.

The ISO is raised by the Sales Department situated at the Head Office. The ERP system is utilised to capture orders. A due date is automatically calculated by the system utilising predetermined parameters. The parameters are 15 working days for ordinary orders, 5 days for turbo shipments orders and 72 hours for urgent orders. An ordinary order is an order with an order quantity in excess of 50. A turbo shipment is an order with an order quantity of 50 or less. An urgent order is an order for the repair on warranty claims from a customer. The order is repaired free of charge.

The sales office employees constantly amend order quantities or add line items to an ISO without informing the cell leader. The changes are discovered once sales office staff inquires why a partial delivery has occurred. As a result the order cannot be delivered to the customer. Often customers request amendments. Company policy dictates that the cell leader must be informed of any changes on the ISO. Unfortunately the policies are seldom adhered to in this regard. The result is production of incorrect parts and unhappy customers.

On time become late deliveries as a result. It is not uncommon for sales office staff to cancel an order after the order has been launched for assembly and work has commenced. The justification given is that the order is overdue and the customer is unwilling to accept late delivery. Shortly after the order has been cancelled a similar order is placed with the correct order quantity. In both instances, the sections capacity is negatively influenced and the management of orders are unnecessarily complicated.

Products are produced in a hybrid line assembly type system. A staff member would receive an order and assemble the parts to build the product according to the customer order. The staff member would complete the preloading for the entire order before it is forwarded to the next staff member in line. The process is known as pre loading. On completion of the pre loading phase, a second staff member would finish assembly process of the product and close the lock. The staff member completes the entire order before forwarding it to the next in line. A third staff member would test and package the lock individually.

The section utilises a Kanban system of inventory management. The Kanban is situated in an open area within the factory and all employees have unimpeded access to the inventory. Therefore is not uncommon that insufficient stock is available to assemble a complete order. Employees are allowed to remove components without official paperwork. There are no scientifically method utilised by which the Base Manufacturing section is informed that Kanban inventory is low and must be replenished. For the Kanban system to perform optimally, the inventory must be replenished on a regular basis.

It is rarely done and poor communications between the cell leaders does not help the situation. Presently it occurs on a regular basis that inventory of components is exhausted before the inventory is replenished. According to the cell leaders of the Cylinder, Padlock and Base Manufacturing sections they are uncertain whose responsibility it is to monitor the inventory levels. According to management the function should be a shared responsibility. Currently the shared responsibility for inventory levels is not practiced. The blaming game commences when shortages do occur.

If regular revision of Kanban sizes does take place, the Base Manufacturing section have to accomplish a large number of changeovers on a regular basis to accommodate the manufacturing of components to replenish the inventory. The regular changeovers results in halting the manufacturing process of the component currently being manufactured and replace it with a different component. The result is the alleviation of one shortage and the creation of another. Due to the constant crisis management of Kanban inventory, there is a negative impact on the ability of the Base Manufacturing section to replenish inventory due to the long set-up times of the machines.

Management of the Pin-Tumbler Depart is suffering as a result. Management set target that the department must attain monthly. The Department was unable to attain the targets for at least the last three years. Management expressed a desire to rectify the situation through the implementation of Lean Manufacturing. A possible solution to the problem researched was the implementation of Cellular Manufacturing (CM). A number of alternative were investigated to achieve the desired outcome.

III. METHODOLOGY

Researchers recommend Case Studies or Action Research whilst researching real life problems in organisations [7, 18, 22, 27, 28, 39, 43 and 44]. The Case Study or Action Research assumption imply it deal with a perception by the researcher that a modification in existing procedures is warranted. Five issues were identified validating exploitation of Case Study or Action Research. (a) Know-how inconsistency is present in contemporary research. (b) Clear reasons as to the value added by the research must exist. (c) Identification of ontological and epistemological issues. (d) Deliberating on meticulous practices and mode for data anthology and examination is important. Fastidious consideration concerning the topics of validity, reliability and triangulation as well as the integrity of the research and truth-seeking conviction in the qualitative theory must exist. (e) Researchers must ascertain it is the proper methodology under the circumstances.

Innovative hypothesis and concepts has been developed utilising Case Studies or Action Research. Researchers portray Case Studies as an exhaustive analyses or assessment of observable facts such as an incident, an entity, a grouping, an action or society. It could be a stimulus for the authenticity of conclusions arising from scrutiny of a particular a case or diagonally diverse cases. Case Studies are ideally proficient in exploiting new theory or ascertain diverse application of existing theory. As a result it is decidedly reliant on the knowledge of the researcher and a comprehensive literature review. Choosing multiple cases or a single case depend on the study undertaken.

