Ph.D. THESIS

PARAMETRIC STUDIES IN AUTOMOBILE MANUFACTURING INDUSTRY USING CELL FOCUSED PLANT SIMULATION APPROACH

A Thesis Submitted to R.T.M.Nagpur University, Nagpur in fulfilment of requirements for the Degree of

Doctor of Philosophy

in

Mechanical Engineering

in the Faculty of Engineering and Technology

by

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March – 2016

Laxminarayan Institute of Technology

Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur
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Forwarded herewith to the **Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra** the thesis titled **"Parametric Studies in Automobile Manufacturing Industry Using Cell Focused Plant Simulation approach"** submitted by **Mr. Jayant H. Bhangale** in the fulfilment of the requirements for the award of the degree of Doctor of Philosophy.

Dr. Ashish M. Mahalle
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ANNEXURE-V

CERTIFICATE

This is to certify that the work presented in this thesis entitled: **"Parametric Studies in Automobile Manufacturing Industry Using Cell Focused Plant Simulation approach"** is the own work of **Shri Jayant Hemachandra Bhangale** conducted in **Laxminarayan Institute of Technology, Nagpur** under my supervision. This work has not been submitted earlier to any University/ Institution for any diploma or degree.

Place: Nagpur

Date: 09/03/2016.

Dr. Ashish M. Mahalle
Supervisor,
Laxminarayan Institute of Technology, Nagpur.

ANNEXURE-VI

DECLARATION/UNDERTAKING

I hereby declare that the work presented in this thesis entitled: **"Parametric Studies in Automobile Manufacturing Industry Using Cell Focused Plant Simulation approach"** was carried out by me under the supervision of **Dr. Ashish M. Mahalle, Associate Professor, Laxminarayan Institute of Technology, Nagpur** from **12/01/2012 to 12/01/2016.** This work which or any part of this work is based on original research and has not been submitted by me to any University/ Institution for the award of any diploma or degree.

JBhangale

Date: 09/03/2016
Nagpur

Mr. Jayant H. Bhangale

Sharda Motor Industries Ltd.

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To,

Mr. Jayant H. Bhangale
Ph.D. Scholar,
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Sub: Permission of Research Work

Dear Jayant,

With reference to your application for carrying out research work in "Parametric Studies in Automobile Manufacturing Industry Using Cell Focused Plant Simulation approach" under the guidance of Mr. Chandrakant Bagdane (Senior Engineer, Production Dept.).

We are glad to inform you that you are permitted to do the research work in our industry. Data collected from our company is only to be use for reference related to research work. We will offer you all the necessary help and facilities.

Thanks

For **Sharda Motor Ind. Ltd**

Atul Sheth
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To,

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Sub: No objection certificate for Research Work

Dear Jayant,

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We do not have any objection for data, photographs & videos provided by us to candidate for use in Ph.D. Thesis & Research publications only.

Assigned work is completed satisfactory & useful for future shop floor cell layout implementation.

Thanks

For **Sharda Motor Ind. Ltd**

Atul Sheth
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Sign.
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and Research Centre, Nasik, MS, for his profound knowledge and motivation in this research work.

I am immensely thankful to, Mr. Atul Seth, Chief Operating Officer (Western Zone- India) , Sharda Motors Industries Ltd., Nasik for providing necessary facilities at all stages of this research work.

I extend a special thanks to Mr. Dilip Zambre, Dy. General Manager, Mahindra & Mahindra ltd., Nasik for their kind help and co-operation.

It is the love, faith and care of these dear friends of mine, that has strengthened me in this work of mine. It is they who have never let me down even in the hardships of my life and have always reminded me of my goals.

With this I remain… ………………………………

----- Jayant H. Bhangale

ABSTRACT

Today, every automobile company's vendors are facing problems of competition, quality and productivity. Companies have a huge impact of lesser customer demand, multiple product variety and quick response to fulfill production target as per market demand. Recent research suggests that cellular layout system is better alternative for automobile industries of developed countries like US, Japan and Germany due to operator and area/space problems. To survive in global competition, Sharda Motors Industries Ltd. is in phase of restructuring, modification of existing shop floor cells and elimination of bottleneck machines. Problems identified in existing layout are low manpower utilization, more time for material handling, high WIP inventory and space utilization. The objectives of the research are to reduce through put time, to increase the target of manufacturing component and completion of target as per demand, to maximize manpower utilization, to minimize space utilization, to reduce manpower requirement. Methodology includes analysis of existing layout, process sequence analysis, planning and relocation for new layout considering optimal distance between machines, optimal material handling route and analysis of proposed layout - i.e. cost analysis with validation through 'Show Flow' Simulation Software. Results shows improvement in parameters like a) Manpower utilization is increased from 72% to 92%, b) Reduction of WIP Trolleys from 14 to 02 per assembly line i.e. Total cost saving for Trolleys in Proposed Layout is Rs. 5,40,000 per annum, c) One piece flow i.e. no pending work between two

stations, d) Reduction of eleven operators per shift. i.e. 22, operators per month (for two shift) results in cost saving of Rs. 52, 80,000 per annum, e) Second economical impact is reduction of one shift per day to achieve same production target as in existing layout i.e. instead of three shift per day, target achieved in two shift per day results in huge cost saving per annum, 33% approximately, f) Machine utilization increases up to 100%, g) No backtracking of material i.e. Rescheduling decisions are avoided, h) With reduction waste in terms of setup time, waiting time, work in process inventory results in improvement of productivity, i)Production target increases due to shorter through time which result into the return business from automobile manufacturers who are satisfied due to shorter throughout time, j) Saving in space is 34.24% by proposed layout implementation due to redesign of layout and combining multiple operations into single operation using new technology and k) Scope for company to run third shift for additional production as per existing or new customer requirement i.e. profit margin will increase by 33 % per annum compare to existing conditions.

ACKNOWLEDGEMENTS

*Pursuing **P.hD** is a learning experience. It's like climbing a high peak, step by step, filled with hardships, frustration, encouragement, trust and support from many. Where one realizes that reaching to top is in fact a teamwork that got you there. Though this it will not be enough to express my gratitude in words to all those who helped me, I would still like to heartily thank all who played their part to enable me achieve this mammoth task.*

The satisfactions, which accomplish a successful completion of any task, are incomplete without the mentioning of the names of those people who makes it possible.

*First of all, I would like to express my deepest gratitude to my Research Guide **Dr.A.M.Mahalle, Head-General Engg., Laxminarayan Institute of Technology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur** for his constant help, unflinching guidance, critical comments, helpful suggestions and constructive criticism extended to me during the course of this study.*

*I would like to express my deepest respect to **Dr. Raju B. Mankar, Director, Laxminarayan Institute of Technology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur** for providing necessary facilities at all stages of this research work.*

*I would like to express my deepest respect to **Dr. G.K.Kharate, Principal, Vice Principal Dr.V.H.Patil, Matoshri College of Engineering***

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Contents

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List of Abbreviations

This section presents a list of abbreviation used within this thesis, along with the full names of the aabbreviation.

AGV-automatic guided vehicle

WIP-Work-in-progress

CMS-Cellular Manufacturing System

CM-Cell Manufacturing

GT-Group Technology

POA-Product Oriented Approach

FCM-Focused cellular manufacturing

WP-Workforce planning

CF-Cell formation

LCCR-Low cost common rail

DED-Double end drive

SPM-Special purpose machine

VSPM-Vertical special purpose machine

TCT-Time for tool change

I-Inside time

O-Outside time

W-Walking time

TMT-Total manual time

CCT-Control cycle time

DBCT-Demand based cycle time

B.T-Basic time

Opr-Operator

Opn-Operation

IC-Initial cost

N-Payback period

NACF-Net Annual Cash Flow

MTBF-Mean time between failures

MTTR-Mean time to repair

List of Publications

1. Performance Issues of CMS in Automobile Industries using Computer Simulation
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   International Journal of Computer Applications (IJCA), USA (0975 – 8887), Volume 52– No.5, August 2012, pp 31-35.
2. Parametric Studies in Automobile Manufacturing Industry using Cell Focused Plant Layout Simulation Approach
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   European Scientific Journal (ESJ), European Science institute, UK, Vol.9, No.9 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431, March 2013, pp 261-275.
3. Studies of Productivity Improvement in Indian Automobile Industries Plant Layout
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   Presented paper in International Conference-JNU 15 on 14th & 15th March 2015 at Jawaharlal Nehru University, New Delhi and published in-
   International Journal of Advanced Technology in Engineering and Science (IJATES), Volume No 03, Special Issue No. 01, ISSN (online): 2348-7550, March 2015, pp 254-263.
4. Studies for Restructuring of Indian Auto Industries Plant Layout based on Cell Formation
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   Presented paper in Post Graduate Conference- MEPCON 2015 on 06th & 07th April 2015 at College of Engg., Badnera and published in
   International Journal of Innovative and Emerging Research in Engineering (IJIERE)
5. Parametric improvements of assembly line based on cell design-Case study of Sharda Motors Industries Limited
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   Communicated *to Sadhana - Academy Proceedings in Engineering Science, Springer publication.*
6. A Study on Parametric Analysis and validation of factory assembly shop using simulation approach
   Authors: J.H.Bhangale & Dr. A.M.Mahalle
   Communicated to *Journal of the Institutions of Engineers (India) – Series C, Springer publication.*

Chapter 01

Introduction

This chapter describes the cellular manufacturing system design problems involved in the research, the objectives of this research and the methodology for changing existing layout into new layout to overcome limitations of existing layout. The chapter also outlines the research and the structure of the thesis.

1.1 Background

Cellular layout is accepted and implemented in developed countries due to space and operator problems. Most of Indian auto companies are working under "Takao San", who is consulted for cellular concept and belonging to Japan. Like TVS, very few companies in India have implemented this layout. Sharda Motors Industries Ltd., Nasik, Maharashtra, India is planning to implement cellular system layout for assembly line, so preliminary work is going on for restructuring of existing assembly line. Efficient Automated Guided Vehicle (AGV) system design and its improvisation is a key to success for any modern manufacturing strategy. In complex cellular manufacturing system, AGV's are required to transport parts from dedicated cell, loading and unloading. In cell formation the bottleneck machines also evolve, then AGV are capable of handling parts between bottleneck machine and dedicated cell.

Some of the problems associated with present layout -

1. Handling of raw material and WIP route have more obstacles for flow.
2. Labour required per shift are more.
3. High WIP inventory.
4. Operator's idle time is more during operation.
5. Uneven layout Space Utilization between adjoining machines.
6. Low machine utilization.
7. High Machine changeover time.

1.2 Issues related to CMS implementation

a. Finding and classification of part families
b. Selection of cell equipment and their allocation to part families (or vice versa)
c. Independence of cell: component operation sequences do not flow through multiple cells
d. Flexibility for cell
    - For internal routing: to manufacture or assemble parts on alternate machinery inside a same cell

- For external routing : the ability to release parts to alternate cells
- For process : the ability of the cells to accommodate new parts

e. Flow Control

- Material obsolescence
- Material costs
- Indirect labour
- Inter-departmental stores

f. Cell Design

- Difficult load balancing
- Low or zero utilization of non-key machines
- Problems in batch size selection
- Bottleneck machines [2].

1.3 Parameters affecting Cell Layout

1.3.1 What is Cellular Manufacturing?

Cellular manufacturing is a manufacturing approach that helps companies to produce a modified and variety of goods for their clients with no waste or minimum waste. In cellular manufacturing layout, machines and workstation are arranged in a sequence for smooth flow of work-in-progress materials and parts through the manufacturing/assembly process, with minimum movement or delay.

Cellular manufacturing makes companies more profitable and competitive by reducing wastes that typically add cost and lead time to the manufacturing process. Waste in this sense means any element of the manufacturing process that adds cost without adding value to the product. Table 1 lists eight types of waste addressed by a manufacturing system [74].

Cellular manufacturing gets its name from the word cell. A manufacturing cell consists of the operators and machines or workstation required for performing the steps in a process sequence, with the machines arranged in the processing sequence. For example, if the process for particular requires cutting followed by drilling and finishing, the cell would include the machinery for performing those operations, arranged in that sequence [2].

Arranging operators and machines in to manufacturing/assembly cells helps industries to achieve important goals like single piece flow and high-variety production/assembly.

Table 1.1 Issues for Research [2]

Sr. No.	Type	Example
1	Defects	Scrap, rework, replacement production, inspection
2	Waiting	Stock outs, lot processing delays, machinery downtime, cell capacity bottlenecks
3	Processing	Inaccurate, faulty processing
4	Overproduction	Manufacturing items for which there are no orders
5	Movement	Unnecessary human motion that are straining
6	Inventory	Excess raw material, WIP, or finished goods
7	Transport	Carrying WIP long distances, inefficient transport
8	Unused employee creativity	Lost time, ideas, skills, improvements

1.3.2 Objectives for consideration

Table 1.2 Classification of objectives [2]

Sr. No.	Optimization factor	Parameter for optimization
01	Minimum cost of	Machine duplication
		Operation cost
		Part subcontracting
		Inter-cell transportation
		Intra-cell transportation
		Space usage
02	Minimum amount of	Duplicated machines
		Inter-cell movements
		Intra-cell movements
		In-cell load unbalance
		In-plant load unbalance
		Parts dissimilarity
		Skipping
03	Maximum amount of	Flexibility
		Efficiency
		Utilization
		Cell independence
04	Minimum deviation from	Parts similarity
		Machine available processing time
		Cell operator wages
		Machine-operator skill matching
		Minimum part movements
		Maximum investment cost
		Operating cost
		Set-up time
		Utilization
		Available funds

1.3.3 One-Piece Flow

In a single -piece flow, parts move through a production/assembly process single unit at a time, at a rate decided by the consumer.

The contradictory of single-piece flow is large–batch manufacture/assembly. Industries manufacture parts in large lot causes to production/assembly builds delay into the process. No parts can progress on the next station until all the parts in the batch have been assembled/ processed. The larger the batch size, the longer the parts wait/queue between production/assembly stations [74].

- Large-batch assembly/production can lower a company's productivity and profitability in several ways.
- It increases duration i.e. lead time between customer's demand and supply of the goods/products.
- It requires manpower, efforts, and space to accumulate and transport the goods.
- In contrast, single-piece flow production solves these problems.
- It allows the company to deliver a flow of parts/subassembly to customers with no or less delay.
- It decreases the man, material and machines resources used for storage space and transport.
- Risk of spoil/damage, deterioration and obsolescence of products can be lower by this approach.
- Other problems can be identified easily to solve before breakdown.

