A brief review of Cellular manufacturing and approach used to solve layout design

Shrikant Rajendra Masne*[1], Rahul Mishra[2]
[1*]*M. Tech Scholar, IES Institute of tech. & Management, Bhopal*
[2]*Assistant Professor, Mechanical, IES Institute of tech. & Management, Bhopal*

Abstract:
Every manufacturing industry has put in continuous efforts for its survival in the current volatile economy. In order to face the situation, industries are trying to implement new and efficient techniques in their manufacturing operations. Cellular Manufacturing is an efficient solution to batch type production with low setup time to produce variety of part types either of same group or different, shorter lead time and higher machine utilization with the best quality and customer satisfaction. The extant literature fails to provide an efficient method to measure leanness of any manufacturing firm. The purpose of this present paper is to discuss about the concept of cellular manufacturing under the umbrella of Lean and to provide an efficient remark for the same.
Key Words: *Lean Manufacturing, Cell Formation, Layout, Algorithm*

INTRODUCTION

In order to be successful in today's competitive manufacturing environment, managers have had to look for new approaches to facilities planning. Cellular manufacturing (CM) has been evolved to fulfill contemporary market demand where traditional manufacturing system was incompetent. Therefore, CM is a solution to efficient batch type with low setup time to produce variety of part types, shorter lead time and higher machine utilization with superior quality (Sudhakarapandian, 2007). Cellular manufacturing (CM) is an application of group technology, entails the creation and operation of manufacturing cells. Each cell is dedicated to processing a specific set of part families. A manufacturing cell typically consists of several functionally such as dissimilar machines, whereas a part family consists of a set of parts with similar processing requirements. One of the first problems encountered in implementing CM is that of cell formation (CF). CF deals with the identification of the part family or families and associated machine groups that constitute each cell. Although the operational benefits of CM have been well-documented in the published literature [Wemmerlow, 1989], it has also been argued that the implementation of cells could lead to a decrease in manufacturing flexibility [Vakharia, 1986]. The major difficulty with cells stems from potentially unstable machine utilizations due to dynamic and random variations in part demands [Morris, 1990]. This has led to some confusion as to the appropriateness of CM by industry users. On the one hand, companies would like to achieve the operational efficiencies through implementing CM systems, but, on the other hand, companies do not want to lose the strategic benefits of flexible operations. Further, as pointed out by Craig, et al. [Craig, 1975], flexibility is one of the critical dimensions of enhancing the competitiveness of organizations and hence the design of flexible cells is an important issue [Singh, 1993].

The primary aim of this present study of review kind is to find out the needs and examine the degree to which the concepts of cellular manufacturing under the umbrella of lean manufacturing are put into practice within Indian scenario. This present paper proposes a brief literature review and method that incorporates several criteria to guide the creation of cells. This approach is unique in several aspects. First, the cell system design generated is a function of the user priorities in terms of flexibility dimensions. This not only allows the user to incorporate preset user priorities but also allows the investigation of flexibility criteria. Secondly, although there is some prior research that has incorporated alternative process plans when identifying cell configurations, this is one of the first methods that focus on part-operation requirements in creating cells. Most of the cell formation research to date assumes that parts are processed on specific machine types and the assignment of operations to machines is determined on a priority. However, to allow for flexibility in machine operation and assignments, we explicitly incorporate this decision into our procedure. Thirdly, the conclusion proposed in this research includes an explicit improvement stage where the user can attempt to modify the candidate design to increase alternative (or all) types of system flexibility.

