A Review of Various Tools and Techniques for Lead Time Reduction

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***Abstract*— In today's business climate, the old adage "time is money" has been expanded to mean that time is competitive weapon. Today customer's demands are quick delivery and good quality at reasonable price. Thus to perform in a global market, short lead times are essential to provide customer satisfaction. Lead time in manufacturer point of view is the time elapse between placing of an order and the actually receipt of goods ordered. There are various components of lead time such as setup time, process time, move time and waiting time. This paper deals with review of various tools and techniques to reduce lead time. Method study techniques use to examine current way of work and develop effective method base on elimination, combining, changing and simplification of activities. Various lean tools such as Single Minute Exchange of Dies (SMED), 5S, Poka-yoke, Kanban, Just-in-time (JIT), Value Stream Mapping (VSM), Jidoka, Cellular manufacturing etc. helps in reducing lead time. Also Manufacturing Resource Planning (MRPII), Theory of Constraints (TOC) classic approaches of Production Planning and Control (PPC) are use to reduce Work in Process (WIP) and flow time**.

***Index Terms*—Lead time reduction, Method Study, Lean tools, PPC, DFP, DSM**

I. INTRODUCTION

In today's world of rapid flux, organizations change their focus on speed. Customers, in today's competitive environment demand shorter lead time, low cost, high quality & highly customize product. The customer is king of today market. Hence to compete effectively short lead times are essential to provide customer satisfaction. Lead time is the time elapse between placing of an order and the actually receipt of goods ordered. Most manufacturing firms spend 5% to 30% of total time actually adding value to the product. The rest of the time is waste. So, there is vast opportunity to reduce lead time. Lead time reduction is the significant productivity improvement driver. Lead time reduction does not mean working harder, faster or with reduced quality, but it means working smarter. Reduce cycle time environments actually produce better quality.

Meyer &Utterback (1993)research shows that rapid development times are not correlated with expected commercial success, and that forcing rapid development when technological and market uncertainties are high may produce failure. [1]

AjitkumarSenapati et al. (2012) stated that in the 1960s and 70s; manufacturer competed on the basis of cost efficiency. In the 1980s, quality was the rage and Zero Defects and Six Sigma came into vogue. Cost and quality are still crucial to world-class operations, but today, the focus is squarely on speed. [2] Table 1 shows four basic ways of lead time reduction.

Table 1: Strategies for cycle time reduction, Towill [4]

Tactics adopted	Engineering procedure
Elimination	Remove a process
Compression	Remove time within a process
Integration	Re-engineering interfaces between successive process
Concurrency	Operate process in parallel

Little's law states that for a given production rate lead time is directly related to inventory. Eq. 1 shows little's law, and it is widely applicable to almost any queuing situation. It shows that by maintaining same production rate reduction in lead time will reduce WIP or means of identifying the largest component of lead time is to find largest inventories and work to reduce them. [3]

$$\text{Inventory} = \text{Production rate} * \text{leadtime} \qquad (1)$$

Section 2 discuss in detail, lead time measures and various component of lead time. Section 3 reviews various tools and techniques presented in literature for lead time reduction. Section 4 illustrates benefits of lead time reduction. In section 5, the paper evaluates and categorizes the applicability of tools and techniques reviewed in the previous section in order to assist practitioner in the choice of appropriate tools and techniques. Section 6 highlights areas in need of further research.

II. LEAD TIME MEASURES

There is an old adage that "The road one takes matters only if one knows where they are and where they are trying to go." There is necessity to firm have a cycle time performance base line against which to compare results of new processes. Abbie Griffin

(1993) presented one set of product development measurement tools, which can be used by firms to generate product development cycle time performance baselines. She has produced relationships between development time and percent change across product generations, complexity and whether or not a formal process was used. She also demonstrate how to use them to either forecast expected project duration, given that you have not changed your development process, or determine whether a process change has actually decreased development cycle time.[5]

Lead time is equal to sum of the processing time, setup, move, queue, wait-in-batch, wait-to-batch, and wait-to-match times. Because queue, wait-in-batch, wait-to-batch, and wait-to-match times all involves waiting, they are collectively referred as waiting time. Eq. 2 is formula for lead time calculation. Waiting time is usually largest of the four components, accounting for as much as 90% of manufacturing lead time in some system.