In daily operation for a single-piece flow, it is not always possible to process/assemble parts just one at a time. Continuous flow of parts, with the less or no delay and waiting period is required. Cellular layout helps by focusing on the material going through the process, not just on the equipment for each operation.

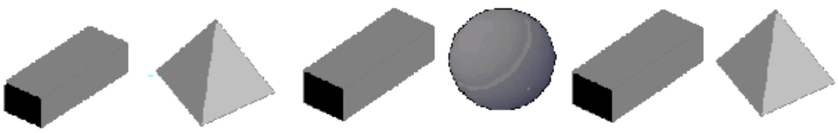

Figure 1.4 Sample of high variety productions [74]

1.3.3.1 Large-Variety Production/ assembly

Today customers expect variety and product customization. Also required quantities to be delivered within a given duration by customer. So company should be flexible enough to demand, otherwise customers will go to your competitor.

Flexibility to produce variety of products is possible by cellular layout as demanded by customers.

It is possible by arranging similar products into families that can be processed on the same operating station in the same order. The time consumed for changeover between products is also shorten due to cell arrangement [74].

1.3.3.2 Process

It defined as continuous flow from (beginning to end) through which unprocessed materials are transformed to finished goods in a sequence of operations. The prime area is the route of the work-in-process materials as they are processed into required object to sell.

Manufacturing/assembly process consists of following stages:

1. Transformation: alteration of shape or quality, assembly or disassembly,
2. Inspection: Qualitative or quantitative comparison in relation to existing standards available in industries.
3. Transportation: change of place/location
4. Storage: a waiting period when nothing else is happening

Materials and parts often go through several of these steps during a manufacturing process; the left side of shows a typical sequence of process steps. Notice that only the transformation step adds value to the product.

1.3.3.3 Operations

An operation indicates required processing action by workers or machines on the raw materials, work-in-process, or finished products. Since operations involve actions, processing improvements focus on how required conversion operations are carried out. Detail study of motions required for a conversion action is carried out step by step.

There is need to improve processes within plant. Improving process involves reforming the flow of raw materials to reduce obstacles and various wastes like

- Non-value-adding operations such as waiting or transport
- Downtime caused by changeover and adjustments
- Distance travelled by work-in-process materials between processing stations
- The need and time required for inspection, or for reworking materials [74].

1.3.3.4 U-Shaped Cell and its significance

Workstations are arranged close together in the sequence of the processing operations. It reduces unnecessary walking of operators and material movement to setup a smooth flow. U shapes bring the starting point of the process and end point close to each other, which reduces the distance the operator has to travel to begin the next processing cycle.

1.3.3.5 Training to operators for Multi-skilled and Multi-machine

Cellular layout often changes the relationship between operators and machines on the shop floor area. The simple change of arranging machines in a process flow, and there is need to run different types of machines by operators to carry the process in sequence.

In an operation-based layout, all the grinding machines, for example, would be located together. However, when the machines are rearranged into a cell according to the process sequence, each grinder may become part of a different cell. In that situation, having one grinder operator for each cell would not be economical. What's more, cells often use equipment that runs on automatic cycles, so most of the operator's time would be spent on watching the equipment run. This is a huge waste of people's intelligence and skill.

These wastes are avoided by training people to operate different equipments in the line. With simple automation, an operator can manage work flow through a sequence of machines in the process. For example, the operator can be setting up a work piece on the equipment for operation no. 2 while the operation no. 1 machine is processing another work piece.

A cell may be run by single operator, or by several operators working together, depending on the dimension of the cell, machine cycle time, and production volume. Cross-training gives flexibility to change how operators work together in a cell.

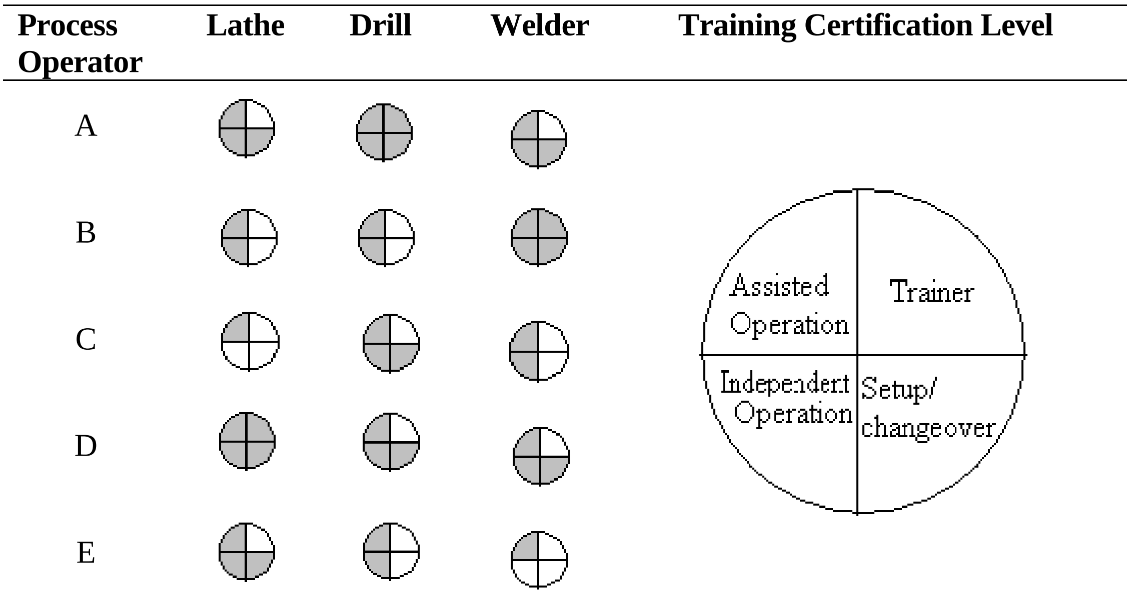

Figure 1.5 Sample of a Cross Training Chart [74]

1.3.3.6 Significance of cross-training to provide maximum flexibility

Cross-training enables operators to perform several functions within a process which permits team to take whole responsibility for their product and processes. After training on several machines, operator is capable to respond to customer's changes in production requirements by stepping into other positions as required. This versatility makes operators more valuable to their shop floor teams and to company.

1.3.3.7 Moving with the Work

To run various equipments are in sequence, an operator to work in position of standing up rather than sitting down. In single-piece flow, the work must move smoothly from beginning to end in the process. To assist this flow, people need to stand and walk. Advantage of moving with the work is that working while standing also enables operator to respond more promptly if equipment problems arise.

1.3.3.8 Flexible equipments and machines

Smaller machines can be used for cellular manufacturing because the goal is to process one or a few items at a time, instead of large batches. Less space is required for smaller machines. Operator walking distance reduces by placing machines close together without any vacant space for excess work-in-process material to accumulate.

Slower equipments/machines are suitable for cellular manufacturing because the objective is not to produce large lots of WIP quickly. Instead, machines process single piece at a time at a speed decided according to customer requirements.

Machines/equipments for U shape layout also need to be flexible. To maximize their usefulness, all machines must be easy to set up quickly to make a variety of parts during a single shift. Flexible may also mean movable. Mounting smaller machines on wheels makes it possible to move them to other locations when a process sequence changes, or to experiment with new production layouts.

Another benefit of using smaller machines/equipments for U shape layout is that they generally are less expensive to purchase and easier to operate and maintain.

1. Analysis of current conditions in layout
2. Converting to a sequence or process-based arrangement
3. Improvement in the process continuously to increase productivity

1.3.4 Study of existing Conditions

The first phase in cell conversion, understanding and analysis of the current conditions, helps the layout experts to determine what operation or process to convert. It also provides a baseline against which to measure improvement.

1.3.4.1 Production Resources

In addition to reviewing the product mix, the team gathers baseline information about production resources, such as

- Shifts per day
- Hours per shift; break time
- Work days per month
- Employee to operation ratio
- Monthly product volume requirements from customers
- Approach for assigning work
- Finished products inventory turns per month

1.3.4.2 Process Route Analysis

A process route analysis table helps the team to identify processing similarities between different products. This enables them to identify groups of products that could be made in a cell, using the same sequence of machines. These groups are called product families.

Assembly Part Code	Process sequence					
	1 Rough cut	2 Cut	3 Mill	4 Drill	4A Outside diameter	5 Gauge
A	○	○	○	○	○	○
D	○	○	○	○	○	○
C		○	○	○		○
I		○	○	○		○
G	○	○	○	○	○	
H	○	○	○	○	○	
J	○	○	○	○	○	
B	○	○		○	○	
E		○		○		○
F	○	○	○		○	

Figure 1.6 Sample of process route analysis [74]

If the company makes low volumes of many product types rather than high volumes of a few volumes of many product types rather than high volumes of a few types, process route analysis is especially important for helping the team choose process to start with.

1.3.4.3 Process Mapping

Next, the draws a process map, which shows the current equipment layout and the path the product takes trough the process. This map is often drawn on a Work Sheet. The map also shows worker positions, WIP storage points, quality checkpoints, and safety precautions.

In addition, the team records

- The distance the product must travel during processing
- The quantity of work-in-process at a given time
- The number of people currently required to run the process

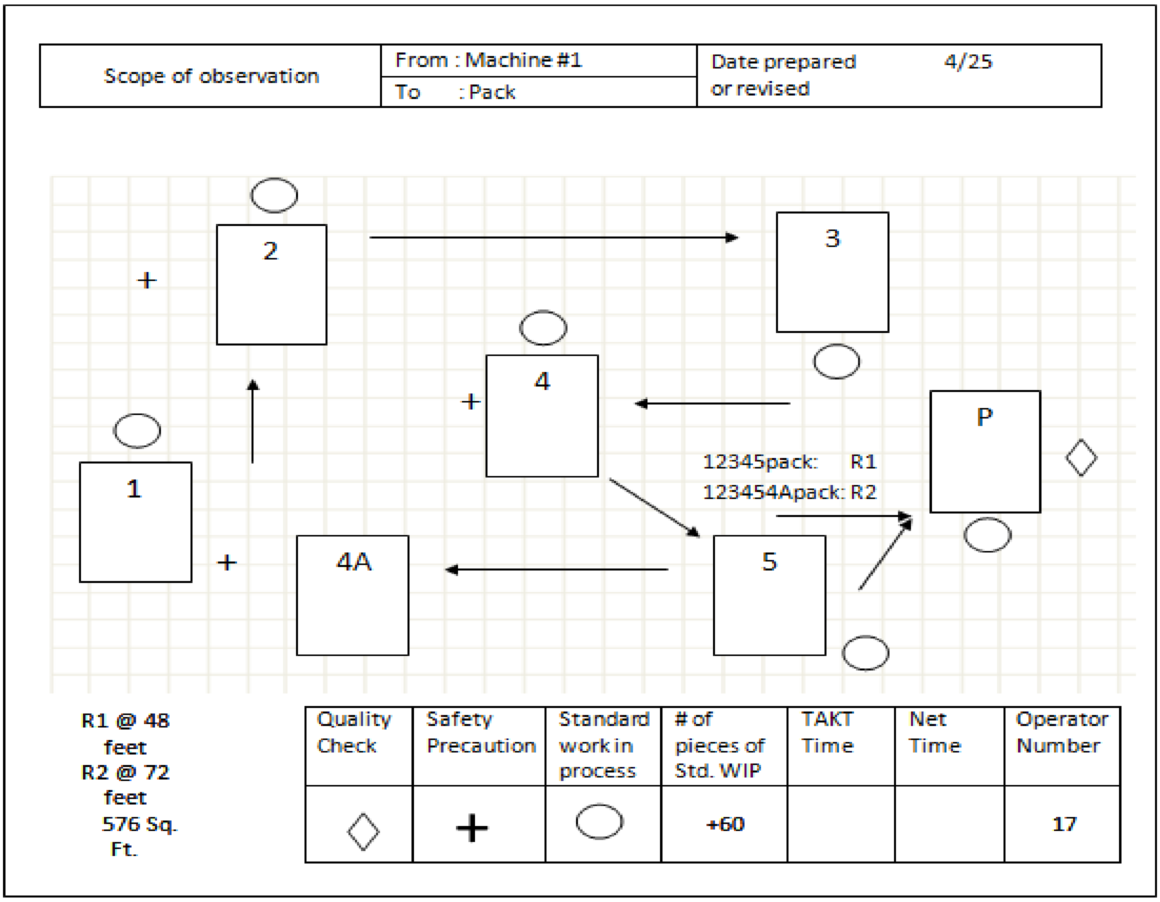

Figure 1.7 Sample of work sheet [74]

The first activity in time observation is measuring the cycle time for each machine operation in the process. The team writes the actions or tasks for one complete machine cycle on the left side of a Time Observation Sheet. In addition to actual machine work, a cycle includes other tasks such as loading and unloading, opening and closing machine guards, programming, returning to a neutral position, and other human and machine actions.

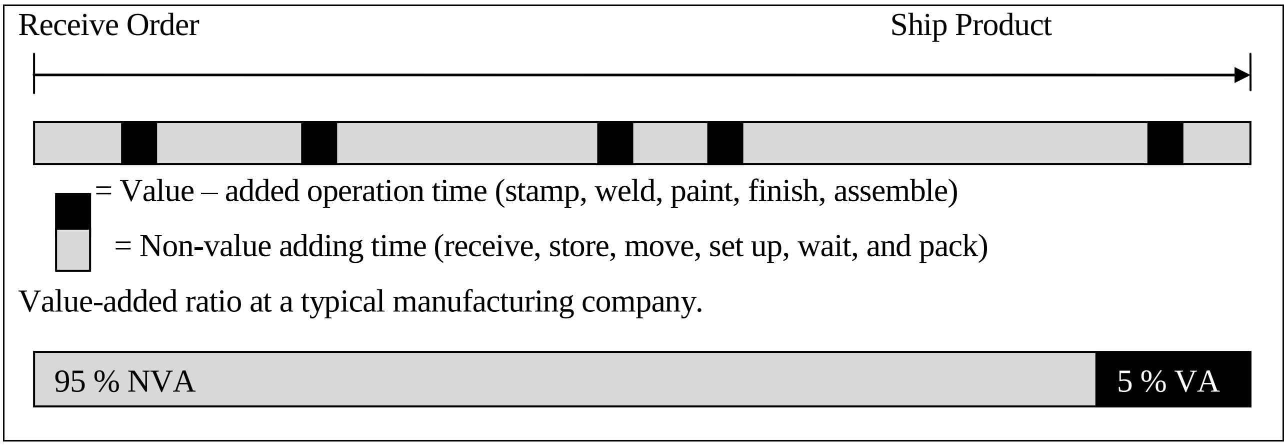

Figure 1.8 Sample of value added ratio [74]

The team observes the time required for each action during several cycles, and then determines an average cycle time for the machine.