The positivist opinion postulates that universal hypothetical facts are more important than tangible workable facts. It is unfeasible to expand universal suggestions and conjectures from a lone case study. The opposite is true. A Case Study could be extremely apt when concentrating on research questions, addressing explicit relevance of proposals to expand or augment continuous improvements. New information respects the specific eccentricity of the organisation, its resources, management, workers and broad ethos. Authentic and existing Case Studies afford an opportunity of sharing knowledge and operational performance within organisations.

Case Studies and Action Research is a recursive procedure which appraises the course of change as it congregates on the way to a better awareness of what is happening. It tracks exploits through transformation and, simultaneously a better comprehension of current knowledge. It is imperative to structure Case Study problems well. Questions must be relevant in identifying wastes occurrence within processes. The entire process utilised in the Case Study must be well documented. With Case Study research, staff members share their first hand experiences of a process performance.

Work ethic and ethos is witnessed firsthand. Problems identified utilising Case Study research could be beneficial elsewhere in an organisation. Success of case research is dependent on setting a case course of action. It guarantees research is conducted in an analogous manner incessantly. The course of action contributes to validity of the research. Part one of the course of action seek out a broad-spectrum of information regarding products produced by processes. Part two seek out information concerning process utilisation within the organisation. Part two aid in determining the causes for process failures. The methodology assists in task and responsibility clarification for management.

IV. LITERATURE REVIEW

A. Cellular Manufacturing

According to [1, 2, 5, 6, 8, 21, 27, 30, 32 and 33] Group Technology (GT) is a production theory founded on grouping components comparable in design, shape or processing needs. Cellular Manufacturing (CM) is an authoritative mechanism of Lean Manufacturing achieving improvements in inefficient processes. CM harness GT theory on the manufacturing concern’s shop floor. It groups machines or operators together. The purpose of CM is simplification and adjustment to the paradigm of high variety and low volumes. As a result CM is an integral part of GT. A basic step utilising CM is the recognition that a group of operators could form a cell. A manufacturing cell is an independent group of operators that manufacture or assemble a category of analogous products or components.

Utilising CM every operator would be responsible to complete an entire order. Sequence based cell formation could be a consequence. It is a type of cell that have level flow pattern with not as much forward and backward movement in the material handling method and decrease in work in progress (WIP) inventory. Shorter life cycles of modern products have made it imperative to implement CM. The time-to-market concept for new products and where product mixes is of intermediate-quantity and intermediate-diversity has also influence the implementation of CM. Gains attained through CM includes decreased set-up times, material handling improves, decreased (WIP) inventory, effective and efficient production processes, and improved levels of quality products and enhanced market response time.

Ahead of executing CM, an organisation has to devote sufficient effort during the planning and design stage. Consequently, attaining CM gains, enterprises must adequately integrate the structural and operational characteristics of a manufacturing factory within the design resolution. Three stages are identified namely the cell configuration conundrum, cell arrangement in the factory and populating the cells with machines or operators. It is further postulated that in an archetypal job shop production setting, processing the prerequisites for every activity is based on a collection of well-ordered operations where everyone can be executed by any operator.

Well-organized operations establish the path of a task in the cell. The methodology is identified as operator sharing job shops. Operator sharing can be portrayed as the ability of a set of operators in a production environment to assign the manufacturing or assembly of diverse components so that a job category in the group can be randomly assigned to any operator in the cell. Operator sharing involves adaptable component navigational abilities permitting components to be guided to one of the shared operators and sharing where replication of certain of the secondary assets is allowed.

B. Production levelling and takt time

According to [12, 13, 15, 19, 20, 23, 24, 29, 33, 36 and 38] heijunka (production levelling) and takt time methodologies are powerful tools in assisting to attain lean status. Optimum results are obtained if the two methodologies are combined. Lean Manufacturing has a focal intent, the proviso of the greatest probable service to consumers by waste eradication of any nature. Consequently, manufacturing execution ought to be harmonised with supply chain strategies and consumer orders, achieving ultimate production volumes for the process identical to consumer orders.

A strong emphasis is put on production levelling through constant volume and product mix, where, in the ideal situation products should be produced in fixed quantities and production wheels. Production levelling is strongly emphasised as a methodology. Levelling is realised by stable quantities and product blends. Production Levelling or, load levelling or load smoothing originates from the Japanese word heijunka. Overproduction is eradicated by exploiting this lean technique. The levelling at this juncture signifies the assembly mix and volume.

