Study on Implementation of Lean Production System in Inner Tube Manufacturing Industry – A Case Study

D.Arunkumar
Associate Professor, Department of Industrial and Production Engineering,
S.J. College of Engineering, Mysore, Karnataka, India

Dr. V.Ramesh
Professor, Department of Industrial and Production Engineering,
S.J. College of Engineering, Mysore, Karnataka, India

Abstract - This case study industry manufactures more than 45 different sizes of tubes for 9 different buyers and is one of the largest manufacturers of Automotive Butyl Inner Tubes in India. In the present plant layout the industries main plant has 8 major aisles. Machines are classified based on the operations and order of process. The machine aisles are arranged using cellular manufacturing concept of process layout. The material handling system is studied and evaluated. The layout of straining section is optimized. Using Kaizen concept a methodology is suggested to effectively utilize the tube storage area. In production work stations, the equipments are arranged in a sequence that supports a smooth flow of materials with minimal transport or delay.

Keywords: cellular manufacturing, cellular layout, kaizen

I. INTRODUCTION

This paper discusses the key areas that characterize the identification of various wastes of Lean Manufacturing and suggests implementation methods to rectify these wastes. In the case study industry there is a situation of high degree of machine utilization along with the multitask labour and decrease in the overhead costs. But the issue is with the inexistence of a proper scheduling of the machines and there is no scientific method of loading the machines. Further, material handling, has been unscientific. A high degree of contradictions has been observed in terms of quality to cost and training. To overcome these issues, several factors were considered to improve the situation. Several tools of Lean Manufacturing concepts have been implemented. The important bottlenecks in the material handling system, equipment & space, WIP inventory have been studied and rectified.

It is seen that the manufacturers face heightened challenges such as rising customers' expectation, fluctuating demand, and competition in markets. One way to stay competitive in this globalized market is to become more efficient.

II. LITERATURE REVIEW

Gupta (1990) [1] opines 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). Wemmerlov U, Johnson DJ (1997) [2] discusses the Cellular manufacturing (CM), which is an application of group Technology and 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.

Irani SA, Subramanian S, Allam YS (1999) [3] is of the opinion that the companies that cellular manufacturing systems have many advantages. They are used for reducing the work in process and flow time, setup times, and tooling costs. Further, the space utilization and move times are reduced, and aims at production planning and control simplification. The markets are characterized by uncertainty in terms of demand fluctuations, product mix changes, and the product life cycles are drastically reduced. These conditions force to reconfigure the cells of the cellular manufacturing systems in order to keep a high level of performance.

Hachicha W, Masmoudi F, Haddar M (2007) [4] proposed a simulation approach considering the stochastic issues in CMSs. They considered the existence of exceptional elements between the parts and the effect of their intercell movements. They compared two strategies: permitting intercellular transfer and exceptional machine duplication.

Hoeck M (2008) [5] proposed an alternative approach for loading problem in a flexible manufacturing cell environment. The innovative logic approach involves three phases, lead orders are identified, transfer batches of the lead part types are calculated, and workload of the machining centers is determined. A simulation environment was used to test the proposed approach.

Huang MG, Chang PL, Chou YC (2003) [6] developed an algorithm for optimal management of rush orders and prescheduled orders when production mix changes.

Cellular layout divides the manufacturing facilities in to small groups called cells which will be exclusively utilized for specific task Nicoletti,SNicosi(1998). [7]. A cell contains equipment and work stations that are arranged to maintain the smooth flow of product without waiting time Farwaz A Abdulmalek ,Jayant Rajgopal "(2007) [8]. The advantages of this cell based layout is to achieve single piece flow, improve the quality of the product, minimize the WIP, reduce the throughput time, reduce the setup time and improve the productivity Burbridge, J (1979) [9].In addition to this, the cellular layout will minimize the material movement between the production process Thomopoulos,N.T .(1986) [10] and create better understanding among the members in the cell [Richard et al, 2003].