After observing each operation, the team determines a sample process lead time for the total process. The process lead time includes the cycle time for each operation as well as the time required for transport of WIP and tools between operations.

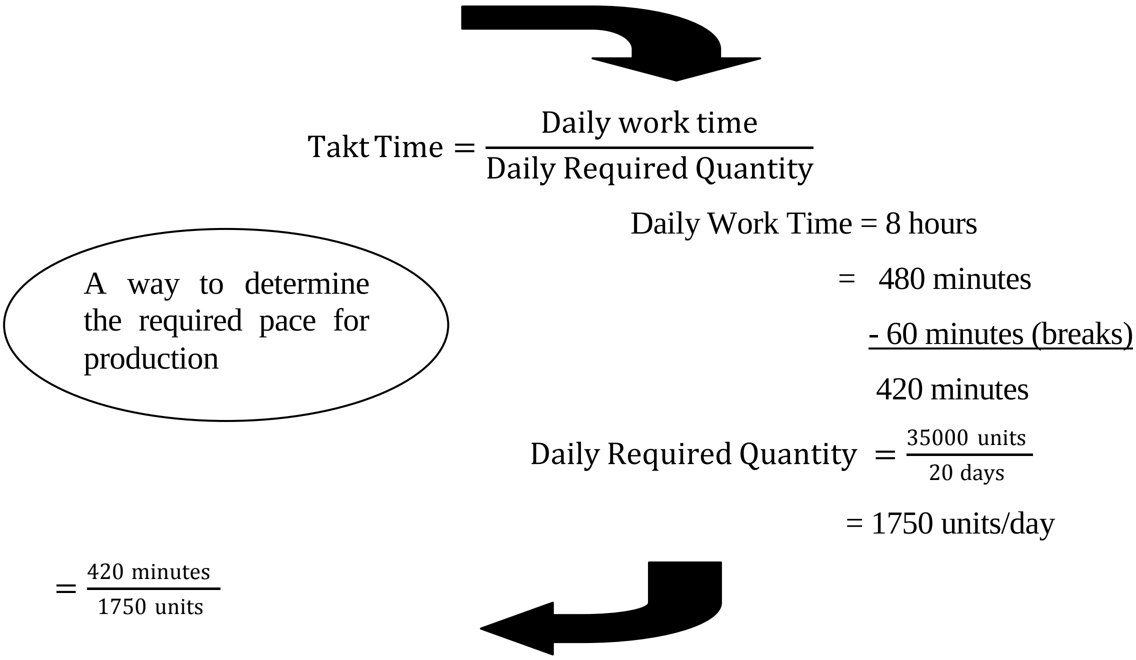

Figure 1.9 Sample of takt time [74]

The team also determines the value-added ratio. The value-added ratio is defined as the actual time spent for machining or working on the part divided by the total process lead time. Many companies will discover that they have surprisingly low value-added ratios.

1.3.5 Propose New Layout

- Layout in the process sequence is the basic principle.
- Machines are placed close together and space for a minimum work-in-process quantity.
- The layout in a U shape, with the last machine near the first to reduce operator's walking distance between cycles.
- The process sequence is often counter clockwise. As operator move around to operate the cell, the right hand, which has more control in the majority people, is then next to the machine; this allows well-organized handling of parts and tools, with less turning.

1.3.6 Factory Simulation

Factory simulation is the software-based modeling of a real manufacturing/assembly system. It helps to analyze and experiment with existing processes in a virtual background, reducing the physical testing time and cost. Parameters like production, equipment, and personnel can be analyzed within a simulation environment.

Engineers using layout simulation have found it valuable for evaluating the impact of capital investments in resources like machinery and equipment, physical facility, proposed changes to material handling and existing layout. Layout simulation is useful to analyze employment and operating rules and suggested new rules to be incorporated into existing production control systems, warehouse controls, and material-handling controls. Managers have found simulation provide a "trial" before making huge capital investments, without changing the existing system with untried changes.

1.3.6.1Need of Simulation

Sharda Motors Industries Ltd., Nasik is an automobile company, which manufactures components and assembly for light, medium and heavy-duty vehicles. It manufactures products of ISO9001 and QS-9000 standard. QS-9000 focuses on continuous improvement, emphasizing defect prevention and reduction of waste in supply chain.

For competing in 21st century market, Automobile industries are planning to switch over to "Cellular Layout" in which manufacturing process is carried out by proper arrangement of machines so that :

- Reduction of time taken by a component (through put time).
- Maximum Utilization of manpower.
- To improve space utilization.
- Reduction of work in process inventory.

Due to these characteristics, Cellular layout is most popular in Japan. In India, few companies like TVS, Maruti etc. have implemented it and other few are in a way of implementation like Sharda Motors Industries Ltd., Nasik, Mahindra & Mahindra Ltd., Nasik etc.

1.3.6 2 Simulation: some rules

A simulation study consists of a number of steps [109].

Step 1

- What is the problem?
- What exactly do we want to know?
- Do we need simulation to solve the problem?

If so, for which part of the problem?

Step 2

- Formulate an objective.
- Find out which information you need.
- Make some manual calculations, both to get a feel for the problem and to use as validation material for a later model.

Step 3

- Collect information. The quality of the information is more important than the quantity.
- One right average is often better than 10000 historical values that give the wrong average.

Step 4

- Make a rough setup for the simulation model on paper. Which elements and which activities will be modeled, which parameters will be used and what will be measured?

Step 5

- Use show flow to create a model. Create a layout, define flows, detail element, job and routing parameters.
- Try to make the model so that the alternatives to be studied can be easily brought into the model.

Step 6

- Verify and validate the model: does the model represent the studied system correctly?
- Are the results in accordance with what you expected from the manual calculations? If not, can you explain this?

Step 7

- Simulate the alternatives.
- Analyze and compare the results of the simulations.
- Are the results reliable?

Step 8

- Draw your conclusions.

Step 9

- To support your conclusions, you could make a presentation of your simulation model. This could be a simple animation or a complete simulation show with animations, illustrations, comments and results: a kind of self running report.

Step 10

- Communicate your conclusions. Feed back to the original objective of the study. Mention the assumptions behind your study.

1.3.6.3 Elements of Show Flow Simulation

Achieve minimal supply with maximal delivery reliability by varying the size of the production orders in combination with the order level. In a Shop with one machine, Raw material/ Component comes in; if other raw material/ components are waiting, they line up in the queue and wait until it is their turn. Eventually they are served and they leave the shop. Typical information one might want to have about such a system is: what is the average waiting time of a component with different combinations of arrival frequencies and serving times. To translate this real world system into show flow entities,

Four elements needed to represent this model: an entrance, a queue, a counter and an exit.

In show flow, model the entrance and the exit by using the in-out element, the queue by using the buffer element and the counter by using the machine element.

Table 1.3 Simulation elements [109]

Sr. No.	Element	Shortcut
1	Machine	M
2	Transporter	T
3	Buffer	B
4	Aid	A
5	Conveyer	C
6	Path	P
7	Warehouse	W

8	Reservoir	R
9	In-out	I

Also need one routing containing four stages (come in, then wait, then get served, then go out). The model will run for a period of one day (default setting). If we zoomed enough, we will see the utilization rate at the counter (third element) and also a graphical history of the queue length (second element).

Status indication:

- Busy means : working on a product
- Idle means : nothing to do
- Blocked means: cannot send the product to the next station. All this information is refreshed with a certain rate. The refresh rate has a very significant influence on simulation speed.

The simulation will stop automatically. There is a good chance that the utilization of the third element is not 80%. This indicates that the length of the simulation experiment was not enough to obtain a reliable result (this is easy to understand when you realize that in a shop; today is not necessarily exactly as busy as yesterday).

1.4 Research Objectives & Scope

1.4.1 Research Objectives

The objectives of this research are as follows:

1. To investigate the development of a method for cell formation.
2. To develop a method for cell layout with a consideration of transportation systems.
3. To build comprehensive decision-support models for cell formation, with consideration given to man, machines and material handling aspects related to following performance dimensions

- To reduce throughput time (Manufacturing Cycle Time/Component (min.))
- To increase the target of manufacturing component and completion of target as per demand, i.e. to reduce response time to orders.
- To maximize manpower utilization.
- To minimize space utilization.
- To reduce manpower requirement, i.e. Worker assignments / Utilization of Manpower
- To reduce setup time
- To reduce unit cost i.e. Cost Analysis

- To reduce material handling/ Pallet Requirement

4. To solve the problem in a context of "product–part– machine" dimension in CMS.
5. Design of Next Generation Factory Layouts.
6. To justify the Cell Manufacturing (CM) design methodology via an experimental design and a comparison with known solutions.

1.4.2 Problem Identification

Problems identified in existing layout are

1. Manpower utilization is low. In existing layout manpower utilization is 60 to 75%.
2. More Time for material handling. Handling time required for components is more in existing layout.
3. High Work in Process (WIP) inventory.
4. Lower Space Utilization
5. Capacity utilization of machines is low.
6. Machine changeover time is more.
7. The wide entry and exit points between lines.
8. Lines have the operator empty-handed too much of the time. Extra operator makes line crowed.

Figure 1.10 shows different products of Sharda Motors Industries Ltd., Nasik. Problems identified in production line of these products while manufacturing and assembly.

1.5 Proposed Methodology

The methodology adopted to achieve the objectives is as follows:

1) Experiments to eliminate waste, to improve the division of processes and balancing of labour.
2) Approach starts by coordinating the timing of production with customer needs.
3) Studying the existing layout
4) Collection of job component data and shift wise production data i.e. no. of shifts, working hours, customer demand, etc.
5) Process sequence analysis of existing layout.
6) Identifying operation sequence & elemental Operation time details for each machine.
7) Calculation of machine capacity for each machine.
8) Calculation of line capacity and takt time.

9) Evaluate the methods, machines, materials, operators for collected job data and shift wise production data.
10) Planning new layouts considering optimal distance between machines, C or U shape.
11) Developing suitable cellular layout for each production line in proposed layout.
12) Shift the machines as per planning.
13) Draft the proposed operating procedures.
14) Take trial to check improvement.
15) Identify the problems in new layout e.g., long cycle times, more changeover time and correct all problems for continuous improvement.
16) Calculation of manpower utilization for each production line in proposed layout.
17) Determination of cycle time for each production line in proposed layout.
18) Determination of material handling route for each production line in proposed layout..
19) Determination of WIP inventory and trolleys requirement for each production line in proposed layout.
20) Analysis of proposed layout - i.e. cost analysis.
21) Simulation of layout using 'Show Flow' Simulation Software.

1.6 Outline of the thesis

The outline of the thesis contains the following chapters:

Chapter1, *Introduction*, defines the background, research objectives. Also, it consists of problem identification in the existing layout, objectives and methodology adopted for carrying out research work in collaboration with industry.

Chapter 2, *Literature review*, summarizes previous and current research in the field connected to the research question.

Chapter 3, *Parametric analysis of layout*, describes a manpower utilization, target achievement and data collection related to existing and proposed layout.

Chapter 4 *Results* consists of comparative mathematical analysis for all existing and proposed layout, which suggest improvements in different aspects.

Chapter 5, *Conclusions*, presents the most important conclusions from the research study and recommendations for future Work.

Shop floor data and the simulation data in this case study are provided in Appendix.

Chapter 02

Literature Review

Previous work on the design and simulation of cell based layout manufacturing systems is reviewed in this chapter. The review is focused on the problem findings and research methodologies used to optimize the problems. The shortcomings of the existing representations of the problems and methods available for solving the problems are also analyzed in this chapter.

2.1 Historical development

Issues related to CMS-

a) Structural issues

- Selection of part populations and grouping of similar parts into families
- Selection of machine and process populations and grouping of these into cells
- Selection of various tooling, fixtures, and material handling pallets
- Selection of work-in-process material handling equipment
- Choice of machines/equipment layout [81].

Wemmerlov and Nancy reported that every decision during the design process whether related to structure or operation, affects system cost and performance. Part-oriented techniques approach cell design from the characteristics of the parts involved and range from simple identification techniques, such as use of part name or part function, to more sophisticated approaches using GT oriented classification and coding systems [103].

b) Operational issues

Aryanezhada et al. reported that in most of the cases planning procedures depends on the type of cells involved, the operating pattern, the type of flow pattern in the cells, the linkages between cells, the cell sizes, the number and sizes of the component families assigned to the different cells, the relative setup times, the degree of automation, etc [5] .

Today's production requirements with respond to product design changes in and customer's demand cannot be meet by Job shops and flow line manufacturing. As a result, cellular manufacturing layout emerged as a potential alternative which identifies similar parts and group them together into families to take benefit of their similarity in product design and processing [89].

In Cell layout, part families formation is based on their similar manufacturing requirements and the grouping of equipment/machines into production cell to process the formed product families stated by Barve et al. [14].

Arora et al. studied cellular processing plants which are running in a non optimal surroundings. Their performance can be improved by optimizing the parameter. Review shows most of the cell formation techniques and algorithm does not propose the required size of the cell and the required number of cells [6].

Kulak et al. studied parameters like Raw material accumulation in days of inventory, Lead time in days, Scrap rate in percentage, Throughput in no. of units , Overtime in hours per week, WIP in days inventory,, Material travel distance in meters for performance evolution [58].

Continuous readjustment of the plan/design of the cellular layout system and the direction in which these adjustments takes place are depends upon latest market development, new manufacturing technique and modern production/planning control systems will constrain the cellular manufacturing application area[31].

Study of scheduling of cell capacity and orders is required to bridge the gap between cell based conceptual works and quantitative contributions; author suggested a framework for the planning tasks structuring [98].

Past research work has been concentrated to the clustering of the machine and parts into cell and part families. So, acute need is to develop the models to specify the optimal number of groups and optimal production mix subject to technological and logistical constraints for optimal performance of cell based manufacturing/assembly layout [6].

2.2 Issues considered for proposed work

2.2.1 Manpower utilization

Proper analysis of layout design improve the performance of production line by parameters like minimizing material handling cost, decreasing idle time, reducing bottleneck rate, increase in efficiency and utilization of manpower, equipment/ machines and space [56].