Capacity equilibrium and harmonization for production processes are ultimately accomplished by matching customer requirements accurately and resiliently for goods produced. Preferably, all components should be manufactured each shift in amounts identical to demand. Levelling transpires once the elevated incidence of arbitrary parts was evened out. Additionally, production cycle time ought to be not more than the normal customer waiting time for order delivery that would facilitate demand based scheduling.

Processes embrace the eradication of waste exploiting of simplicity. As a result, the creation of standard operations and methods is vital in establishing reliable operations. A major process adjustment in conversion to lean is the transformation in all operations from push to pull. Components from a previous operation must be pulled by the next operation. To guarantee a pull system, a constant flow is essential. Organisations operations must adhere to a standardized takt time. It guarantee that each operation operate at the same tempo

Following the same tempo, snarl-up in operations contributing to stoppages can be forestalled. Levelling production necessitate processes that are managed utilising takt time. Takt time signify how often the manufacturer ought to fabricate one part. The computation of takt time is influenced by the tempo of sales meeting customer needs Takt time matches production rate with sales rate.

If the rate of production is superior to the rate of demand, WIP occurs. Once the rate of production is less than the rate of demand, the consequence is queue forming, shortages and inferior service levels. By scrutinizing takt times businesses are capable of levelling production and delineating best possible capacity exploitation. Takt time is most often achieved through rapid changeovers, setup time and flexible cells. Additionally, pull production utilising Kanban should be executed to maintain level production.

C. Kanban

According to [11, 12, 14, 16, 17, 18, 19, 20, 24, 34, 35 and 42] management of processes utilising the Kanban methodology is important in attaining lean status. The phrase Kanban is a Japanese phrase that literally translates as card, signal or sign. In its normal form it signifies to an operation whether manufacturing of a component is necessary. No Kanban card, signal or sign, no production takes place. Normally a Kanban system operates two types of Kanban signals. They are: the production Kanban (P Kanban) and the movement or conveyance Kanban (C Kanban). At the other end of the continuum the Kanban system can be a paperless system.

A lighting system can be operated. Components are accumulated in prearranged standard sized containers, to which a Kanban is assigned. If a Kanban system is in operation, a prearranged quantity of inventory is accessible. The production system is not authorized to exceed the prearranged quantity of the Kanban. The significance of load levelling is the importance of a credible level production plan. The plan is compiled from data such as inventory information, bills of material (BOM's) and orders received from customers. Consequently, it is a major obligation that the development of production volumes is prepared accurately for the next production period.

Ranking products manufactured due to high levels of variety in models produced, is a noteworthy characteristic of load levelling. A significant influence on attaining load levelling is existing capacity in the production unit. The existing capacity is known as Production pitch or pitch. The pitch is computed for each product category exploiting the aggregate elapsed time for a particular product type. Currently, the focal point for countless make-to-order facilities is the minimisation of production time in attaining a competitive advantage.

Kanban can be perceived as an exceptional mode of production control. It is a managerial function which plans, directs and controls component distribution and process behaviour in an organisation. The dilemma pertaining to production control is to establish the quantities and time at which to manufacture. Regulating the magnitude of orders in a process continue to be an uncomplicated technique of regulating workload. Arrival of orders at the commencement of a process is better controlled if a pull system is executed.

A discrete manufacturing system is well suited for the implementation of the Kanban methodology. The most important objective in attaining lean is the execution of a pull system. The Kanban methodology is a recognized discrete part pull system. A pull system is the coalescence of numerous components that is the foundation of lean manufacturing. As a consequence, the requisite mean backlog for each operation to attain a specified utilization level is less. It decrease release time if compared to the completion time of orders.

Kanban implies a manner of visual control and standardised work. The conversion to pull and finally to lean status commences with the adaptation of operations to execute a Kanban system. Exploiting the methodology, the factory set up steer guide noteworthy amendments in the manner operations function. Confines are created thwarting staff members in relapsing to pass bad habits. Exploiting the Kanban system, a pool of staff members set up the requisite parts for building components on a tray and the second pool execute the assembly of the final products.

D. Supermarket and water spider

Each assembler in the cell would assemble a specific order. Correct use of the Kanban system would ensure that correct inventory levels are maintained. According to [11, 14, 26, 31, 37, 40, 41, 43 and 44] supermarkets is established for the assembly of components. Exploit the Kanban methodology, supermarket sizing is a planning action carried out in computing storage points for materials. Numerous techniques such as Kanban boards, lights, cards or electronic Kanbans could be exploited. Deployment of the tactic guarantees inventory control.