LEAN MANUFACTURING

Lean manufacturing (LM) is a multi-dimensional management practice including just in time, quality systems, work teams, cellular manufacturing, supplier management, etc., in an integrated system. The core motivation of lean manufacturing is that these practices can work synergistically to produce finished products at the pace of customer demand with little or no waste. The characteristics and impacts brought by lean practices have been presented in a number of works [Shah, 2007]. It is demonstrated in the Japanese automotive industries as Toyota Production System

(TPS) [Ohno, 1988]. TPS allows the continuous improvement of a business through the relentless elimination of waste, or non-value-added activities. Waste, in TPS, is defined as anything that does not add any value to the product or service from a customer's perspective [Ohno, 1988]. There are seven types of fundamental wastes defined in TPS correction, overproduction, motion, material movement, waiting, inventory, and processing [Shingo, 1992]. To eliminate these wastes, TPS uses tools such as workplace organization, visual communication and control, quick changeovers, pull system, error proofing, etc. [Likr, 2003]. Further, features of a typical LM model include: single piece flow production, non-value-added time elimination, production in the work content time only, relocation of required resources to the point of use, and leveled production by all the processes at the Takt time [Pattanaik, 2008]. Pavnaskar has studied and organized a total of 101 lean manufacturing tools to serve as a link between manufacturing waste and lean tools to assist companies in lean transition [Pavnaskar, 2001]. Every manufacturing industry has put in continuous efforts for its survival in the current volatile economy. In order to face the situation, industries are trying to implement new and efficient techniques in their manufacturing operations. Some of the established tools in this context are lean practices, and its realization has been growing among the industries, particularly in automobile sector. The successful application of various lean practices had a profound impact in a variety of industries, such as aerospace, computer and electronics manufacturing, forging company, process industry (steel), and automotive manufacturing [Sethuraman, 1996]; as a matter of fact, some industry may already be using some of the methodologies without actually realizing it. A study of the literature indicates that survey-based lean assessment work has been carried out in Australian manufacturing industry [Sohal, 1994], electronics manufacturing [Doolen, 2005], Spanish ceramic tile industry [Tomas, 2006], and Malaysian electrical and electronics industry [Wong, 2009]. In light of the above findings, the present study is the first attempt that explores the degree of use of lean practices in machine tool industry and provides direction for future research.

Mohanram (2011) stated that, further research in this area is needed to develop a suitable training demonstrator to teach lean concepts, train the employees, and transform them as lean thinkers. This would help to foresee the firms operations, learn to recognize the value-added and non-value-added activities, and inculcate the habit of wearing "muda spectacles" at all times by everyone. Further, a detailed description of how the lean concepts could be systematically combined, to facilitate the organizations to meet the Takt time in confronting surge and volatile environment, needs to be addressed. This new proposal has to be effectively implemented, not only to manufacturing industries, but also to reach the minds of young engineers.

CELLULAR MANUFACTURING

A cell is a combination of people, equipment and workstations organized in the order of process to flow, to manufacture all or part of a production unit Wilson, L. (2009). He has discussed various characteristics of effective cellular manufacturing practice. He is of the opinion that they should have one-piece or very small lot of flow. The equipment should be right-sized and very specific for the cell operations. It should have C or U shape arrangement or layout so that the incoming raw materials and outgoing finished goods are easily monitored. It should have cross-trained people within the cell for flexibility of operation. There are lots of benefits of cellular manufacturing over long assembly lines. Heizer, J., and Render, B. (2000) have in their paper discussed that the cellular manufacturing concept can lead to reduced work in process inventory, as the work cell is set up to provide a balanced flow from machine to machine.

It can lead to reduced direct labor cost due to the improved communication between employees, better material flow, and improved scheduling. It prompts for the high employee participation due to the added responsibility of product quality monitored by themselves rather than separate quality persons. Olorunniwo F. (1996), states that, there is a need for a new generation of factory layouts that are more flexible, modular, and more easily reconfigurable. Flexibility, modularity, and re-configurability could save factories from the need to redesign their layouts each time their production requirements change. Several layout design strategies have recently been proposed by researchers in order to improve the performance of job shops which are working under volatile manufacturing environments. Irani S. A (1999), divided these layout strategies into modular layouts, reconfigurable layouts, agile layouts and distributed layouts. Wemmerlov U., Hyer N.L. (1987) has opined that the modular layout concept uses the idea of grouping and arranging the machines required for subset of operations in different routings into a specific (classical) layout configuration that minimizes distances or cost. In reconfigurable layout approach it is assumed that resources can be easily moved around so that relocation of departments is feasible. Once this assumption is made then the layout problem becomes a multi-period facility layout problem. In agile layout approach the design objectives of the layouts are different than the classical design objectives. In this approach performance measures, such as production throughput, cycle time, work in progress inventory etc. are used as the design objectives. Any type of layout like cellular, functional etc. can be developed by using performance measures. The difficulty with this approach is lengthy simulations. Generally simulation optimization approaches are more employed for designing such layouts. Wemmerlov U., Hyer N.L. (1989) developed a multiple objective parametric simulation optimization system for designing such layouts.