Nikoofarid and Aalaei proposed approach to minimize holding and backorder costs and manages machines and workers over a certain planning horizon [67].

Farimah and Aliasghar results showed that increase of workload sharing in a cell does not amplify the production volume continually. Complete workload sharing is not always capable of adding of production volume. Stations with less manual and machining operations are controlled better and operators simultaneously controlled bottleneck stations [32].

Mitala and Pennathur examined human presence is necessary to compensate for practical/technological limitations, and that a intelligent human-centered approach to design/development of cellular layout system promote flexibility, reliability, productivity and the interdependency of human & technology[64].

Chenguan get the problem of how to reconfigure conveyor to assembly cell system called serus. A detailed mathematical approach incorporating two issues of how many serus established and how many workers should be assigned to each seru is developed. Such a manufacturing system merges the considerable flexibility of the job shop and the high efficiency of the conveyor used assembly line [26].

Viviana and Harold studied labor flexibility in cellular layout system characterized by intra-cell operator’s mobility. The balance in the operators’ workload and the level and type of machine sharing are important concepts to improve the performance of cellular layout implementations. The selection of the best labor allocation strategies should simultaneously consider production output, lead times, and the quantity of work-in-process stock in the system [99].

The overall survey results show that the three major human issues in cellular layout system are communication, teamwork and training [17].

Fitzpatrick and Askin suggested program for formation of effective human teams. Operating /processing zone combination useful for identifying better route [33].

Jannes addresses effective cross-training of workers shows that if operators and machines are connected, directly or indirectly, by task assignment decision. Cross-training promotes the formation of effective ‘chains’ between operators and machines through which task/work can be shifted, directly or indirectly, from a heavily loaded operator to a less loaded operator [52].

Author considers a workforce planning approach considering human aspects like technical and non-technical skills, operator’s training, and personalities of operators. The research has demonstrated the importance of considering human factors early in the planning process of manufacturing systems [63].

Satya and Douglas described the assignment of operators to cells and existing layout system analysis. Management and the supervisor played an important role. The role and the responsibilities of the supervisor, an operational decision, played an important role [91].

Shahrokhi and Bernard developed an approach which provide platform for modeling and in-depth analysis of operator performance in computerized three dimensional environments. Author revealed that present human models are not adapted for evaluating the variation of human behavior and performance [80].

The simulation experiments performed gave the importance of work-force management and coordination, even in highly automated facilities where work force tasks are limited. The outcomes highlighted the potential that will be achieved by enlarging the tasks assigned to single workers, rather than focusing on specialization [25].

Gursel focused on cell loading issues and product processing sequence in labor-intensive cells to minimize make span and machine requirements needed in labor-intensive cells[36].

Authors suggest a design approach for assembly line based on effective teams, where team is having well-defined job responsibilities. Team based assembly is substitute to the traditional production/assembly line. These types of assembly lines are more superior to traditional lines to achieve structure flexibility and manufactured goods quality and also to provide better work environment to workers[53].

In simulator training of plant operation, different types of human errors take place in the confused condition of the operator under abnormal situations. Cell layout simulation approach is useful to identify these human errors [54].

Technology and humans in modern manufacturing environments are interdependent. Interdependency is key to getting the most out of advanced manufacturing technology and achieving the productivity and quality goals in product manufacture [64].

Fully cross-trained workforce is a desirable feature for the strategic benefits it provides optimization of production resources and processing requirements [24].

Performance of team is depends on individual operator behaviors and interpersonal interactions within cell as well as operators technical competence [33].

The relations between operators and machines i.e. the required technical qualification of workers form ‘chains’ which is use to reallocate/shift assigned work idle worker. Assigned load to the bottleneck operator is an important parameter for determining operational performance of human teams such as smaller throughput time of job and a higher delivery performance of job [81].

Scheduling of parallel machine is based on the assembly cell loading considering similarities among parts in relation to the similarity of number of machines required. As the similar parts are grouped in the same cell, requirements of the number of machine and space are minimized. There is need to minimize intra-cell manpower transfers to simplify the machining operational control and easier processing operations in the cell during product sequencing. So it is necessary to bridge the gap between available skills with required skills per operator basis [36].

As the difference in labor efficiency is essential to line imbalance in labor intensive manufacturing industry, a model is suggested to balance production/assembly line through optimal operator allotment with the concern of operator capability/efficiency [84].

Each worker on the team was responsible for making a different component. In this manner, the workload/task was uniformly distributed among different multi-skill workers i.e low, intermediate and high skill workers [63].

2.2.2 Operation time

Aryanezhada et al. suggested assumptions for cell based layout design in automobile industry that the setup times on each machine are predetermined based on the precedence of jobs [5].

Barve et al. reported important points to set a production at a particular range are:

1. Cell formation for different machines
2. Standard time required for a cell
3. Decision regarding running of a machine for one, two or three shifts
4. Once layout has been made no changes can be made in layout with increase in demand
5. Minimum walking time required between two machines in a cell, due to this standard

time is reduced [14].

The cell formation problem in cellular layout is the decomposition of the manufacturing systems into cells. Part families are identified which are fully processed within the cell. The cells are formed to take the advantages of group technology such as shorter set-up times, in-process inventories, lead times and reduced tool requirements [1].

Reductions in manufacturing throughput time can results in lower work-in-process and finished goods inventory levels, lower costs, and less forecasting error (because forecasts are for shorter time horizons) [27].

Willem and Jalal find need to refine the search for which critical operations (bottlenecks) cycle time to be reduced further, rather than a prior shortening of cycle time settings (robot welding times), some of which are non-bottleneck operations that will not affect average daily output [100].

Fahad studied focused cellular manufacturing that groups parts by end-items and forms cell of machines to manufacture and assemble end-items. Flexible cellular manufacturing syatem has a batching benefit i.e. less waiting time to batch components before final assemble. Cellular manufacturing scheme experiences shorter assemble waiting time since all the parts of an end-item are processed together in a single cell [34].

Converting to assembly cells also decreases move time per component, processing time per component, processing variability, optimizing manufacturing throughput time achieved through reducing production batch size and and transfer batch size. High processing workstation utilization is a major contributor to larger manufacturing throughput time, when variability in processing the component is high. In some cases, it is not possible to decrease processing variability, then it is necessary to reduce workstation utilization to achieve lower throughput times [50].

Planning and scheduling of processing activities depend on the times/costs required to setup the facility for performing the activities. However, existing literature ignores this issue [10].

2.2.3 Production volume

To meet requirements of new product features and customer demand, general- purpose equipments/machines are used in cell base layout which saves time and cost. Thus it provides better flexibility for production of a variety of products as suggested by Chalapathi [22].

Pasupuleti studied the performance measures like mean lateness, mean flow time, mean tardiness and the make span are considered to evaluate the dispatching rules. It is useful to identify the sequence of components to process on each machine and the entire schedule for all the processing operations of the components [70].

In case of traditional machine operations on components, simultaneous arrangement of part-families and machine-cells is required. The effectiveness of the processing method depends upon the data like quantity and accuracy of the part machining/assembly information as studied by Karuna et al. [57].

Most of Indian automobiles companies are now automation in plant like computer based design up to computerized integration of machine and equipment during production as research by Suleyman [79].

Aryanezhada et al. correlated production volume of each part and demand for final product [5].

Cellular manufacturing system has been implemented to reduce motion, transportation wastes, workers salary and their requirement. The results revealed an improvement in productivity of the cellular manufacturing system. Modified material handling devices have been used to reduce the motion wastes and unwanted transportation [16].

Productivity can be increased by reducing non value adding process which can be identified through seven wastes (a. defects, b. inventory, c. motion, d. waiting, e. over processing, f. overproduction, g. transportation) and through work study. Cellular layout is a manufacturing philosophy in which similar parts are identified and grouped together to take benefit of their parameters similarities in design and production [73].

Results of the experiment confirm that labor productivity is improved by implementation of U-shaped layout can. This finding is critically important, because layout experts cannot blindly convert existing layout to a U-shaped layout and try to obtain considerable cost savings by raising labor efficiency. Labor productivity is more during high demand periods when labors process three or fewer tasks on average i.e. low cycle time or fast assembly line pace. Parameters like operator travel time, fixed task locations, parallel workstations, material handling limitations and established dock locations are majority contributors for improvements in labor productivity. Analyzing these types of parameters accurately and sufficiently is difficult at best, so a series of industrial case studies shows the true benefits of U-shape cellular assembly lines [40].

2.2.4 Machine capacity utilization

As per Choobineh the conflicting objectives considered in the present work are as follows:

1. Minimization of intra-cell workload imbalance: The mean squared deviation, defined as the average of the squared differences between individual machine utilization and the cell utilization, is the measure of load imbalance within a cell.

2. Minimization of inter-cell workload imbalance: This is the measure of variability of total workloads among the cells. It would make sense if cells were assumed as separate plants processing various parts of a variety of products, which will be sent to the final assembly area to assemble the products. Then the arrival times of these parts to the assembly area should be synchronized to prevent high-level inventories. Another drawback of late arrivals is the increase in the flow time and decrease in the throughput rat [23].

Machine flexibility is an important parameter to improve the throughput rate in assembly shop. Assumption is that each job has fixed and flexible operations. Make span can be reduced by providing some flexibility to existing structure.Flexibility to processing operations can be assigned to any one of the machine in line or to a subgroup of machines, not necessarily to nearby machine. [43].

2.2.5 Material handling

The principle of cellular manufacturing is to break up complex manufacturing/assembly activities into several groups of machines (cells), each being dedicated to the processing of a part family. Each part type is manufactured in a single cell which simplifies raw material flow and makes planning/scheduling task easier as reported in the survey by Wemmerlov and Johnson [102].

Aryanezhada et al. assumption states that intra-cell and inter-cell movement times of each component and duration times for setting up and performing machining operations are given for CMS design phase in auto industry [5].

The Study focused on an improvement of routing flexibility considering availability of alternate machine for a product family, and secondary resources utilization [38].

Gursel and Cihan introduced a component sequencing issue to minimize the intra-cell manpower transfers and showed that proposed methodology reduces the a major rearrangement of machines in cellular layout and also reduces the need for diverse skill requirements [36].

Set up of machine cells and their part families to optimize inter-cell and intra-cell material flow is the primary objective of the formation of a cellular layout system [42].

Product sequence generation requires sequential processing tasks. Assembly hierarchy of product and parallel assembly of products permits other none sequential sequence choices results into simplified product sequence generation and feasible layout configurations [46].

The material handling system design problem as a whole requires that the logical and physical aspects of material flow be combined by means of material handling equipment and that the design be justified from both performance and economic perspectives [59].

Number of alternative processing routes and additional secondary resources are useful for carrying simulation study in plants [38].

2.2.6 Floor space utilization

Aryanezhada suggested that both machining/processing and subassembly/assembly operations are carried out in single cell [5].

Huawei et al. found method having combination of logical design and a physical layout constraint is more beneficial than traditional layout design used in companies [45].

Design of reconfigurable assembly systems by incorporating both machines and workforce can results into cost effective layout flexibility stated by Hu et al. [46].

Elmaraghy et al. prepares methodology to reduce number of cycles, decision points to lower cellular layout systems complexity [30].

Thottungall and Sijo proposed the optimal layout for the plant to combine product based layout and process layout into suitable cellular layout [97].

Smutkupt and Wimonkasame developed a system that can search for a good layout and then show more important information about production. Both concepts are implemented as computer software with the plant layout design module and the plant layout simulation module [93].

According to Dwijayanti et al. states that appropriate restructuring of existing layout improves the performance of assembly line. It decreases bottleneck rate, reduces idle time, minimize material handling cost, utilization of labour, equipment and space and raise the efficiency [28].

Shop floor layouts studied by using component routing information, material handling devices specifications, raw as well as work-in-process material storage requirements and part packaging information. Factory layout based on material flow travels, flow frequency and cost. It gives more efficient factory layouts, which result in lesser material handling and increased throughput. Simulation is useful to run trial experiments without disturbing an existing processing/assembly system [106].

The U-line relocates machines around a U-shape curvature line in the order in which assembly activities are performed. In case of negligible set up time, U-shape assembly lines are operated as mixed-model lines where each processing station is capable to manufacture any component in any cycle. Multiple U-shape lines are suitable in case of larger setup times and dedicated to different parts [51].

Poornachandra and Vira suggested group technology to achieve integration of assembly activities with production of parts. It is preferred to have a layout system design which has a mix of group technology and integration efficiencies, compared to a design which outperforms on group technology criteria and completely lacks integration of assembly operations with production of parts. [72].

Gerald empirically confirmed that workforce productivity will improve when switching from a straight-line assembly layout to a U-shaped assembly layout. These research findings shows limitation of U shape cell layout change when factors like the number of processing tasks and part cycle times are varied [40].

Multi-skilled operators are required to operate various machine and equipments or processes in U-line. Operators should work in standing up and walking position [61].

Total material flow cost can be reduced by incorporating intra-cell decisions in cell formation and inter-cell design process in cellular layout manufacturing systems [88].

Restructuring the cell layout to meet the customer needs may be more time-consuming and costly. Reconfiguration of assembly line becomes impracticable if the major changes occur very frequently. Companies tend to adopt a traditional machining layout combined with the advantages of cell based layout systems. [15].

The alternative types of cell arrangement discussed in this paper are: using a common cell for sharing machines between cells, allowing part families to have alternating routes, and relocating the machine cells into an assembly line. These types of cell arrangement could be more appropriate in considering a switch from a traditional job shop to a group technology layout of fully independent cells [8].

2.2.7 Cost factor associated with plant layout

Ghosh et al. reported the Product Oriented Approach (POA): the process route of each part is studied from route sheet and parts requiring similar processing operations are grouped together. The optimizing criteria may be minimizing costs in terms of intercellular movements, machine duplication etc [42].

As per Choobineh the conflicting objectives considered in the present work is minimization of total cost i.e. total cost comprises of machinery/equipments investment cost and working/operating cost [23].

Saghafianl and Jokar proposed a model of assembly cell formation in relation to inter-cell and intra-cell layout issues to optimize total inter-cell and intra-cell flow costs instead of reducing the number of inter-cell movements. Authors also proposed integrative model for simultaneous determination of cell layout formation as a replacement for sequential processing approach [88].

Shahram et al. presented the cellular design to utilize existing and new equipments/machines in a product processing. Author suggests that simply rearranging existing and new equipments/machines into cells are beneficial, but it required huge initial investment. Improvements in available machines and material handling set up is required to increase cell productivity and lower restructuring investment to a economical level [90].