2.1. 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) [16]. Following are the characteristics of effective cellular manufacturing practice. Should have one-piece or very small lot of flow. The equipment should be right-sized and very specific for the cell operations. Is usually arranged in a C or U shape so the incoming raw materials and outgoing finished goods are easily monitored. Should have cross-trained people within the cell for flexibility of operation. Generally, the cell is arranged in C or U shape and covers less space than the Long assembly lines There are lots of benefits of cellular manufacturing over long assembly lines. Some of them are as follows Heizer, J., and Render, B. (2000) [17]. Reduced work in process inventory because the work cell is set up to provide a balanced flow from machine to machine. Reduced direct labor cost because of improved communication between employees, better material flow, and improved scheduling. High employee participation is achieved due to added responsibility of product quality monitored by themselves rather than separate quality persons. Increased use of equipment and machinery, because of better scheduling and faster material flow. Allows the company higher degrees of flexibility to accommodate changes in customer demand. Promotes continuous improvement as problems are exposed to surface due to low WIP and better communication. Reduces throughput time and increases velocity for customer orders from order receipt through production and shipment Apart from these tangible benefits, there is the very important advantage of cellular manufacturing over the linear flow model. Due to the closed loop arrangement of machines, the operators inside the cell are familiar with each other's operations and they understand each other better. This improves the relation between the operators and helps to improve productivity. Whereas in long assembly line one operator knows only two operators (before and after his operation in the line) it seems that operators are working independently in the line Classical layouts (product, functional and cellular type layout configurations) are generally generated for a given part spectrum and demand. Moreover, in these layout designs, it is assumed that part spectrum and demand is almost stable for a considerable long planning horizon (2–5 years). Unplanned changes in part spectrum and demand generally requires reconfiguration of these layouts. Reconfiguration may become very expensive and hard to validate if the factory is operating in a highly volatile environment. Knowing that the manufacturing system is operating under a rapidly changing environment where flow patterns are not traceable, routings varying drastically from part to part, then its layout should be flexible. In other words, there is a need for a new generation of factory layouts that are more flexible, modular, and more easily reconfigurable. Flexibility, modularity, and reconfigurability could save factories from the need to redesign their layouts each time their production requirements change Olorunniwo F. (1996), [12] 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), [11] divided these layout strategies into four groups: • Modular layouts • Reconfigurable layouts • Agile layouts • Distributed layouts In modular layout approach, the layout is constructed as a network of basic layout modules (functional, cellular, flowline etc.). Modular layouts are based on the assumption that, at least in the short term, the product spectrum is known and demand is stable. If any changes occur then several layout modules are eliminated and new ones are added. 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 Wemmerlov U., Hyer N.L. (1987) [13]. 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 a multi-period (or dynamic) facility layout problem the optimal location of each department in each production period is tried to be found by minimizing the total cost of material handling and relocation (Baykaso˘glu and Gindy 2001; Baykaso˘glu et al.1998 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 employed for designing such layouts. Wemmerlov U., Hyer N.L. (1989) [14] 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,SNicosi (1998). [7]. 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) [1, 3, 5,6]

2.2 Cellular layout for LM:

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, 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.

Cellular Manufacturing a method to arrange factory floor labor into semi-autonomous and multi-skilled teams, or work cells, who manufacture complete products or complex components. As Irani S. A (1999), [11] describe in the handbook of Cellular Manufacturing Systems, Cellular Manufacturing (CM) is an application of the Group Technology (GT) concepts to factory reconfiguration and shop floor layout design.