Cellular manufacturing (CM) is an application of group technology, a manufacturing philosophy in which parts are grouped into part families, and machines are allocated into machine cells to take advantage of the similarities among parts in manufacturing. The significant benefits of cellular manufacturing are a reduced setup time, reduced work-in process inventory, reduced throughput time, reduced material handling costs, improved product quality and simplified scheduling, etc. Nicoletti, S. Nicosi (1998) has opined that the cell formation (CF) problem is the first step of the design of cellular manufacturing systems. The main objective of CF is to construct machine cells and part families, and then dispatch part families to machine cells to optimize the chosen performance measures such as inter-cell and intra-cell transportation cost, grouping efficiency, exceptional elements, etc. Numerous methodologies have been reported to identify machine cells and their associated part families. Some of the widely used methods are the similarity coefficient methods (SCM). A manufacturing cell consists of several functionally dissimilar machines which are placed in close proximity to one another and dedicated to the manufacture of a part family. In Cellular manufacturing, part families are formed based on the similarities of design and manufacturing attributes of the parts to be produced. Then a group of machines along with the part families to be produced are formed as cells (Chalapathi, 2012).

ROLE OF CELLULAR LAYOUT

Cellular layout helps to achieve many of the objectives of LM due to its ability to help eliminate many non-value added activities from the production process such as waiting times, bottlenecks or difficulty, transport and works-in-progress. Many companies implement cellular layout for certain parts of the production process but not the entire production process. A case study on implementing a cellular production layout for a series of intermediate production processes at Franklin Corp., a US manufacturer of upholstered furniture, reported a 36% increase in labor productivity as a result of implementing a lean manufacturing system. In the present day of manufacturing, cells can be formed easily for any industry whether it is a small-scale or a large-scale industry. When the Takt times are calculated for every part manufactured in the industry through intercellular and intracellular part movements, then the problem of locating machines on the shop floor occurs when it is a job type production unit; this problem is the main reason for reconfiguration of machines and layout design for every demand. To eliminate these problems, a proper method is required to achieve a rhythm in manufacturing lean line by identifying value adding, non-value adding, and necessary non-value adding activities within a proper cell layout through an optimum feasible Takt time . It is not so difficult to identify an optimum cell layout from any industrial data; only identification of cells is not the complete solution because the cells should have a proper rhythm of manufacturing line, minimizing wastages like bottleneck time, waiting time, material handling time, etc. Therefore, to make cellular manufacturing efficient, it is necessary to implement various concepts of lean manufacturing within this cellular layout. In this paper, a case study is presented to design a cellular layout for the implementation of the lean manufacturing or, in other words, a cellular layout which follows lean principles.

CELL FORMATION

In recent years there has been a tremendous growth in the number of CF methods. The surge of interest in the area has been fueled not only by surveys that have shown the benefits of CM systems [1] but also because there is substantial industry interest in implementing CM systems. In the context, Tilsley and Lewis [Tilsley, 1977] were the first to propose a CF method where routing flexibility was a primary consideration. They essentially propose a system of `cascade' cells that are created such that the more critical part families can be processed in more than one cell. Thus, machines required to process critical part families are allocated to more than one cell. Although the algorithmic details of the procedure are not provided, they do point out the importance of building in routing flexibility when machines within cells are subject to breakdowns. Machine downtime in a cell could be handled by having multiple machines of the same type in a cell or by routing operations performed on one machine in a cell to other machines in the same cell; however, these factors are not considered in their procedure.