$$\text{Lead time} = \text{Setup time} + \text{Processing time} + \text{Move time} + \text{Waiting time} \qquad (2)$$

Danny J. Johnson (2003) studied the basic factors that determine manufacturing throughput time and explain why each factor occurs. Manufacturing throughput time is length of time between the release of an order to factory floor and its receipt into finish good inventory. These factors are processing time, production and transfer batch size, setup and move time, variability and workstation utilization. Author also presented a conceptual framework that illustrates the action that can be taken to reduce each factor, and relationships between them. Framework provides an easy-to-use tool that managers can use determine a course of action to reduce manufacturing throughput in their own plants. [6]

III. TOOLS AND TECHNIQUES FOR LEAD TIME REDUCTION

As described earlier lead time is compose of setup time, processing time, move time and waiting time. There are different tools for different component. This section first shows tools for setup time reduction, and then discussed tools to reduce other component.

A. Setup Time Reduction

A.Allahverdi and H.M.Soroush (2008) demonstrated that scheduling activities profoundly depends on setup time/costs. Treating setup times/costs separately from processing times/ costs allows operations to be performed simultaneously and hence improves resource utilization. [7]

M.Diaby et al. (2013) developed nonlinear optimization model to determine optimal level of setup reduction, defect rate reduction, and production cycle time for each product subject to demand, process improvement budget, and manufacturing and warehousing capacity constraints. A convex geometric programming approximation of these models is developed in order to solve them. [8]

1. Single Minute Exchange of Die (SMED)

S.Patel et al. (2001) illustrate that reducing set-up time mainly by teamwork, standardization methods, work study, new machinery/technology, empowerment, fixtures/fittings, pre-set tooling and automatic tool changers. If set-up times are to be reduced to single digit figures then the companies need to embrace the SMED methodology. [9] S.Patel et al. (2001) studied set-up time reduction and mistake proofing methods in a small company involved in the machining of precision components in small batches with high variety for aerospace industry. Authors evaluated setup to examine the type of improvements which can be made using Shingo's SMED methodology. [10]

Patel Chintankumar (2012) demonstrated that by implementing SMED methodology on C.N.C machine which produced platen; reduce down time 113.75 min to 59.75 min per month. Also production of platen increases. [11]

2. Method Study

S.Patel et al. (2001) stated that companies are reducing set-up time using method study techniques as opposed to Shingo's SMED methodology. The Companies use typical step for reduce setup times are 1) Selecting the setup which provide greatest return on the investment of the time spent studying them, including those which offer the greatest scope for improvement , or which are causing bottlenecks and delays. 2) Recording all relevant facts of the present setup with respect to the sequence of time, interrelationship of activities and path of movements. 3) Examining those facts critically and in sequence relation to: Purpose; place; sequence; person and means. 4) Developing the most practical, economic and effective method in relation to elimination, combining, changing, and simplification of the setting-up activity. 5) Installing the improved set-up procedure and method. 6) Maintaining the method by periodically checking it in use. [9]

B. Processing, Move and Waiting time reduction

As stated earlier major component of lead time is waiting time. To achieve significant result in lead time reduction this component must attack first. Good plant lay out can help to reduce move time. Processing time can reduce by reduce ineffective time from that. Various tools and techniques which use to reduce these are discussed in below.

1. Work Study

Total lead time can reduce by reducing work content and reducing ineffective time. Work study techniques such as Method study & Work Measurement aid in these. Method study is concerned with the reduction of the work content of a job or operation, while Work measurement is mostly concerned with the investigation and reduction of any ineffective time. [12]

Khalid S. Al-Saleh (2011) was performed method study and time study in the Motor Vehicle Periodic Inspection (MVPI) station in Riyadh, Saudi Arabia. It was found that the inspection time for one station was reduced from 126 to 46 sec per vehicle and increase in output 175%. [13]

S.Chidambara Raja etal. (2012) Used time & motion study and lean concept to reduce motion waste and improving productivity in automotive industry. The problem in current layout identified first and analyzed through simulation. Then the layout was modified, simulated and the results were compared. The Results revealed modified layout saved 47.85 meters distance travelled and 11.95% productivity improved. The modified layout also reduced two operators and saved 640 rupees per shift. Total annual saved was Rs.5, 99,040 which is considerable saving in the total revenue. [14]

2. Lean Tools

A lean manufacturing facility is capable of producing product in only the sum of its value added work content time. The goal of lean manufacturing is to minimize waste in terms of non-value-added activities, such as waiting time, motion time, set-up time, and WIP inventory, etc.