Wemmerlov U., Hyer N.L. (2002) [15] define a cell as a group of closely located work stations where multiple sequential operations are performed on one or more families of similar row materials, parts, components, products or information carries. They define a manufacturing cell as a cell whose main purpose is to physically process, transform, transmit and add value to materials whose end state are products or components and an office cell as a cell whose main task is to process, transform, transmit, and add value to information. Moreover, they discuss four perspectives on cells: resource perspective, spatial perspective, transformation perspective and organizational perspective. Ham et al. (1985) define a manufacturing cell as an independent group of functionally dissimilar machines, located together on the floor, dedicated to the manufacturer of a family of similar parts. A Cellular Manufacturing System (CMS) design is usually partitioned to several phases, including the selection of parts and part families, machines and machine cells, tools and fixtures, material handling facilities and layout . Wemmerlov U., Hyer N.L. (1987) [13]. Obviously, these phases are not independent and should all be considered through cell design goals. The overall goal for the design process is to achieve performance improvement with respect to lead time, inventory, quality or other measures Wemmerlov U., Hyer N.L. (2002)[15] or in other words, to achieve advantages of a CMS. Irani et al. (1999) presented a complete list of advantages of cellular manufacturing. The most important ones, also reported by Wemmerlov U., Hyer N.L. (1989) [14]. Wemmerlov U, Johnson DJ (1997) [2] and, Olorunniwo F. (1996), [12] include reduction in move times, throughput and lead time, WIP and finished goods inventory levels, setup times, as well as improvement in quality, capacity and equipment utilization. The basic idea in Cellular Manufacturing is to group parts that have similar processing needs into part families, and machines that meet these needs into machine cells. Each machine cell is dedicated to the manufacture of a part family. The advantages of Cellular Manufacturing over traditional manufacturing are many folds. To mention a few of them reduced setup time, work-in-process inventory, lead-time, simplified flow of materials, improved human relations etc. Cellular Manufacturing combines the efficiency of a flow shop layout with the flexibility of a job shop layout The first problem that must be addressed when considering a Cellular Manufacturing is that of cell formation. 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 [3]-[4]. This kind of layout is also appropriate for both automated and non automated manufacturing systems

III. CURRENT STUDY

The medium scale industry has 8 major aisles. Machines are classified based on the operations it has to perform and in the order of process, the machine aisles are arranged. The process layout is shown in the Figure 1.

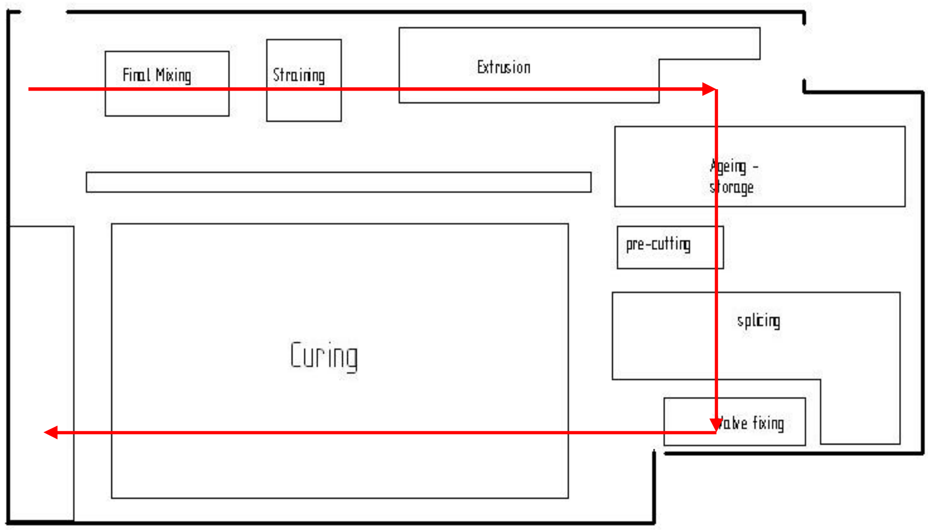


Fig 1 Process Layout

In this type of layout the machines of a similar type are arranged together at one place. Cellular layout is used for batch production. The emphasis is given on general purpose machine. The work is allocated to the machines according to loading schedules with the object of ensuring that each machine is fully loaded. The main disadvantages of the existing layout in the medium scale industry is material handling costs are high due to backtracking, more skilled labor is required resulting in higher cost, work in progress inventory is high needing greater storage space and more frequent inspection is needed which results in costly supervision.