Dahel and Smith [Dahel, 1993] propose a procedure to create cells such that routing flexibility and cell independence could be simultaneously considered. They essentially formulate the CF problem as a multi-objective mathematical model that simultaneously attempts to create independent cells (by minimizing intercellular materials and flexible cells (i.e., cells containing the largest variety of machine types). Their logic is that routing flexibility of the system is maximized when we can create such flexible cells.

In terms of flexibility dimensions, there has been a remarkable lack of interest in designing cells that can respond quickly to changes in the part demands (in terms of new part introduction and in terms of changes in volumes of current part). To address this issue, Vakharia, et al. [Vakharia, 1997] develop a framework and measures for different flexibility types relevant in the context of CM systems.

These types are:

· Machine type flexibility: the ability of the machines grouped into cells to process a large number of distinct operation types; · routing flexibility: the ability of the cell system to process parts completely in multiple cells.

· Part volume flexibility: the ability of the cell system to deal with volume changes in the current part mix; and

· Part mix flexibility: the ability of the cell system to handle different product mixes with minimum disruption.

Out of all these flexibility types, routing, part volume, and part mix flexibilities are determined by the cell system design generated, whereas machine type flexibility is also a function of the technological constraints on the machines. Hence, the cell formation method is of paramount importance when implementing a Cellular Manufacturing because the success of Cellular Manufacturing depends greatly on the initial grouping of machines and parts. Ever since the concept of Cellular Manufacturing is introduced attempts were made by different researchers and practitioners to develop algorithms for the efficient cell formation. There are many types of layout design in manufacturing system such as process layout, product layout and cellular layout. A process layout is suitable for high degree of interdepartmental flow and little intradepartmental flow. It is proper for low-volume, high variety environment. On the other hand, a product layout is used for high-volume, low variety environment. A cellular layout is suggested for medium-volume and medium-variety environment (Hachicha, 2007). This kind of layout is also appropriate for both automated and non automated manufacturing systems.

LAYOUT DESIGN

Layout design and the flow of materials have a significant impact on performance of any manufacturing system. These can help to increase production productivity, reduce work in process and inventory, short production lead time, streamlines the flow of materials, cost and reduce non value added activities from the production process of waiting and transportation, which make the factory meet customers requirement quickly. There are many types of layout design in manufacturing system such as process layout, product layout and cellular layout. A process layout is suitable for high degree of interdepartmental flow and little intradepartmental flow. It is proper for low-volume, high variety environment. On the other hand, a product layout is used for high-volume, low-variety environment.

A cellular layout may be suggested for medium-volume and medium-variety environment. This kind of layout is also appropriate for both automated and non-automated manufacturing systems.

Various approaches have been suggested for forming manufacturing cells and layouts. Good discussions of CMS can be found in Burbidge (1963), Suresh and Meredith (1985) and Selim et al. (1998). Techniques range from the simple to the sophisticated and flexible. The simple techniques usually manipulate part-machine matrices. The sophisticated ones can handle many constraints in forming cells such as maximum cell size, different demands for different products, number of cells and set-up costs.

MULTI-PERIOD PLANNING

Now days, shorter product life cycles are an increasingly important issue in cellular manufacturing. One cannot assume that the designed cells will remain effective for a too long time. Ignoring the planned new product introductions would necessitate subsequent ad-hoc changes to the cellular manufacturing system (CMS) causing production disruptions and unplanned costs. Thus one has to incorporate the product life cycle changes in the design of cells. This type of model is called the multi-period CMS. In this model, we assume that a reasonable forecast of new product introductions and part mix or volume changes can be made so that a multi-period plan is possible. For a review of the general multi-period layout planning models see Balakrishnan and Cheng (1998). Wicks and Reasor (1999) identify three common objectives to be met when designing the multi-period CMS, i.e., 1) minimizing the inter-cell transfer of parts, 2) minimizing duplication of machines, and 3) minimizing the between-period reconfiguration of cells. Subcontracting firms are good candidates for this model as these firms produce a variety of parts for a number of customers (Drolet et al. 1996). Balakrishnan and Cheng (2005) suggested a two-stage method to solve multi-period problem. Based on the static CMS and rearrangement of the CMS are separated so that each is solved separately. Thus it is flexible in that the decision maker can be used different preferred methods for each stage. In the paper the authors use a genetic algorithm for the static phase and dynamic programming for the dynamic phase, but point out that any method may be used. They also do some sensitivity analysis in the dynamic phase to illustrate the use of the dynamic approach in helping to improve the CMS.