A.Gunasekaran et al. (2000) conducted case study at Valeo; a French company located in England that produces wiper system for automobile industry in UK. The objective of the project was to improve productivity in two cells of the company, namely the Honda/Rover cell and the headlamp cleaning cell. They concluded Making minor improvements in SMEs, such as reducing the set-up time, would lead to a considerable reduction in non-value adding activities in terms of using smaller lot sizes and making the production line ``lean'' to support JIT material flow in a manufacturing cell. SMEs should start with 5 S's implementation, as they do not require much capital investment, other than some training. JIT/Kanban and Hoshin exercise using activity-based analysis are the key strategies and method that could be used in SME to improve productivity. [15] Joel S. Jensen and Mark N. Frolick (2000) applied lean concepts in General Motor Service Parts Operation. General Motors used a modified version Toyota Production System. General Motors reduce cycle time in Parts Distribution Centers by Time-boxing the parts picking process means equal work assignments, Fixed Storage, and Visual Control. [16]

ShishirBhat B.N. (2008) applied cellular manufacturing concept in forging shops. Cellular manufacturing is an application of Group Technology philosophy. Author demonstrated main benefit of apply cellular manufacturing is reduce cycle time and improve profit. [17]

P. Kuhlang et al. (2011) connected Value Stream Mapping (VSM) and Methods-Time Measurement (MTM) and offers new distinct advantages to reduce lead time and increase productivity based on lean principles and standardized processes. The interaction of VSM & MTM aid to identification, elimination and avoidance of waste and thus leads to design efficient and effective process. The joint mutual benefit of the combined application arises from the increase in productivity, from the standardization of processes, from the reduction in lead time/ inventory and from the accurately determined times; it also enables and ensures the predictability and the capability to assess the target status. [18]

M.Balakumar and D.Rajenthirakumar (2013) used lean tools for improving productivity of the compressor assembly plant by reducing the cycle time. Kaizen philosophy is applied for reduce cycle time & cycle time of assembly operation were reduced 92min to 80 min. [19] Meby Mathew and D.Samuelraj (2013) demonstrated cycle time of car assembly line reduced 29.41 min to 23.3 min by line balancing. This improved further by application of lean tools such as 5 S's, SMED, Jidoka and TPM to standardized work. This study helped to identify the waste and eliminate it step by step and thereby reducing the cycle time again by proper line balancing. [20]

3. Production Planning and Control

Typical functions of a PPC System include planning material requirements, demand management, capacity planning and the scheduling and sequencing of jobs. The key purposes of such functions include reducing Work in Progress (WIP), minimizing flow Times and lead times, lower stockholding costs, improving responsiveness to changes in demand, and improving Delivery Date adherence. Much effort is spent to reduce lead time by improving production planning and control systems and developing more sophisticated scheduling procedures, and these efforts have shown success.

A. Agrawal et al. (2000) developed an effective Lead Lead-time Evaluation and Scheduling Algorithm (LETSA) that can perform detailed backward scheduling of operations belonging to a large assembly on a given facility with an objective of minimizing the cycle time. The LETSA algorithm generates a feasible schedule with a near-optimal cycle time. It proceeds in a backward scheduling manner similar to MRP II, in which the last operation is scheduled first and the remaining operations are scheduled subsequently while respecting all precedence constraints. [21]

M. Stevenson et al. (2005) reviewed 'classic approaches' to Production Planning and Control (PPC) such as Kanban, Manufacturing Resource Planning (MRP II) and Theory of Constrains (TOC), and elaborated upon the emergence of techniques such as Workload Control (WLC), Constant Work In Process (CONWIP), Paired cell Overlapping Loops of Cards with Authorization (POLCA) and web- or e-based Supply Chain Management (SCM) solutions. This highlights the importance of a PPC implementation strategy. [22]

4. Design for Production (DFP)

Design for Production (DFP) evaluates how many parts the manufacturing system can output and how long each order will take. That is, it evaluates manufacturing capacity and measures the manufacturing time. Product development teams need, early in the product development process, methods that can estimate the manufacturing cycle time of a given product design. If the predicted manufacturing cycle time is too large, the team can reduce the time by redesigning the product or modifying the production system. DFP methods evaluate a product design by comparing its manufacturing requirements to available capacity and estimating manufacturing cycle time.