Further, the Inner tube production process is studied for the analysis. This consists of 8 major processes starting from the final mixing to the curing of tubes. The inner tubes produced are called as green tubes, since they are not cured and are in a 'green' state. i.e., further chemical processing is possible. Once the tubes are cured, then they are ready for usage. It has been observed that the production lines are a combination of both push and pull systems as shown in Figure 2. The push portion is only up to the ageing process and the pull system is incorporated from the curing press. It is a known fact that the lean concept envisages a complete pull system throughout the production line, but since ageing process holds most of the inventory, implementing a total pull system is becoming difficult by the industry.

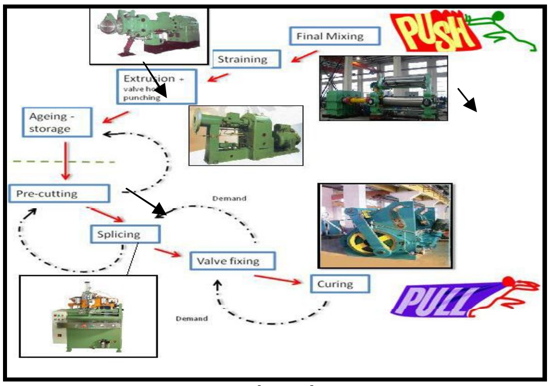


Figure 2: Inner tube Production Process

Wastes observed in the Industry

The initial observation in the medium scale industry revealed the following wastes as summarized in the Table. 1.

Table 1 Wastes observed

Wastes	Description
Transportation	Daily supply of raw material by truck even though stores are present in the plant
Inventory	High amount of work in process (WIP)
Movement	Excess worker movement during operation and material handling
Wait	Machine downtime, slow processing and human errors cause waiting of product and worker
Over processing	Seen on extruder and during recycling of tube
Over production	Excess production of strained butyl bits or green tubes
Defect	Valve open, splice open, surface crack, inclusion etc

Objectives

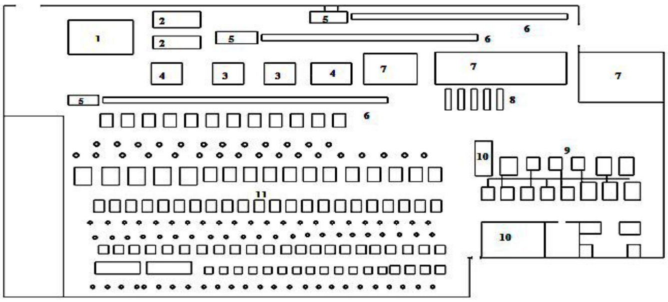
This paper discusses the study of layout and evaluation of plant material handling system, effective and efficient Utilization of Equipment and space, elimination of wastes through improvement in existing methods, minimization of inventory levels, improving man - machine productivity through reduction in fatigue, defects and wastage reduction.

IV. PROPOSED STUDY

Evaluation of Material Handling System

The medium scale industry produces 45 different sizes of tubes. Every tube has its own specific size and specifications. Based on such technical parameters, the overall cycle time for every tube is different. On the other hand, every machine can produce and process almost all the sizes; though such case is restricted. The factory is maintaining multi-function worker system. "Gemba" analysis showed that there are several problems in the production and material handling system on the shop floor. Extensive brainstorming with the guidance team helped to come up with a plan to establish a flow process diagram for a particular batch of production in order to evaluate the material handling system and to quantify the problems. To optimize the layout issues, the flow process diagram was drawn.

The study has been carried out in R & C Extruder unit in A23 press. The Material chosen for the study was TCB04 its weight is 365 g/tube, batch quantity of 564 tubes, batch time of 40 min/batch and lead time is 640 min/batch, the time in as butyl rubber rolls is 10:50 A.M / Shift 1 and time out for green tubes is 9:30 PM/ Shift 2. A flow process diagram for the layout is shown in the Fig 3.



1. Final Mixing – 84" MILL.
2. Straining – Plus one barwell strainer.
3. Warming Mill – 42" MILL.
4. Feeding Mill – 42" MILL.
5. Extrusion – R&C, Kada & Troester Extruder.
6. Valve hole punching.
7. Ageing – Storage trolleys.
8. Precutting.
9. Splicing.
10. Valve Fixing
11. Curing – Press

Fig 3 Flow Process Diagram

4.2 From-To Chart:

The "From-To Chart" is charted between the machines in the final mixing, straining, extrusion and ageing sections. The Table 1 shows the number of worker movements to and from a machine. Standard time is established only for final mixing as the mixing procedure is the same irrespective of material and size. Straining duration depends on the composition of material and temperature of the final mixed roll.