Askin et al. (1997) have proposed a four-stage algorithm that designs cells to handle variation in the product mix. Initially a mathematical programming based method is used to assign operations to machine types. Subsequent phases allocate part-operations to specific machines, identify manufacturing cells, and improve the design. Experiments are also conducted to evaluate the effect of factors such as utilization and maximum cell sizes on the effectiveness of the algorithm.

Again, cells once designed are expected to remain unchanged during the planning horizon.

VIRTUAL MANUFACTURING CELLS

Many of the researchers have suggested the use of Virtual Manufacturing Cell Systems (VCMS) when product demand is uncertain or unpredictable. In a virtual (logical) cell, machines are dedicated to a product or a product family as in a regular cell, but the machines are not physically relocated close to each other. The paper by McLean et al. (1982) is one of the first to propose such an approach. An example of VCMS is shown in Figure 1.

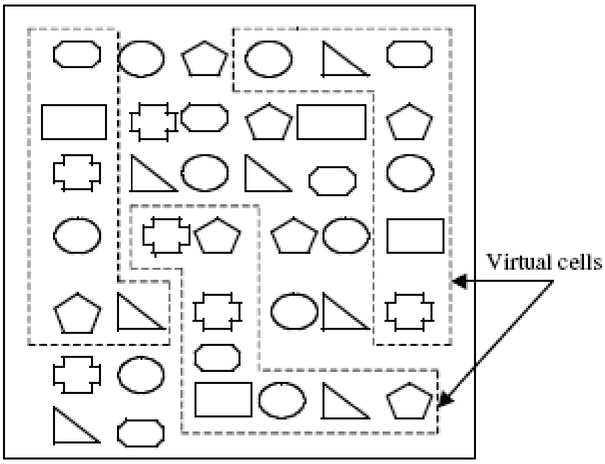

Figure 1: A virtual manufacturing system

In a VCMS, machines in a functionally organized facility would be temporarily dedicated to a part family. When a part requires processing it is routed to those machines dedicated to the part family. Thus as in physical cells, dominant flow patterns arise. Machines in the virtual cell are set up for that product family. If the demand pattern changes, the machines in any virtual cell can be reassigned to another part family. Since no machines have to be moved, there is really no rearrangement cost. This is an important advantage since using physical cells in the face of uncertain demand might result in cells having to be rearranged frequently on an ad-hoc basis. If the machines are not mobile, this could result in high costs (if the cells are reconfigured) or high inefficiency (if the cells are not reconfigured).

Ratchev (2001) describes an iterative and concurrent method for designing virtual manufacturing cells through four steps. The first step involves identifying component requirements and generating processing alternatives. Then the boundaries of the virtual cell capabilities are defined, following which the machine tools are selected. The final step is system evaluation. Prince and Kay (2003) discuss the use of virtual groups (VG) to enhance agility and leanness in production. Both VCMS and VG use the concept that machines in a cell need not be physically located close to one another. However, while VCMS focuses on managing the process, VG focuses on the management of products from design to production. So the relationship of VCMS to VG is somewhat analogous to the relationship between CMS and GT. GT is a much broader concept than CMS and in fact includes CMS as its component. GT involves among other things, part family identification, engineering design rationalization and variety reduction, and process planning.

APPROACH USED IN CELLULAR MANUFACTURING

Filho and Tiberti (2006) introduced grouping genetic algorithm with new crossover, mutation operators, correction scheme and a new codification scheme of chromosomes based on machine groups rather than individual machine and the methodology efficiently seemed to converge faster. Hu and Yasuda (2005) pursued a research based on alternative process routes for cell formation problem and developed a GGA (Grouping Genetic Algorithm) methodology with new chromosome representation, separate crossover heuristic and special mutation technique which produces efficient and optimal solution. The effectiveness of the method depends upon the quantity and accuracy of the information available (Karuna et al., 2012). Many current cellular manufacturing applications are running in a non optimal environment and their performance could be improved by optimizing the parameters.