It results in a storage space where the anticipated components are held to assemble a specific order. The storage area has a number of trays filled with components to assemble any anticipated order. Assemblers request a tray of components from the supermarket facilitating the completion of an order assigned to the assembler. The water spider is an employee whose task it is to furnish assemblers with the correct components to assemble any order. In addition, the water spider launches Kanban cards to the manufacturing department to replenish stock of components when required.

The water spider is the quality liaison between the manufacturing department and assembly department. The water spider addresses any quality problem identified by the assemblers with the manufacturing department. Another duty of the water spider is as liaison between the Sales Department and the assembly department. The staff member controls all orders arriving at the assembly department and order of assembly. The staff member will not allow queue jumping of any order.

V. RESULTS AND CONCLUSIONS

The paper presents a case study introducing the restructuring of an assembly department at a make-to-order concern through application of lean tools. The restructuring coupled the assembly department's design purpose to operational purpose. The expanded structure in the paper concentrates on the proposal of allocating group tasks, usually referred to as orders to an individual staff member. The staff member is accountable in ensuring the completion of the entire order. The next order in the queue is allocated to the assembler after an electronic Kanban has been activated.

As a result a pull system instead of a push production system is in operation. The assignment is intended to allow flawless execution of tasks by integrating the methodologies of CM, Heijunka, takt time, Kanban, supermarkets and water spider. It centres the restructuring of the assembly department's endeavours by eradicating non value adding operations. It is accomplished through a reduction in inventory investment. Research was embarked on for the throughput rate under the previous state and improvements actually achieved.

The objective was to establish whether non value adding operations were decreased. Appropriate corrections were undertaken to enhance flow time. The flow time is computed as the aggregate of setup times, transportation time, waiting time in assembly queue and processing time. Endeavours reported on in the article are mostly focussed on the main issues listed above. If any improvements can be obtained on one or more of the listed issues, savings is usually assured.

During a kaizen event over a five day period certain improvements were investigated and implemented. A major improvement implemented was changing from the hybrid assembly line system to cellular manufacturing. Each staff member was classed as a cell. As a result the staff member is responsible for completion of a customer order. Every workstation was designed with this purpose in mind. The wastes encountered in the previous system were eliminated. One assembler did not have to wait for someone else to complete a certain portion of the assembly process before work at that next workstation could commence.

The literature review is unambiguous regarding the types of Kanban signals that can be introduced. It was decided that the customer order would be one type of Kanban card. It was utilised by the water spider to inform the manufacturing department the type of components that would be required and the quantity. The assembler would use an electronic Kanban to pull work. An andon type of lighting system were utilised for this purpose. The system had a red light, no work required. The amber light informed the water spider to prepare the next order for assembly. The green light signified that the assembler is ready to accept the next order for assembly.

The orders were arranged in due dates guaranteeing that no order jumped the queue at the assembly area. It guaranteed that the assembler concentrated on the oldest order first and progressed to the youngest. The result was that on time deliveries increased fivefold. Every assembler knew exact what was required to meet their daily and monthly targets. The water spider solved all problems that the assemblers encountered. The time wasting was eliminated.

The following improvements were achieved in the researched case: In the previous state 9 operators were required to produce daily quotas. After improvements were undertaken 7 operators were required. A saving of 77% was achieved. The 2 staff members that were saved were utilised as the water spiders feeding work into the department. Total operator cycle time in previous state was 8, 50 minutes. After implementation of improvements it was reduced to 6, 20 minutes. A 77% improvement was achieved. The throughput rate of lock per day in the previous state was 470 per day and increased to 500 per day after improvements were instituted. It represents a 7% increase in throughput rate. Productivity /units/order was under the previous state 52 orders per day and improved to 71 orders per day after improvement. It represents a 37% increase. WIP levels were reduced from R1 200 000, 00 to R600 000, 00 per month. It represents an improvement of 50%.

Some decision-making consequences arose from the study:

1. The executives of the organisation must be sensitised to the significance of complete incorporation of the methodologies in order to attain unsurpassed outcomes with reference to performance indicators as listed above.
2. The flow of components must be made simpler as a condition for a large number of improvement initiatives.
3. An acceptable choice of lean methodologies is imperative in achieving constructive results concerning the performance indicators in improving throughput time, WIP levels and lead time.
4. The computation of the takt time for the processes ought to contemplate capacity limitations and the effect of scrap production on the production rate.

The paper evaluated a limited quantity of lean methodologies. Conversely forthcoming research can be embarked on to expand the current methodologies exploited to embrace other lean methodologies. To facilitate exploitation of production flexibility for enhanced operations, the intensity of intricacy should be synchronized effectively. An alternative arrangement of lean methodologies may accomplish unrelated conclusions in another organisation. Due date linked measures as a scheduling technique ought to be researched additionally.

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