Table 1 Existing Travel Chart

To From	Entrance	84" Mill	Strainer	Rack	42" Mill	Extruder	Ageing-trolley
Entrance	--	1					
84" Mill		--	1				
Strainer			--	14			
Rack			14	--	14		
42" Mill				14	--		
Extruder						--	13
Ageing-trolley						13	--

The data of standard time and observed time for the various processes between the machines in the final mixing, straining, extrusion and ageing sections are shown in the Table 2.

Table 2 Value added time

Process	**Standard Time duration in minutes**	**Observed time duration in minutes**
Final Mixing	15	18
Straining	--	19
Extrusion	--	40

Based on the data collected, the machining Cycle Efficiency is calculated. It is observed that the Machining Cycle Efficiency is 1.40%. This low efficiency is an indication of poor manufacturing environment caused by inadequate material handling and poor plant layout. Further, Material Handling Ratio was observed to be 46.67%. The Movement per operation ratio is calculated by dividing number of movements by number of operations and for the above process the value is 24.25. This is also too high as per the occupational Safety & Health Administration (OSHA) standards optimum M/O ratio has to be around 4.

From the above ratios it can be concluded that the production efficiency has to be increased with the reduction in material handling personnel, material handling costs and also reduction in the number of movements of the worker.

V. LAYOUT OPTIMIZATION OF STRAINING SECTION

In this case study, the straining operation is performed to filter out the foreign particles such as sand, metallic inclusions, inorganic particles etc. The chance of such inclusion is high in the 84" Mill as final mixing is done in open air. The problems encountered in the straining section are excess worker movement which results in fatigue to the worker, Cross & excess zigzag movement of the worker and wasteful occupancy of floor space by the machines. An existing arrangement of the machines in this section is shown in the Figure 4.

Table 2: Details of the movements of worker

Index	
Worker movement before straining	
Worker movement after straining, to rack	
Trolley from 84" Mill	

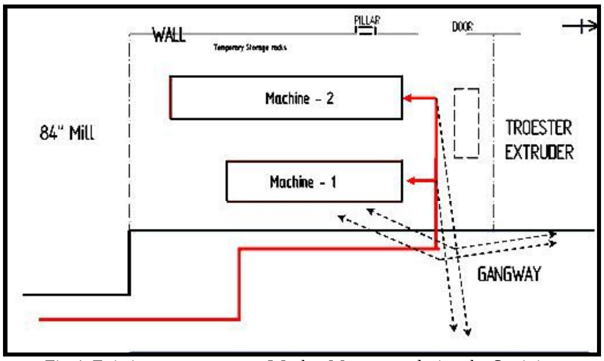


Fig 4: Existing arrangement – Worker Movement during the Straining

After extensive brainstorming with the team, the proposed arrangement was finalized and is shown in the Figure 5. The changes to be made to achieve optimum position of the strainer are,

- Rotate the strainer by 90° so that the intake opening faces the gangway.
- The door and wall and right side of the pillar is to be removed so that the strainers are placed slightly behind.
- The end portion of the strainer has to occupy the utility space behind the wall.