Nsakanda et al. (2006) modeled a CFP with multiple dimensions such as operations sequence, part demands, machine capacities, multiple process plans and multiple routings and developed a GA method combined with price-direct decomposition method, and computational experiment produced good results for large-scale problems. Tabu search is believed to be one of the most successful meta-heuristic techniques for the NP (Non-Polynomial) complete applications. A comprehensive introduction to TS (Tabu Search) can be found in the book by Glover and Laguna (1997). Sun et al. (1995) modelled the CFP (Cell Formation Problem) with an objective of minimizing inter-cell material flows as a graph partition problem and developed a TS-based iterative improvement algorithm to solve the resulted problem. Logendran and Karim (2003) also considered long-term memory based on minimal frequency to solve CFP, and a TS approach was developed to improve solutions which was initially developed followed by six different versions of it in order to investigate the impact of long term memory and the use of fixed versus variable tabu list sizes. All approaches outperformed the mixed-integer programming model obtaining solutions which are close to optimal in no significant amount of time. Cao & Chen (2004) stated a CFP with fixed charge cost by minimizing the summation of inter-cell material handling cost, cell construction cost and machine related costs using an embedded. Optimization procedure to transform the original mixed integer programming model into a pure binary problem, hence applied TS to yield optimal or near optimal solution of the reduced problem. Das et al. (2006) proposed the multi-objective mixed integer-programming model for CMS design by minimizing machine operating and utilization cost and total material handling cost and maximizing system reliability. The methodology introduced is hybridized SA (Simulated Annealing) with GA operator to obtain better neighboring solutions. Arkat et al. (2007) developed a sequential CFP model based on SA for large-scale problems and compared their method with GA. They reported similar results for both methods where SA needed less computational time. Safaei et al. (2008) proposed a model of dynamic cellular manufacturing system (DCMS) with different objectives of minimizing total machine cost, intercell and intracell material handling cost, reconfiguration cost and solved their model using mean field annealing (MFA) embedded SA and MFA-SA. Wu et al. (2008) experimented with a SACF model which is sequential in nature, which follows minimization of number of voids and EEs. Evolutionary algorithms (EAs) are global, parallel, search and optimization methods, found on the principles of natural selection (Darwin, 1929) and population genetics (Fisher, 1930). PSO algorithm was first proposed by Kennedy and Eberhart (1995) in the mid-90s, which is one of the latest evolutionary optimization techniques. PSO is inspired by the metaphor of social interaction and communication in a flock of birds or school of fishes. In these groups, there is a main agent who guides the movement of the whole swarm. The movement of every individual is based on the main agent and on his own knowledge. PSO (Particle Swarm Optimization) is population-based and evolutionary in nature. Therefore, particles in a PSO method normally follow the main agent which is the one with the best performance. The techniques required to investigate the effect on different performance measures if the number of cell / cell size/composition of cells varied (Arora et al., 2011). a mathematical programming approach is proposed to design a layered cellular manufacturing system in highly fluctuated demand environment. A mathematical model is developed to create dedicated, shared and remainder cells with the objective of minimizing the number of cells. In contrast with classical cellular manufacturing systems, in layered cellular systems, some cells can serve to multiple part families (Bulent, 2015).

CONCLUSION

There has been much literature in the area of cellular manufacturing. Most of the research in this area assumes that cells once designed need not to be redesigned for a considerable length of time. However, with the advent of global competition and advancements in technology, life cycles of products have become much shorter. CMS and particular layout can be selected for minimization of the costs of material handling and investment in machines. Some recent work in CMS has started to address cell reconfiguration and uncertainty issues. Moreover all the measures have been quantitative. However, often there may be a combination of qualitative and quantitative considerations in designing layouts for effective resource utilization. The present aspect may be an important qualitative criterion in designing layouts and could be incorporated by the use of multi-objective methods in layout design**.** One of the advantages of pure CMS is that workstations are designed to be in proximity of one another, based on product flow. This opens opportunities for organizing the best teams of workers with decision making responsibilities. Future research needs to examine how these issues could be integrated with flexible cell design, which helps dealing with demand and part mix variations, but where machines may not be physically located to next to each other. Future case studies of the implementation of some of the procedures described in this paper may shed lights on these issues. Boudreau (2004) presents a survey of papers that appeared in the first fifty years of the journal Management Science related to organizational behavior.