Jeffrey presented a approach for cell formation that allows demand variability and also considers the cell size to find the cost to manufacture each part [49].

While designing a cellular layout system, grouping the machines in cells and the parts as part families, their capacity, material handling costs, namely intercellular and intracellular movement costs with respect to machines layout are of the most important issues being considered carefully suggested by Mohammad et al. [63].

Reza et. al studied features like the variable number of cells, the integrated cell flexibility. Authors also studied conflicting objectives like a. decreasing the total cost associated with machine relocation, purchasing new machines/equipments, inter-cell material handling, processing on machines, overhead, and formation of new cells and b. to optimize the imbalance of assigned workload among various cells [78].

2.2.8 Application of simulation

Jeffrey studied the capability to integrate simulation with manufacturing and enterprise systems. The benefit from this integration has led to the acquisition of several simulation vendors by system integrators and enterprise software vendors [49].

To fulfill customer demand, layout may be adjusted (1) at the system level by adding machines, (2) at the machine level by adding spindles and axes, or changing angles between axes, and (3) at the control software by integrating easily advanced controllers stated by Yoram and Moshe [107].

Simulation helps for developing efficient equipment and also save time and money from mistakes in redesign and re-fabricating equipment in comparison with conventional methods [65].

Tillal and Ray investigated the existing manufacturing simulation software environments that may offer variable detail modeling and to classify models' entities related to the levels of detail and to develop mechanisms in order to increase the level of detail of models effectively [95].

Razman and Ali studied that simulation models are useful for assembly industrial issues [75].

Chryssolouris et al. investigated that simulation statistically analyze what-if scenarios, thus reducing overall time and cost required for taking decisions, based on the system behavior [20].

Greasley used simulation to determine the material storage required for a manufacturing facility and it is achieved by storing attribute values [35].

Iqbal and Hashmi described that simulation helps in evaluating plant layout before actually building them and assists in avoiding the cost involved in doing physical re-layout. By virtual factory layout, a designer feel of the actual setting of the factory, easy to visualize, understand and evaluate. Re-location of the machine can be done such that the cell material handling cost decreased as well as the bottleneck removed [47].

Caputo presented a simulation model that allows the elaboration of an operative plan of production through the verification of finite capacity scheduling of resources. The model tends to minimize costs of stocking and set-up, considering other production costs as constant [21].

Williams and Orlando used discrete process simulation for optimum design considering tooling systems, cellular material handling systems, and ergonomic workplace design. Improvement of the cycle time during the simulation study had required inclusion of various stop, switch, and control positions, plus control logic sequences, within the simulation model [104].

The case study showed that automated processes are an excellent scope for simulation experiments. A major drawback of this method is that simulation models can not be standardized. That means if the structure of real system changes the model has to be adjusted [71].

Simulation approach can be applied in the plant to improve the operational production planning and control. The understanding of the simulation of layout needs various

software components such as design and planning software or simulation tools [106].
Dombrowskia and Ernsta suggested a simulation approach to analyze shop floor layout variants that are adequate for future changing requirements. Scenario-based simulation model is feasible for design/development, analyze and parametric evaluation of various variants of the manufacturing/assembly layout [29].
Michael and Engelbert developed the Method for situation-based Modeling and Simulation of Assembly Systems based on the Assembly System Base Model, the Modeling Language, the Modeling Procedure, the Resource Library and the Manufacturing Capability. The method is able to represent the layout, factory objects and interdependencies in an assembly system model [62].
Success of simulation trials are depends on parameters like a. human resource structure of the departments and their interrelationships, working shift patterns and production rules and the accuracy of data related to machine capacity [3].

Simulation studied by Yinhua et al. examined the results that match well qualitatively with observations of actual plant operations and simulator training. It is useful to analyze the generation mechanism of various types of human errors [108].
Simulation is used to modify existing layout systems by modeling, trials and analyze. Most of the simulation models are accepted by industries through usage of ERP as stated by Jeffrey [48].
Desired production rate, small buffer size and optimized cycle time are main issues for effective and efficient manufacture/assembly layout. It is necessary to analyze the impact of different cycle times and buffer sizes on existing layout while restructuring [92].
More recent work has focused on the design of 3D interaction in an immersive VR environment. Initially the standard 3D interaction interface of the VR software was examined. Here the user has to immerse the representation of their hand into the computer generated object [55].

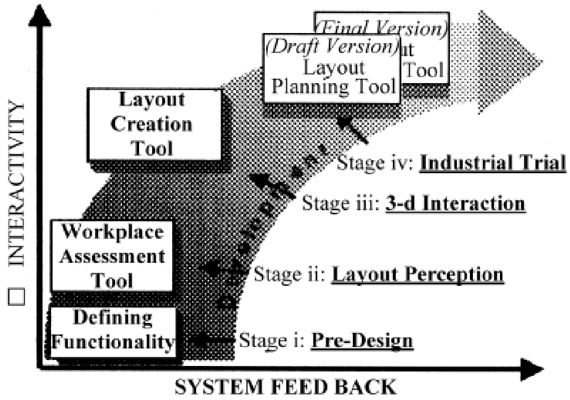

Figure 2.1 Development stages for the layout planning tool in relation to interactivity and feedback [55]

2.3 Concluding Remarks

Previous literature results in issues like separation with present assembly line layout problems, adoptability for rapidly changing environment and finally set up of new modified assembly layout. The existing layout of the plant is considered to be too rigid to change partially or completely in accordance with the customer requirements. Previous research discussed part or product families and utilization of similarities in manufacturing/assembly operation requirements. Finally, three resources identified for study are man, machines and material handling within cell. In essence, Cellular manufacturing system can be defined as manufacturing cells, dedicated to the production of one or multiple parts/products, whose resources may not be physically adjacent in the shop floor but logically placed accordingly their functions or applications. The models developed so far have discussed common factors based on maximum utilization of cellular manufacturing systems. By studying literature, there is necessity to recognize industry reality surrounding cellular manufacturing system, through additional, and more rigorous empirical research.

Chapter 03

Parametric analysis of layout

This chapter describes the problems associated with existing layout and calculation of various parameters of existing layout to analyze in present study. This chapter also describes the formation of new layout to overcome limitations of existing layout and calculation of various parameters for proposed layout to analyze in present study.

3.1 Significance of layout

3.1.1 Principles of plant layout

1. Integration: overall integration of all pertinent factors such as men, material, machinery and supporting activities in a way that affect the layout.
2. Utilization: an effective utilization of all the inputs i.e. machinery, people and space.
3. Closeness: practical minimum distance for moving material supporting services and people between operations. Space should be efficiently used both horizontally and vertically.
4. Flow: work flowing through the plant is in stream line and in logical sequence i.e., in same order or sequence that forms, treats or assembles the material.
5. Expansion: easy to expand-without disturbing the existing layout and production schedules.
6. Flexibility: Easy to arrange, or adjust at minimum cost and least inconvenience.
7. Versatility: Adaptable to changes in product design, sales requirement and process improvement.
8. Regularity: A regular or straight division of area and relatively even sizes of areas.
9. Capital Investment: Avoid unnecessary capital investment.
10. Convenience: For all employees, in both day to day and periodic operations.
11. Satisfaction and Safety: Ensures work satisfaction and safety for all workers [2].

3.1.2 The need for re-layout decision

Why do layout problems arise? Ordinarily when one thinks of plant layout, one links it with planning an entirely new plant starting from scratch. Although such occasions undoubtedly do arise, this usually is not the reason all the time. More frequently, layout work consists of making minor changes in the existing layouts, locating new machines, revising a small section of the plant, or making occasional changes in material handling systems or so. The most common reasons for redesigning of plant are the result of one or more than one of the following:

1. Inefficient operations i.e. high cost of production, bottlenecks etc.
2. Changes in the design of production/services.
3. Introduction of new product services.
4. Changes in mix of outputs.
5. Changes in volume of output.
6. Obsolescence or failure of existing equipment.
7. High percentage of rejection.
8. Congestion in plant, lack of storage space etc.
9. Workers complaint regarding working conditions, (noise, light, temperature etc)
10. High rate of accident or safety hazard.
11. Changes in the location of market for existing products.
12. Environmental changes.
13. Changes in factory legislation.
14. Redesign of material handling system [2].

3.1.3 Proposed layout

After cell information, it is essential machines at proper location. Due to change in demand it directly affects a layout if proper layout is not present. Generally, shape of layout is ‘U’ shape, also cell having triangular, rectangular, trapezoidal etc. is used. Cell operation is based on elemental operation time details. One operator can operate one cell, so that minimum operator required as compared to existing layout.

Cellular layout is having its advantages like minimum space requirement; production takes place as per the demand and minimum operator requirement. But, the major problem that arises in a cellular layout is when one machine in a cell goes under breakdown then entire cell gets affected. Also skilled operator is required for performing an operation in cell.

Cost factors are –

Material handling cost - Rs. 0.50 per feet

Operator cost per month- Rs. 20000 per month

Material handling device cost per year - Rs. 30000 each

Cost of land for per square feet is assumed as Rs. 1000.

Chapter 04

Results and discussion

Analytical study for Xylo and Scorpio Exhaust system assembly lines is presented in this chapter considering various parameters which affects to larger extents on restructuring of shop floor layout in industry.

4.1 Case study no. 01- Scorpio W105 front pipe assembly layout

From the study and analysis it is found that:

a. Manpower utilization

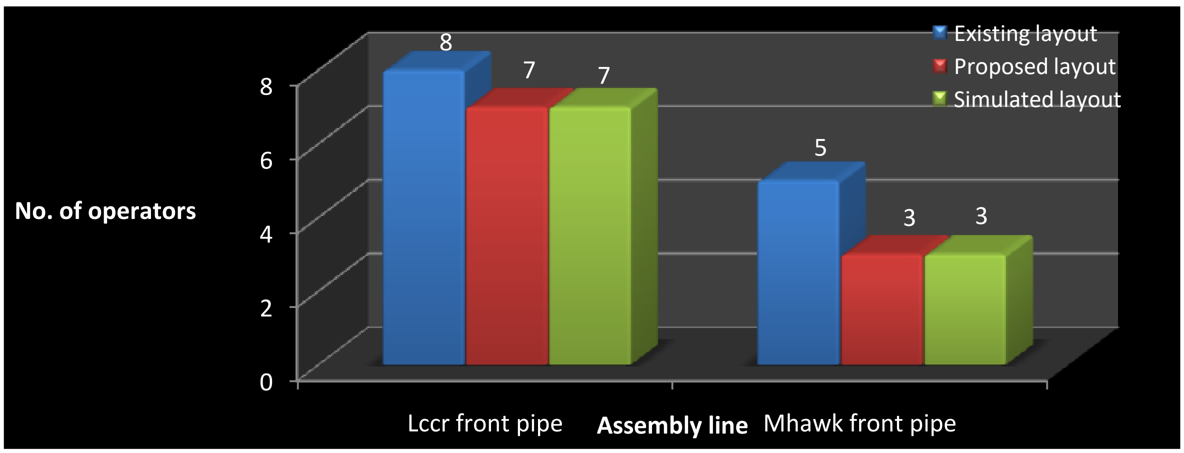

Figure 4.1 Manpower utilization of Scorpio front pipe assembly line

1. No. of operator required is reduced by three.
2. Manpower utilization increases by 12.5 % for lccr model and 40 % for mhawk model.
3. Average utilization of Scorpio W105 front pipe assembly line increase by 23%.

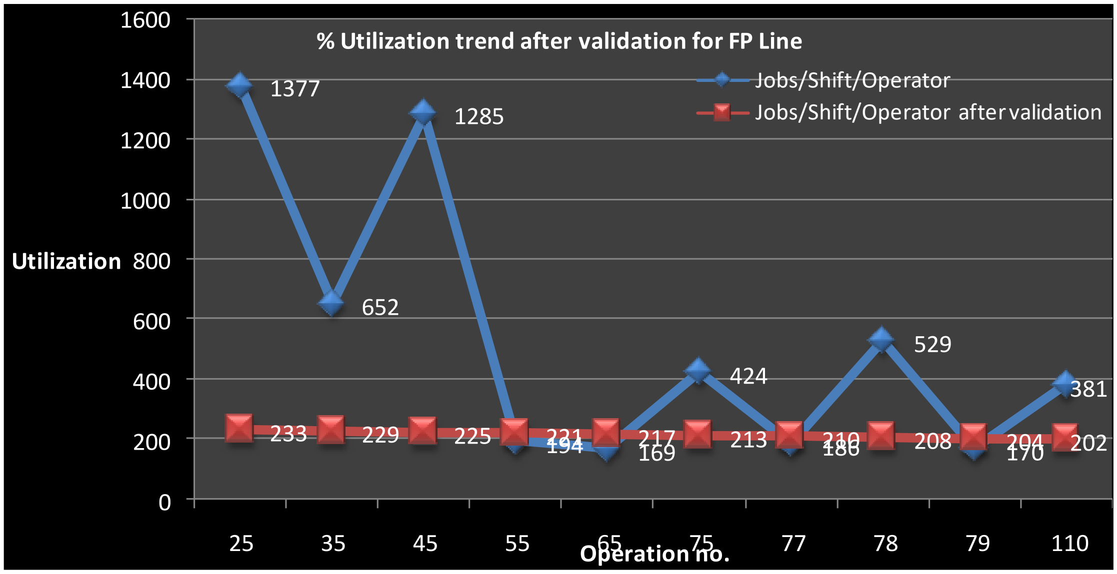

Figure 4.2 Percentage utilization trend after validation for Scorpio front pipe assembly line

Analysis shows percentage utilization trend after validation is positive and synchronized to cell capacity to meet demand as per production target.