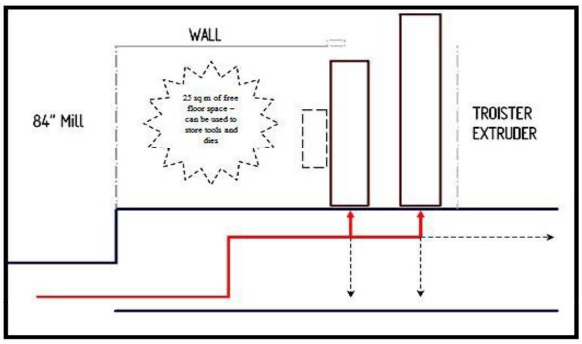


Fig 5: Proposed arrangement – Worker Movement during the Straining

VI. KAIZEN ON 'SEIRI' OF TUBE STORAGE AREA

Ageing is a very important process in rubber based industry. Rubber in the green state is very vulnerable to the external temperature and weather. The lengths of the extruded tubes vary due to varying weather. Hence in the medium scale industry, the inner tubes produced through extrusion have to be aged for a minimum of 2 hours, and must be exhausted within the next 24 hours. This ageing is done on trolleys which are placed in the 'Tube Storage Area'. Due to inefficient planning and arrangement of the trolleys along with unreasonable wastage of space the ease of access to the trolleys was compromised. The chokepoint was addressed with Kaizen in de-congesting, simplifying and making a more logical and convenient arrangement of the trolleys.

It has been observed that the space between the trolleys was very minimal and only one worker can move at a time, it was very difficult for the worker to carry the tubes for a long distance in the congested way. The trolleys which were meant to store heavier tubes are kept at the farthest location of the tube storage area and few trolleys occupy the gangway as well. The tube storage area occupies a very large area of floor space in the plant. In view of these, the proposal has been made to eliminate these problems.

The new arrangement houses 21 trolleys whereas the existing houses only 18. Additional gangway for worker movement is provided, after the type-4 trolley. This facilitates 2 workers to access a trolley in the same row/gangway and Type-6 trolley is directly open to the gangway out of the aisle, facilitating easy access. The trolley sizes are, Type 1: 1.97m x 0.95 m Type 2: 2.74 x 0.88, Type 3: 2.86 x 0.95, Type 4: 1.97 x 0.85, Type 2.86 x 1.22 and Type 6: 2.44 x 0.88.

The existing and proposed arrangements are shown in the Fig. 5.and 6.

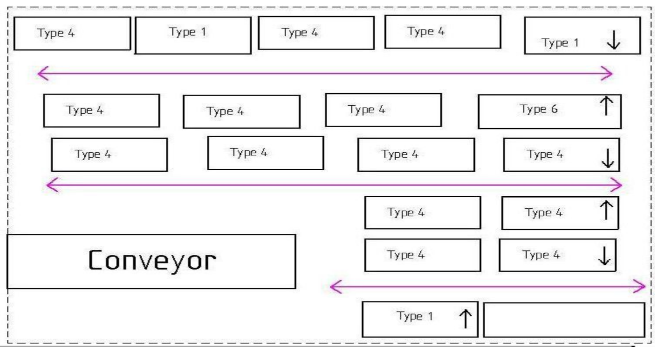


Fig 5 Existing Arrangement

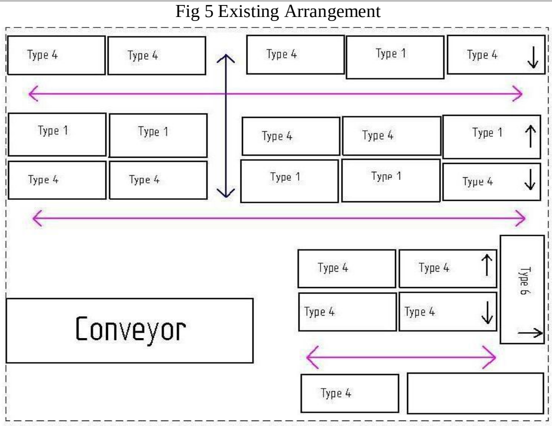


Fig 6 Proposed Arrangement

Similarly, the Tube storage area 3 is also studied and it is observed that, the existing arrangement houses 25 trolleys and the new arrangement requires only 23 trolleys and also provides ease of access. This results in the increase in the width of gang space. The advantages are the Type-3 and type-5 trolleys are placed in easy access position, Type-1 trolley is placed open to gangway and additional space for worker movement in the central portion of the area.