REFERENCES

[1] Askin, R.G., Standridge, C. R. (1993), Modelling and Analysis of manufacturing systems, Hamiton Printing, USA, pp.163-165.

[2] Abdulmalek FA, Rajgopal J (2006) Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. Int J Prod Econ 107:223–236

[3] Bulent et. al. (2015) Comparison of layered cellular manufacturing system design approaches, omputers & Industrial Engineering 85 (2015) 346–358.

[4] Burbidge, J. (1979), Group Technology in the Engineering Industry, Mechanical Engineering Publications LTD, London, pp. 60-68, 103-105.

[5] Craig, R.J., Moore, J.M. and Turner, W.C. (1975) Planned pro- duction ¯exibility. Industrial Engineering, 7(1), 33±37.

[6] Dahel, N.E. and Smith, S.B. (1993) Designing flexibility into cellular manufacturing systems. International Journal of Production Research, 31(6), 933±945.

[7] Dyer JH, Ouchi WG (1993) Japanese-style partnerships: giving companies a competitive edge. Sloan Manag Rev 35:51–63

[8] Doolen TL, Hacker ME (2005) A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers. J Manuf Syst 24(1):55–67
[9] Gupta T, Seifoddini H (1990) Production data based similarity coefficient for machine-component grouping decisions in the design of a cellular manufacturing system. Int J Prod Res 28:1247–1269
[10] Houlahan CJ (1994) Reduction of front-end loading of inventory: making the airframe industry lean through better inventory management. Massachusetts Institute of Technology, Cambridge
[11] Hachicha W, Masmoudi F, Haddar M (2007) - An improvement of a cellular manufacturing system design using simulation analysis. Int J Sim Mod 4(6):193–205.
[12] Hoeck M (2008) A workload control procedure for an FMC integrated in a job shop. Int J Comput Integr Manuf 21(6):666–675
[13] Huang MG, Chang PL, Chou YC (2003) Fast algorithm for evaluating the similarity of manufacturing processes within dynamic production environment. Int J Prod Res 41(17):4171–4183.
[14] Haque B (2003) Lean engineering in the aerospace industry. Proc Inst Mech Eng, B J eng manuf 217:1409–1420
[15] Irani SA, Subramanian S, Allam YS (1999) Introduction to cellular manufacturing system. In: Irani SA (Ed.), Handbook of Cellular Manufacturing Systems, (pp. 29–30) ISBN 0-471-12139- 8. Wiley: New York
[16] Irani S. A. (1999), Handbook of Cellular Manufacturing Systems; Wiley, New York
[17] Jina J, Bhattacharya AK, Walton AD (1997) Applying lean principles for high product variety and low volumes: some issues and propositions. Logist Inf Manag 10(1):5–13
[18] Liker JK (2003) The Toyota Way: 14 management principles from the world's greatest manufacturer. McGraw Hill, New York
[19] Laughlin, K (1995) Increasing competitiveness with a cellular process. Ind Eng (April):30–33.
[20] MacDuffie JP, Sethuraman K, Fisher ML (1996) Product variety and manufacturing performance: evidence from the international automotive assembly plant study. Mgmt Science 42:350–369
[21] Morris, J.G. and Tersine, R.J. (1990) A simulation analysis of factors influencing the attractiveness of group technology layouts. Management Science, 36(8), 1567±1578.
[22] Monden Y (1983) Toyota Production System. Industrial Engineering and Management Press, Norcross
[23] Nicoletti,SNicosi a G.,Group Technology with flow shop cells ,University of Roma,Itally(1998).
[24] Nicoletti, S., Nicosia, G., Pacifici, A. (1998), Group Technology with flow shop cells,University of Roma, Italy.
[25] Olorunniwo F. (1996), Changes in production planning and control systems with implementation of cellular manufacturing; *Production and Inventory Management, First Quarter*; 65-69.