b. Operation time

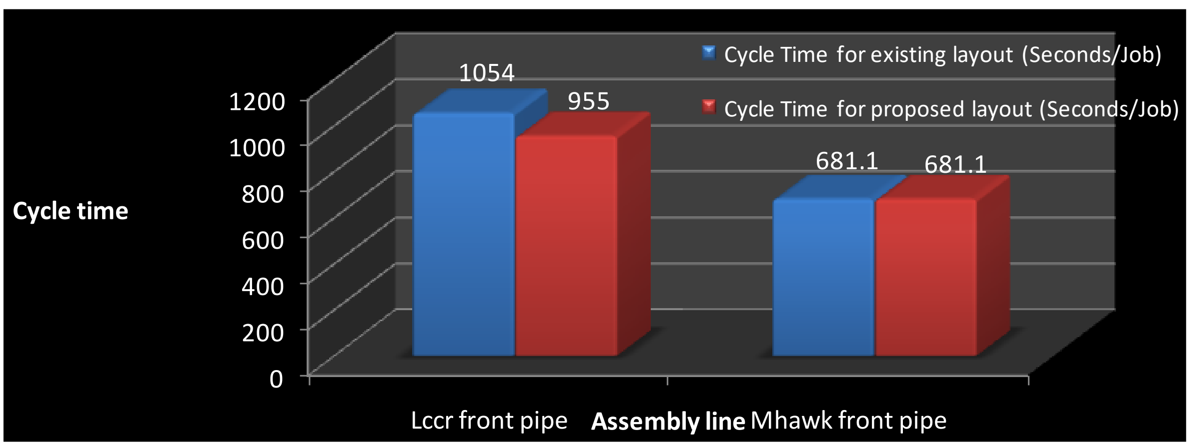

Figure 4.3 Cycle time for Scorpio front pipe assembly line

Operation cycle time decreases by 9.39 % for lccr model and remains constant for mhawk model.

c. Production volume

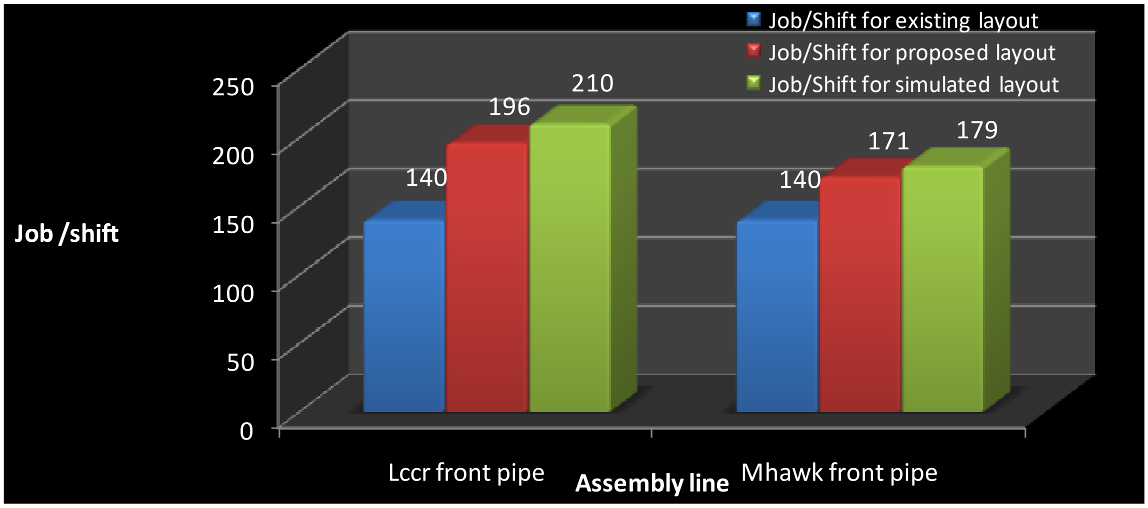

Figure 4.3 Job per shift for Scorpio front pipe assembly line

1. Production volume increases by 40 % in proposed layout for lccr model and 21.43 % for mhawk model.

2. Production volume increases by 50 % in simulated layout for lccr model and 27.86 % for mhawk model.

3.From above values, production volume for proposed line is equal to production volume for simulated assembly line after validation.

d. Machine capacity utilization

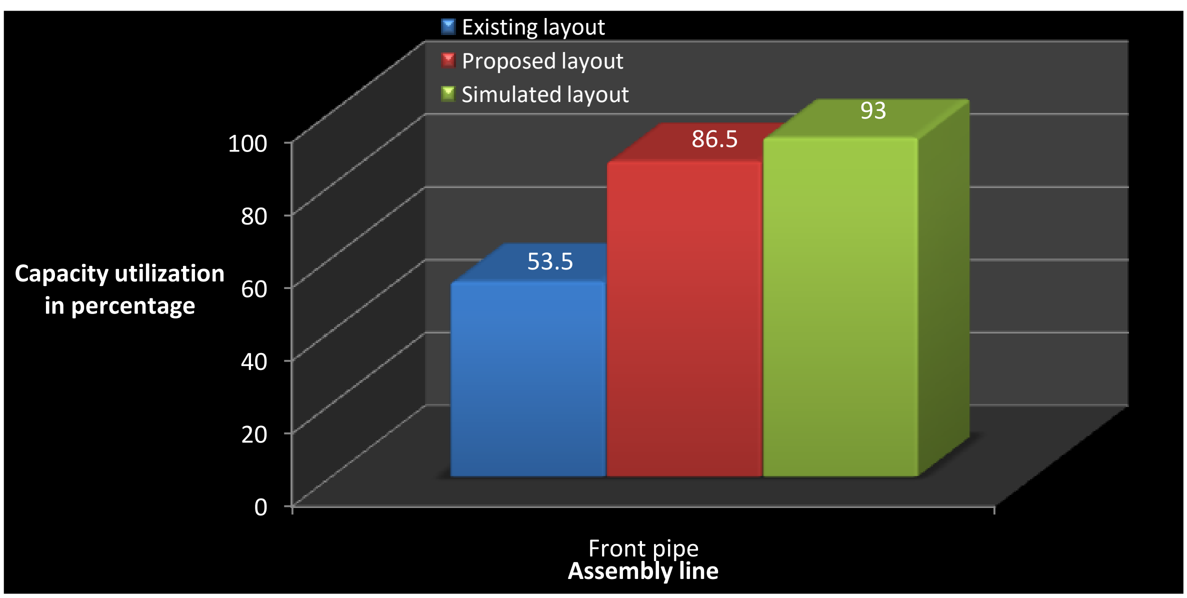

Figure 4.4 Machine capacity utilization for Scorpio front pipe assembly line

1. Machine capacity utilization increases by 61.68 % for proposed front pipe assembly line and 73.83 % for proposed assembly line after simulation.

2. From above values, machine capacity utilization for proposed line is equal to machine capacity utilization for simulated assembly line after validation.

e. Material handling

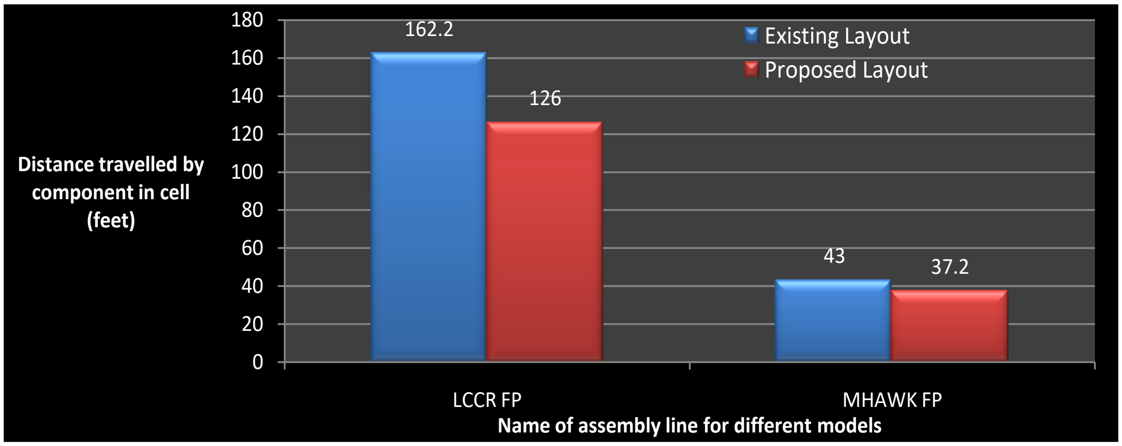

Figure 4.5 Distance travelled by component in cell for Scorpio front pipe line

Distance travelled by component in cell is reduced by 22.32 % and 13.49 % for lccr and mhawk model respectively.

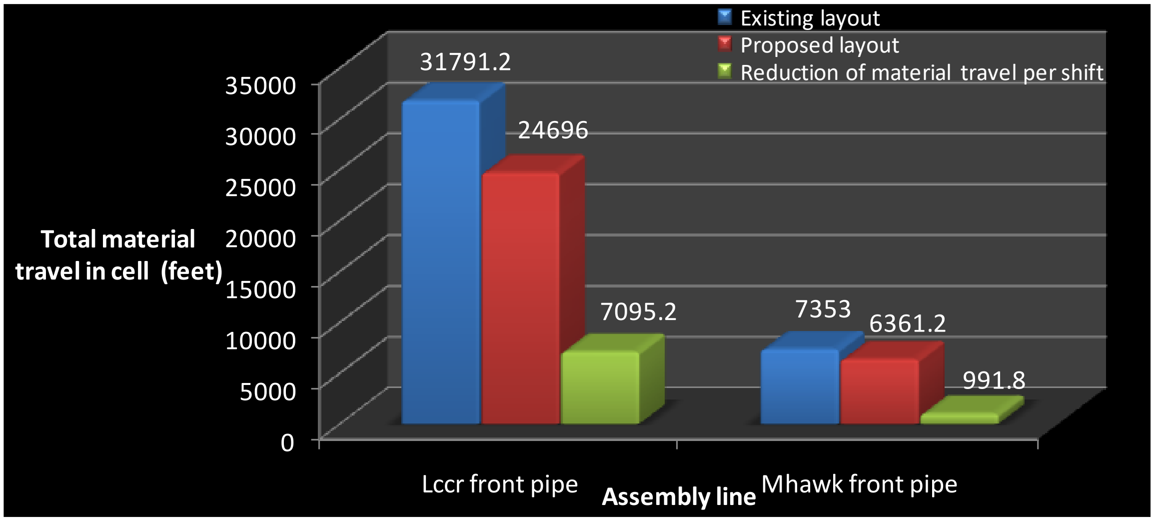

Figure 4.6 Total material travel in cell for Scorpio front pipe line

From above values, total material travel in cell for front pipe is reduced by 991.8 feet per shift.

f. Cost factor associated with plant layout

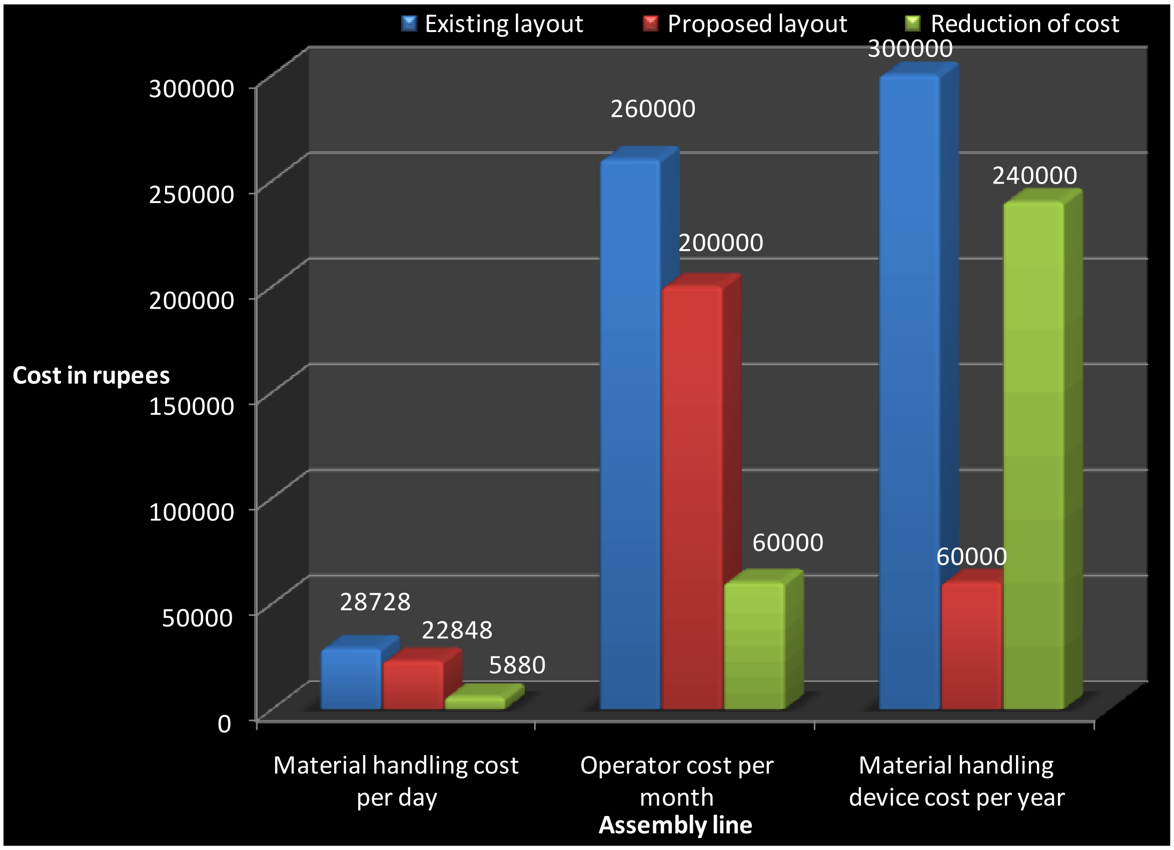

Figure 4.7 Cost element associated with Scorpio front pipe line

1. For proposed assembly line, total cost incurred will be reduced by Rs.5,880 for material handling per day, Rs. 60000 for labour cost per month and Rs.2,40,000 for material handling equipments per year.