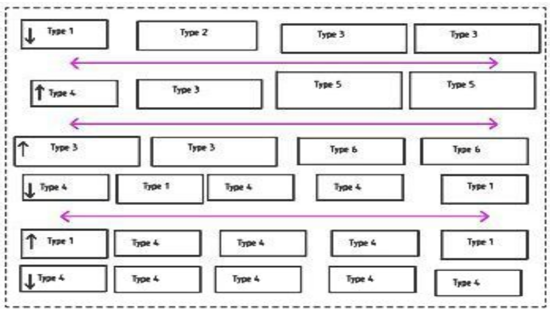


Fig 8 Existing Arrangement

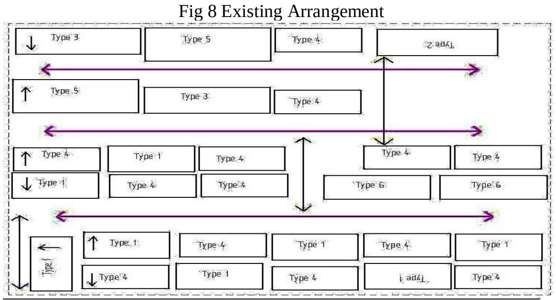


Fig 9 Proposed Arrangement

It has been observed that the area covered by existing arrangement is 227 Sq m and the area covered by the proposed arrangement is 201 Sq m and there is a saving of 11.25% floor space.

VII. RESULTS AND CONCLUSION

From the ratios, it can be concluded that the production efficiency has to be increased with the reduction in material handling personnel and material handling costs. Also it suggests about the reduction in the number of movements by the worker

The change in position answers all the problems encountered in the straining section. With the reduction of zigzag motion of the worker, fatigue reduces. Additional advantage of free 25 sqm space is obtained over the earlier congested 5 sqm, which can be effectively utilized to store dies and toolboxes in an easy access position.

The existing arrangement poses a lot of problems as mentioned in the problem statement. The incorporation of the new arrangement resolves all the issues. It reduces worker fatigue and simplifies the arrangement. It makes the storage area more uniform. Also, there is a considerable saving in the floor space which can be utilized for other purposes such as tool storage or equipment service bay.

The best solution is to remove one pre-cutting machine as the cutting demand can be met with 3 machines for MMC sizes and 1 machine for bigger sizes. By removal of one machine, the power consumed by it is saved. Useful floor space is achieved. Also, that worker can be employed elsewhere.

REFERENCES

[1] 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 doi:10.1080/00207549008942791

[2] 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.

[3] 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

[4] 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.

[5] Hoeck M (2008) A workload control procedure for an FMC integrated in a job shop. Int J Comput Integr Manuf 21(6):666–675

[6] 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.

[7] Nicoletti,SNicosi a G.,Group Technology with flow shop cells ,University of Roma,Itally(1998).

[8] Farwaz A Abdulmalek ,Jayant Rajgopal ‘Analysing the benefits of Lean Manufacturign and value stream mapping via simulation :A process sector case study “,Int.J.Production Economics”(2007)223-236

[9] Burbridge, J. (1979), Group Technology in Engineering Industry, Mechnaical Engineering Publications Ltd,London, PP 60-68.

[10] Thomopoulos,N.T.(1986),Mixed Module line balancing with smoothed station assignment Management Science,PP 593-603.

[11] Irani S. A. (1999), Handbook of Cellular Manufacturing Systems; Wiley, New York

[12] 12.Olorunniwo F. (1996), Changes in production planning and control systems with implementation of cellular manufacturing; Production and Inventory Management, First Quarter; 65-69.

[13] Wemmerlov U., Hyer N.L. (1987), Research issues in cellular manufacturing; International Journal of Production Research 25(3); 413-431.

[14] 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.

[15] Wemmerlov U., Hyer N.L. (2002), “Reorganizing The Factory” competing through cellular Manufacturing; Productivity Press.

[16] Wilson, L. (2009). How to Implement Lean Manufacturing. New York: McGraw-Hill Professional Publishing. p. 29- 214

[17] Heizer, J., and Render, B. (2000), Principles of Operations Management 4th Edition. Pearson College Div. ISBN-10: 0130271470. p. 336-420.