Jeffrey W. Herrmann and Mandar M. Chincholkar (2000) developed DFP decision support tool that analyzes capacity requirements, estimates the manufacturing cycle time of the new product, and provides feedback to the product development team. Product development team use this feed back to reduce manufacturing cycle time. The decision support tool has five modules: the user interface, the process planner, the aggregation module, the approximate queuing network model, and the analysis module. Then they illustrated an example how product development team would use DFP decision support tool for a specific product design and manufacturing system. The tool can quickly evaluate changes to the new product design or changes to the manufacturing system. [23]

5. Design Structure Matrix (DSM)

Design Structure matrix (DSM) was originated by steward in 1989. It is also called dependency structure Matrix. DSM is tool to identify the dependencies between activities and to sequence the development process. The DSM is a square matrix with one row (i) and column (j) per activity. The activities are listed in roughly chronological order. Figure 1 shows DSM matrix. Diagonal elements are place holder in a simple DSM, and off-diagonal elements indicate activity interfaces. Sub diagonal matrix elements show feed forward information and super diagonal element indicates feedback. Thus, if activities in rows and corresponding columns of DSM have no direct interfaces, entries ij and ji in the matrix will be empty. On other hand, both entries ij and ji are filled, this indicate two way inter dependency. Traditional CPM/PERT method and Gantt charts do not adequately represent this type of relationships.

	A	B	C	D	E	F	G	H	I
A									
B	X								
C	X	X							
D			X						
E	X	X	X						
F		X	X	X	X				
G	X	X	X			X		X	X
H	X	X				X	X		X
I							X	X	

Figure 1 - Design Structure Matrix, Maria Carrascosa et al. [23]

Tyson R. Browing (1998) showed capability of dependency structure matrix based method to shorter lead time and reduce project risk. Super diagonal entries represent feedback it means rework is require for already completed (upstream) activities when information received from dependent activities (downstream). When downstream create rework for upstream activities, the resulting change may cause second order rework for interim activities (those between upstream and downstream activities). Hence input changes to activities can generate new information and force iteration in the process. The goal of DSM analysis is resequence the activities so as to minimize iteration and their scope. Thus reorder the rows of DSM to get all the entry below the diagonal. If it will not possible to get all entries below the diagonal, then try to get super diagonal entries as close to diagonal as possible. He also demonstrated cycle reduction challenges and how DSM aids to overcome that challenges. [24]

Maria Carrascosa et al. (1998) developed model to estimate product development time using dependency structure matrix. [25] Abdelsalam and Bao (2006) developed simulation-based optimization framework that minimizes Product development time through resequencing of activities. The framework integrated tools 1) DSM 2) Mathematical modeling 3) Simulated Annealing (SA) algorithm; and 4) Monte Carlo simulation. Product development projects (PDPs) are characterized by their iterative nature; some activity may need to be redone until a satisfactory solution is reached. In the planning and scheduling phase, the duration of activities iteration cannot be precisely estimated. DSM improves understanding of the project by providing a compact visualization of the project and a clear understanding of information flow patterns among its activities. [26]

IV. Benefits Of Lead Time Reduction

Reducing lead time has many benefits. Main benefits are as follows.

- Reduce WIP
- Reduce Safety Stock
- Reduce costs
- Improved Product Quality
- Faster response to customer need
- Increased Flexibility
- Reduce time to market
- Increase Profitability

C.H.Glock (2012) demonstrated that mixture of setup time and production time reduction is appropriate to lower expected total cost (ETC) in inventory. [27]

V. SUMMARY

Figure 2 summarizes various tools and technique applicable to lead time component. SMED is tools to reduce setup time from hours to minutes. Work study techniques use for work simplification, reduce work content and reduce ineffective time. Lean manufacturing focuses on reduction of all kind of waste to make continuous flow of the work, reduce lead time, reduce movement of worker, eliminate non value added activity, reduce inventory in the production space. Lead time also reduce by improving production planning and control. DFP methods evaluate a product design by comparing its manufacturing requirements to available capacity and estimate manufacturing lead time. If predicted lead time is too large, the time can reduce by redesigning product. DSM helps in reduce lead time by proper sequencing of development activities.