2. From above results, total cost saving per annum will be Rs. 25,82,880.

4.2 Case study no. 02- Scorpio W105 mhawk muffler & tail pipe assembly

a. Manpower utilization

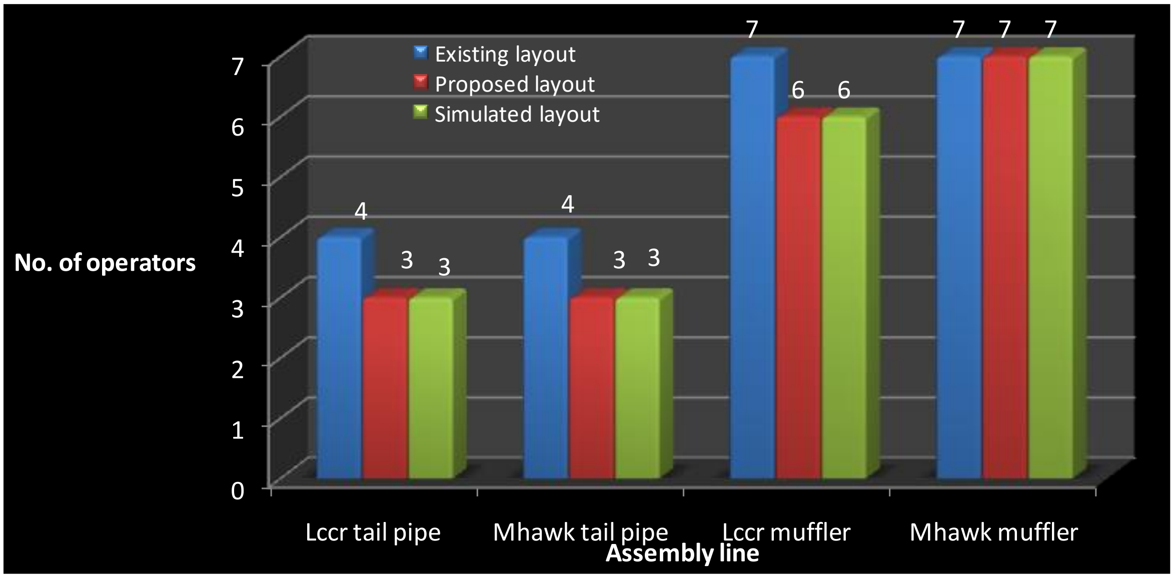

Figure 4.8 No. of operators required for Scorpio mhawk muffler & tail pipe line

1. No. of operator required is reduced by 02 for lccr tp & mhawk tp, 01 for lccr muffler line.
2. Manpower utilization increases by 25 % for lccr/mhawk tail pipe model and 14.28 % for lccr muffler model. Manpower utilization remains constant for mhawk muffler model.
3. Average utilization of Scorpio W105 mhawk muffler & tail pipe assembly line increases by 16.07 %.

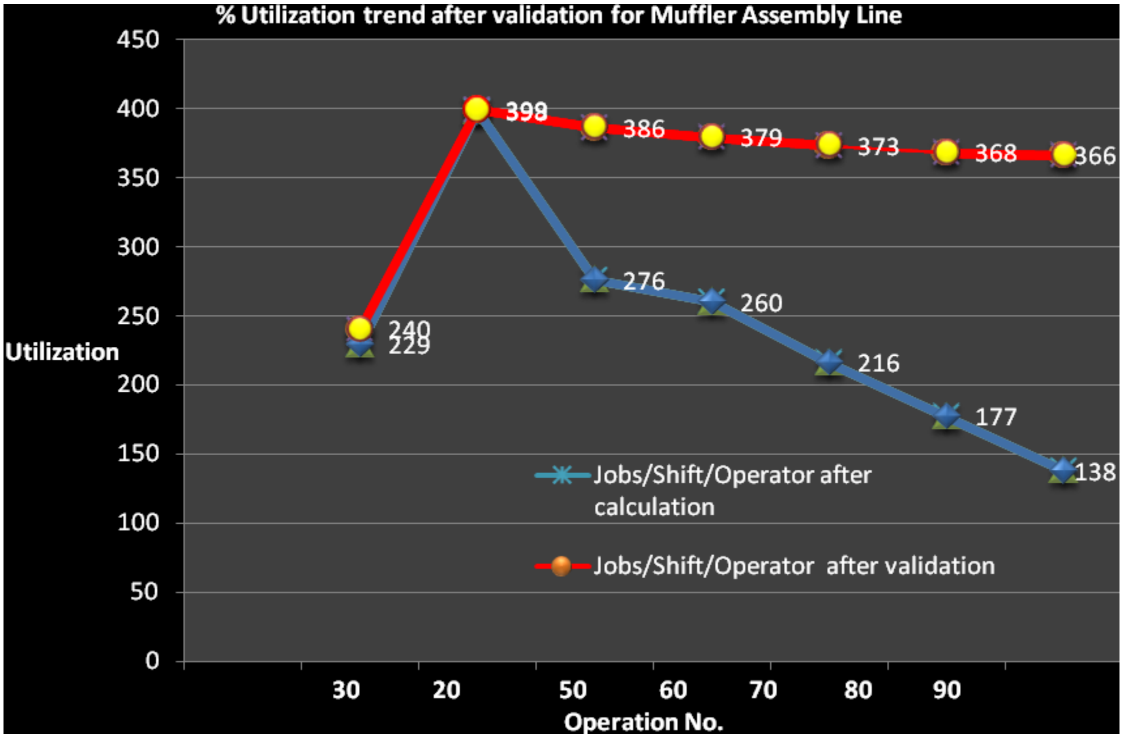

Figure 4.9 Percentage utilization trend for Scorpio muffler assembly line

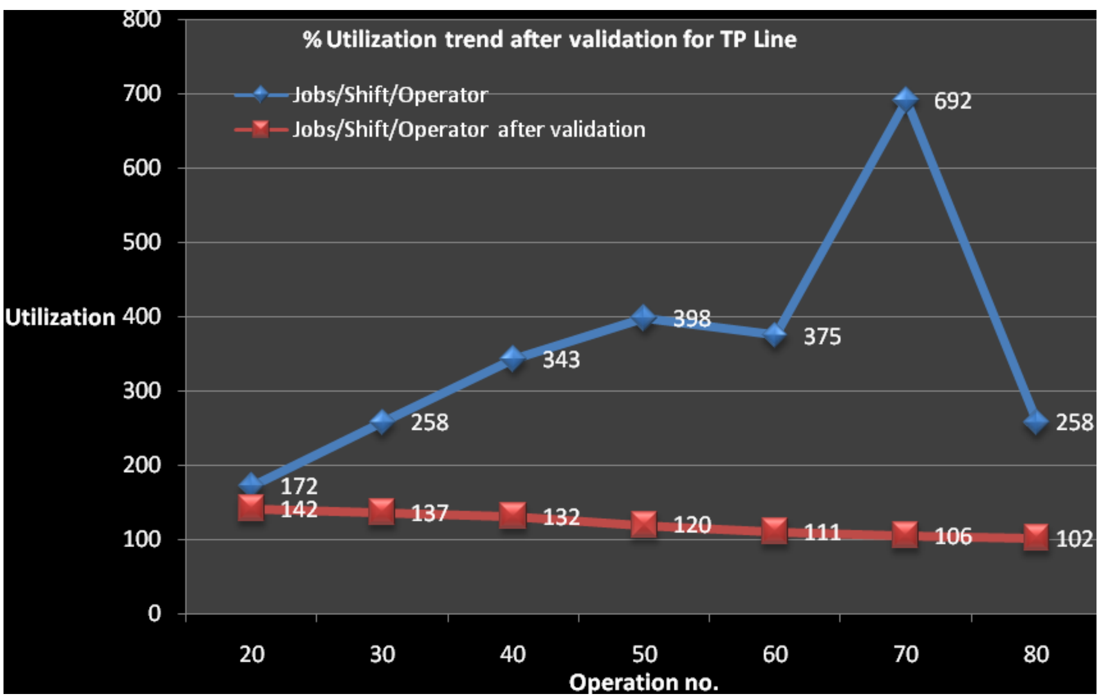

Figure 4.10 Percentage utilization trend for Scorpio tail pipe assembly line

Analysis shows percentage utilization trend after validation is positive and synchronized to cell capacity to meet demand as per production for Scorpio mhawk muffler & tail pipe line.

b. Operation time

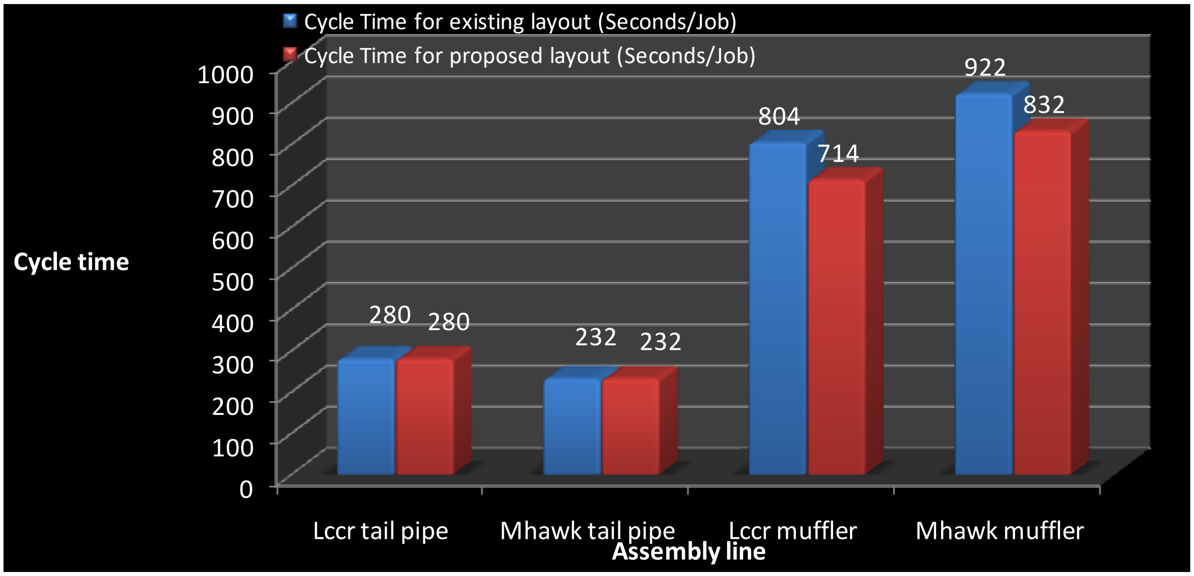

Figure 4.11 Cycle time for Scorpio mhawk muffler & tail pipe line

1. Operation cycle time remains constant for lccr and mhawk tail pipe model.

2.Operation cycle time decreases by 11.19 % for lccr muffler model and 10.81 % for mhawk muffer pipe model.

c. Production volume

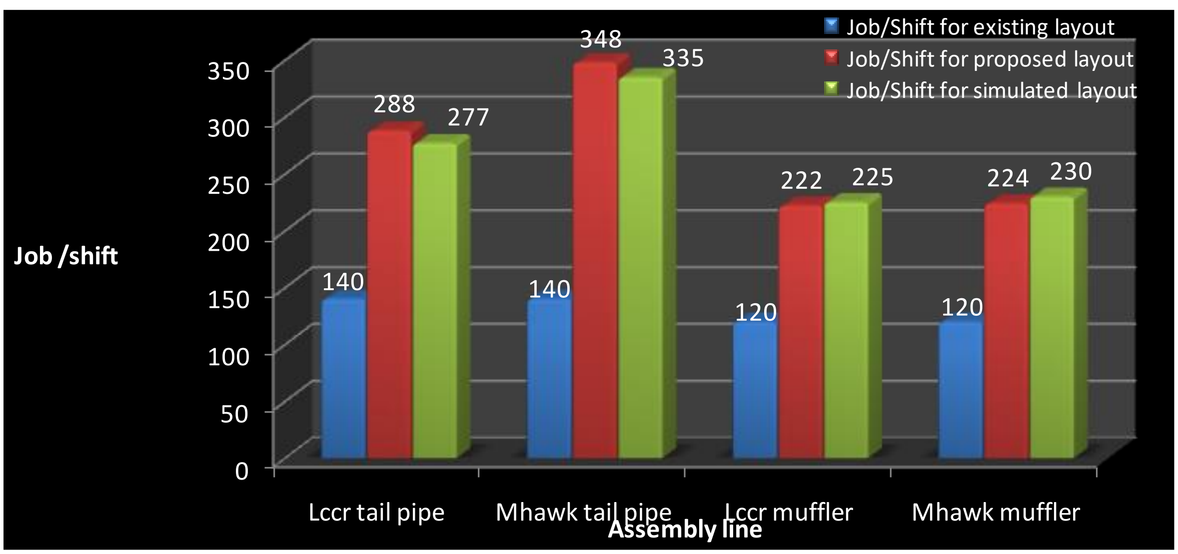

Figure 4.12 Job per shift for Scorpio mhawk muffler & tail pipe line

1. Production volume increases by 105.71 %, 148.57 %, 85 % and 86.67 % for lccr tail pipe model, mhawk tail pipe model, lccr muffler model and mhawk muffler model respectively.

2. Production volume in simulated layout increases by 97.86 %, 139.28 %, 87.5 % and 91.67 % for lccr tail pipe model, mhawk tail pipe model, lccr muffler model and mhawk muffler model respectively.

From above values, production volume for proposed line is equal to production volume for simulated assembly line after validation.

d. Machine capacity utilization

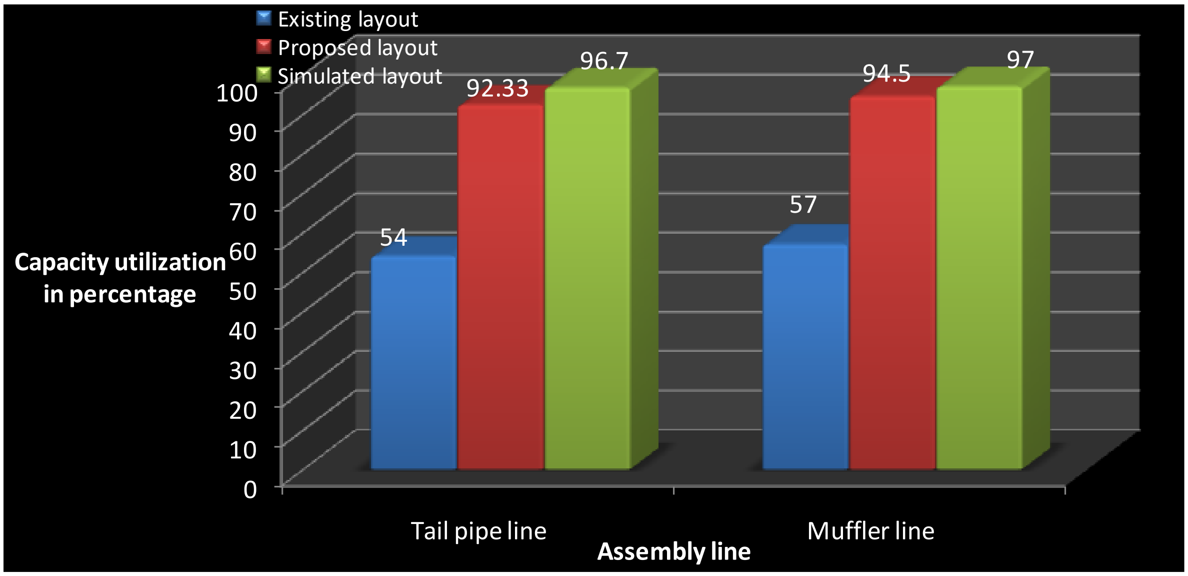

Figure 4.13 Machine capacity utilization for Scorpio mhawk muffler & tail pipe line

1. Machine capacity utilization increases by 70.98 % and 65.79 % for proposed tail pipe assembly line and muffer assembly line respectively.