[26] Ohno, T. (1988). Toyota production system: beyond large-scale production. Cambridge,MA, Productivity Press.
[27] Ohno T (1988) Toyota Production System: beyond large scale production. Productivity, Portland
[28] Pattanaik LN, Sharma BP (2008) Implementing lean manufacturing with cellular layout: a case study. Int J Adv Manuf Technol, 42:813. doi:10.1007/s00170-008-1629-8
[29] Pavnaskar SJ (2001) Developing a structured toolset for lean product development. Master of Science Thesis, Michigan Technological University, Houghton, Michigan.
[30] Sahoo AK, Singh NK, Shankar R, Tiwari MK (2008) Lean philosophy: implementation in a forging company. Int J Adv Manuf Technol 36:451–462.
[31] Sohal AS, Egglestone A (1994) Lean production: experience among Australian organizations. Int J Oper Prod Manage 14 (11):35–51
[32] Singh, N. (1993), Design of cellular manufacturing systems, European Journal of Operational Research 69, pp.284-291.
[33] Spear, S, Bowen, KH (1999) Decoding the DNA of the Toyota Production System. Harvard Bus Rev (September–October):96–106.
[34] Shingo S (1992) The Shingo prize production management system: improving process functions. Productivity, Cambridge
[35] Singh, N. (1993) Design of cellular manufacturing systems: an invited review. European Journal of Operational Research, 69(4), 284±291.
[36] Shah R, Ward PT (2007) Defining and developing measures of lean production. J Oper Manag 25:785–805
[37] Tilsley, R. and Lewis, F.A. (1977) Flexible cell production systems ± a realistic approach. Annals of the CIRP, 25, 269±271.
[38] Tomas B, Antonio MJ (2006) An empirical study of lean production in the ceramic tile industry in Spain. Int J Oper Prod Manage 26(27):505–531
[39] Vakharia, A.J. (1986) Cell formation in group technology: a framework for evaluation. Journal of Operations Management, 6(3), 257±272 (1986).
[40] Vakharia, A.J., Askin, R.G. and Selim, H.M. (1997) Flexibility considerations in cell design. in Handbook of Cellular Manufacturing, Irani, S.A. (ed.), John Wiley and Sons, New York, pp. to appear.
[41] Wong YC, Wong KY, Ali A (2009) A study on lean manufacturing implementation in the Malaysian electrical and electronics industry. Eur J Sci Res 38(4):521–535
[42] Wemmerlov U, Johnson DJ (1997) Cellular manufacturing at 46 user plants: implementation experiences and performance improvements. Int J Prod Res 35:29–49 doi: 10.1080/002075497195966.
[43] Wemmerlov U., Hyer N.L. (1987), Research issues in cellular manufacturing; *International Journal of Production Research* 25(3); 413-431.
[44] Wemmerlov U., Hyer N.L. (1989), Cellular manufacturing in the U.S. industries: A survey of users; *International Journal of Production Research* 27(9); 1511-1530.
[45] Womack, J.P., Jones, D.T., & Roos, D. (1990). The machine that change the world. New York, Free Press.
[46] Womack, J.P., & Jones, D.T. (1996). Lean thinking: banish waste and create wealth in your corporation. New York, Simon & Schuster.

[47] Womack JP, Jones DT (1996b) Lean thinking: banish waste and create wealth for your corporation. Simon & Schuster, New York

[48] Womack JP, Jones D (2003) Lean thinking: banishing waste and create wealth in your corporation. Free, New York

[49] Womack JP, Jones DT (1996a) Beyond Toyota: how to root out waste and pursue perfection. Harvard Bus Rev (September–October):140–158.

[50] Womack JP, Jones DT, Roos D (1990) The machine that changed the world. Rawson, New York

[51] WemmerloÈ v, U. and Hyer, N.L. (1989) Cellular manufacturing in the U.S. industry: a survey of users. International Journal of Production Research, 27(9), 1511-1530.

Corresponding Author Mail ID- srmasne@gmail.com