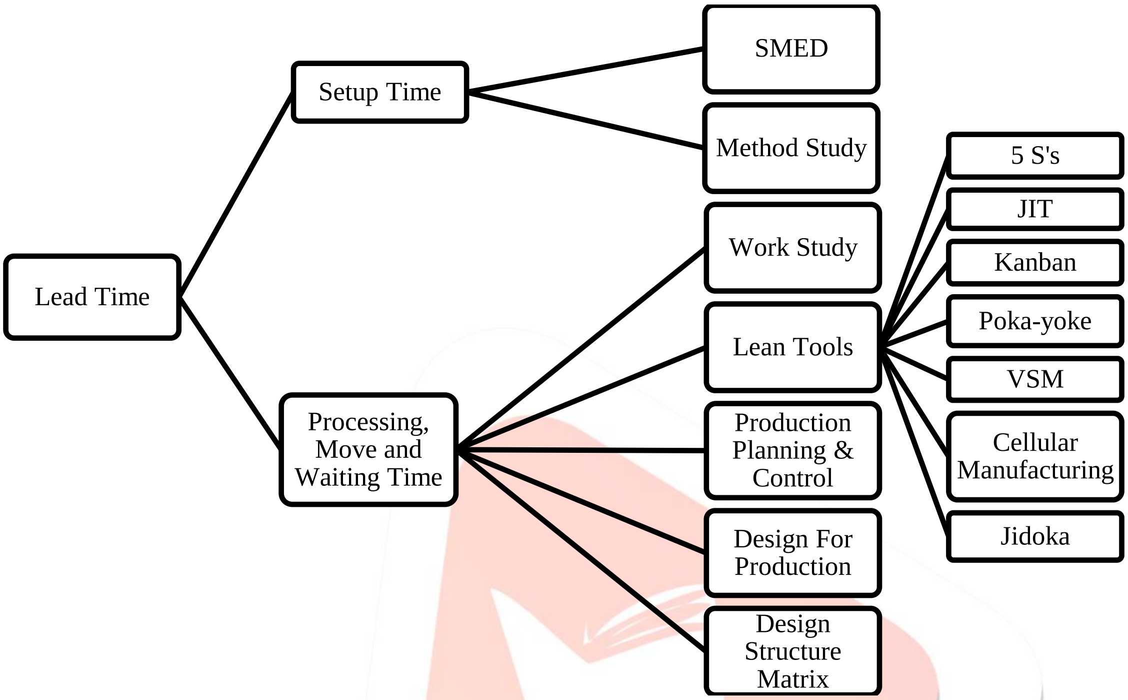

Figure 2 – Summary of tools and techniques for Lead Time reduction

VI. GAPS IN THE LITERATURE

The paper has reviewed various tools and techniques for lead time reduction and applicability of that in suitable lead time component. Through this review and evaluation process under-researched areas have emerged that outlined below.

- In introduction section we illustrated that lead time can reduce by four ways. Elimination, compression, and integration of processes and operate processes in parallel. Wide range of literature available for reduce lead time by first three ways, but very few literature available to lead time reduction by operate processes in parallel.
- Concurrent Engineering is a work methodology based on parallelization of task. But it deals with parallelization of different function's activities and integration of different function i.e. design engineering, manufacturing engineering etc. It not considers parallelization of same function activities.
- Further research is required to determine compatibility of integrating different tools and techniques to perform process in parallel and reduce lead time. For example, the feasibility of integrating method study techniques with DSM tool.

❖ Planned future research

Authors are currently work on reduce production lead time of automatic band-saw machine in Multi-cut machine tools located in Vadodara, Gujarat. The company does not have standard sequence of processing. Authors integrate method study techniques and Network technique to work simplification and analyze process to see dependencies of activities. Base on activities dependencies we will prepare network. To reduce lead time we must determine which activities lie on critical path and try to eliminate or compress critical activities. If the reduction is not sufficient, repeats this process until satisfactory result will achieve.

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