2. Machine capacity utilization increases by 79.07 % and 70.17 % for simulated tail pipe assembly line and muffer assembly line respectively.

From above values, machine capacity utilization for proposed line is equal to machine capacity utilization for simulated assembly line after validation.

e. Material handling

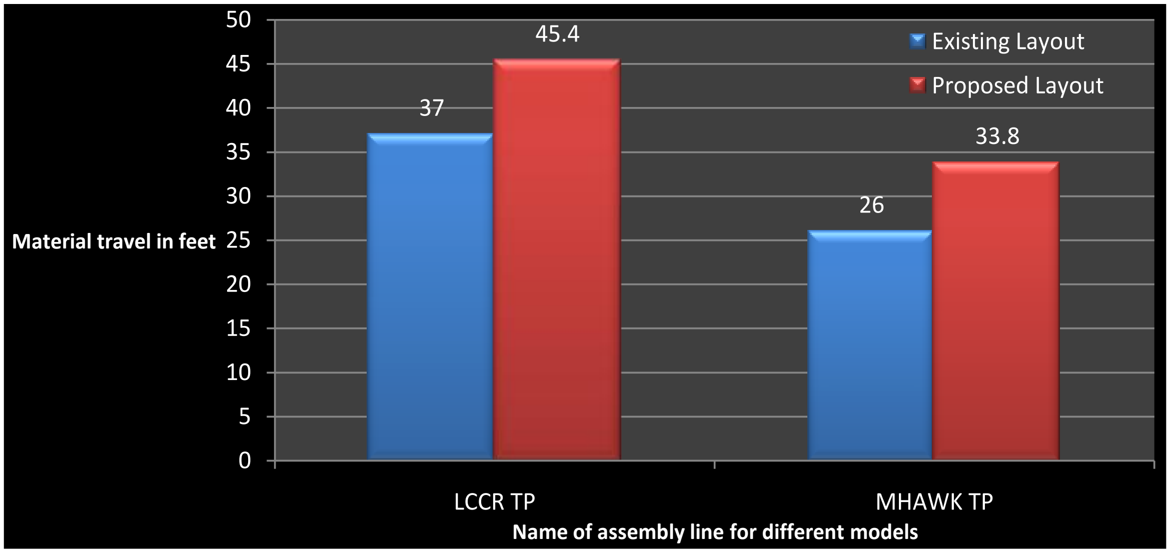

Figure 4.14 Distance travelled by component in cell for Scorpio mhawk tail pipe line

Distance travelled by component in cell increases by 22.70 % for lccr tail pipe model and 30 % for mhawk tail pipe model.

Material movement distance slightly increases to provide separate storage area between two machines for excess WIP material.

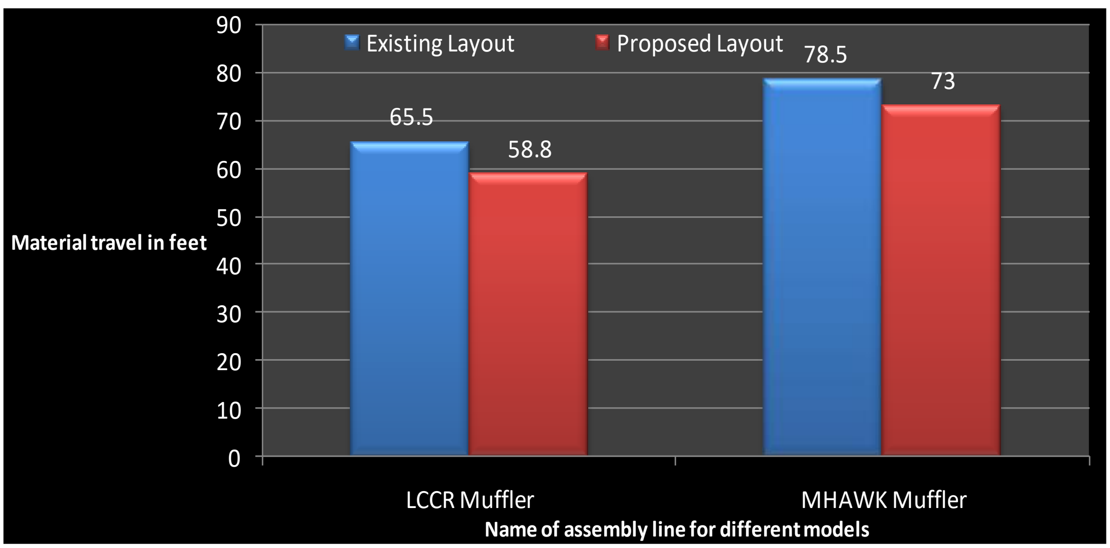

Figure 4.15 Distance travelled by component in cell for Scorpio mhawk muffler line

Distance travelled by component in cell decreases by 10.23 % for lccr muffler model and 07 % for mhawk muffler model.

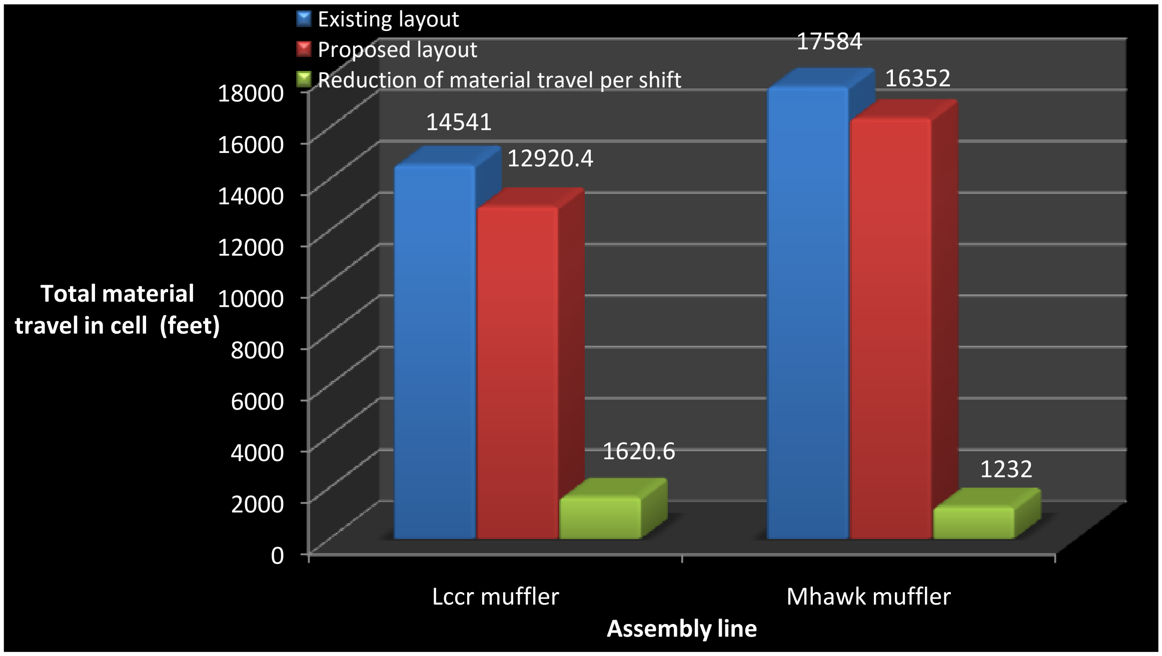

Figure 4.16 Total material travel in cell for Scorpio muffler line

From above values, total material travel in cell is reduced by 1620.6 feet per shift for lccr muffler and 1232 feet per shift for mhawk muffler.

f. Cost factor associated with plant layout

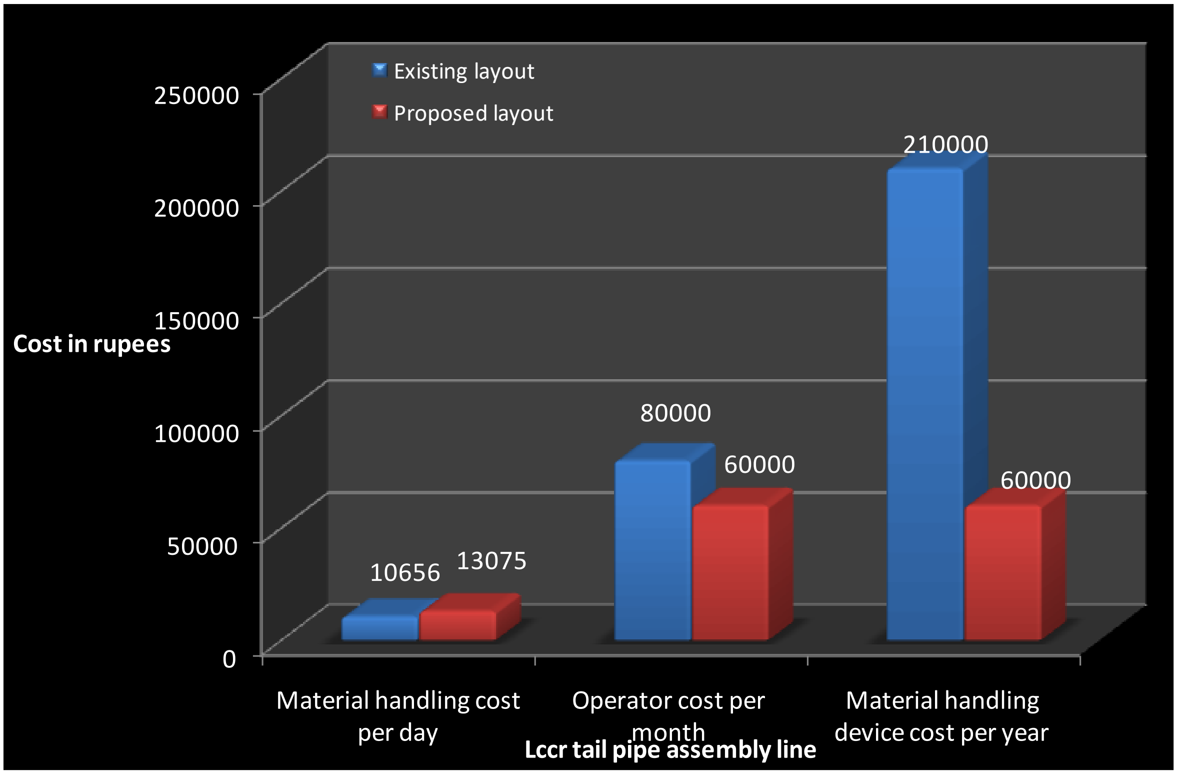

Figure 4.17 Cost factor associated with Scorpio lccr tail pipe line

For proposed assembly line, total cost incurred will be increased by Rs.2,419 for material handling per day while total cost incurred will be decreased by Rs. 20,000 for labour cost per month and Rs.150000 for material handling equipments per year. Total cost per annum increases by Rs. 2,77,644.

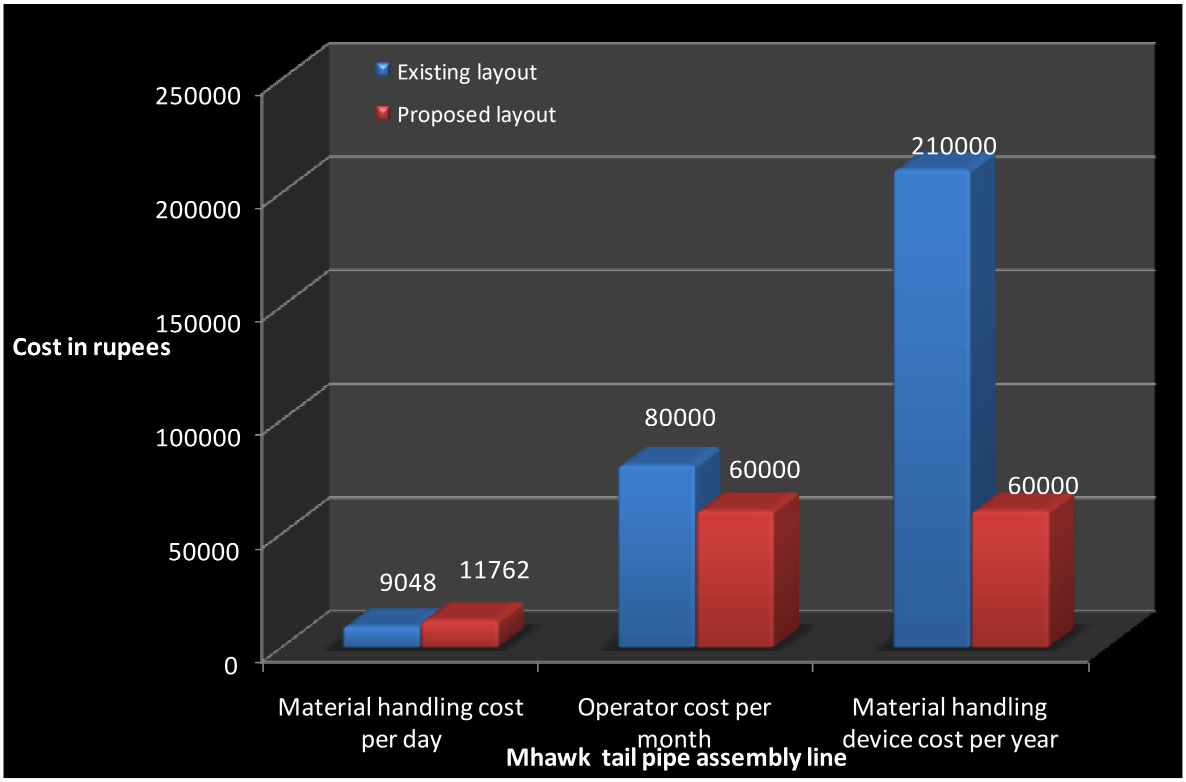

Figure 4.18 Cost factor associated with Scorpio mhawk tail pipe line

For proposed assembly line, total cost incurred will be increased by Rs.2,714 for material handling per day while total cost incurred will be decreased by Rs. 20,000 for labour cost per month and Rs.1,50,000 for material handling equipments per year. Total cost per annum increases by Rs. 3,59,064.

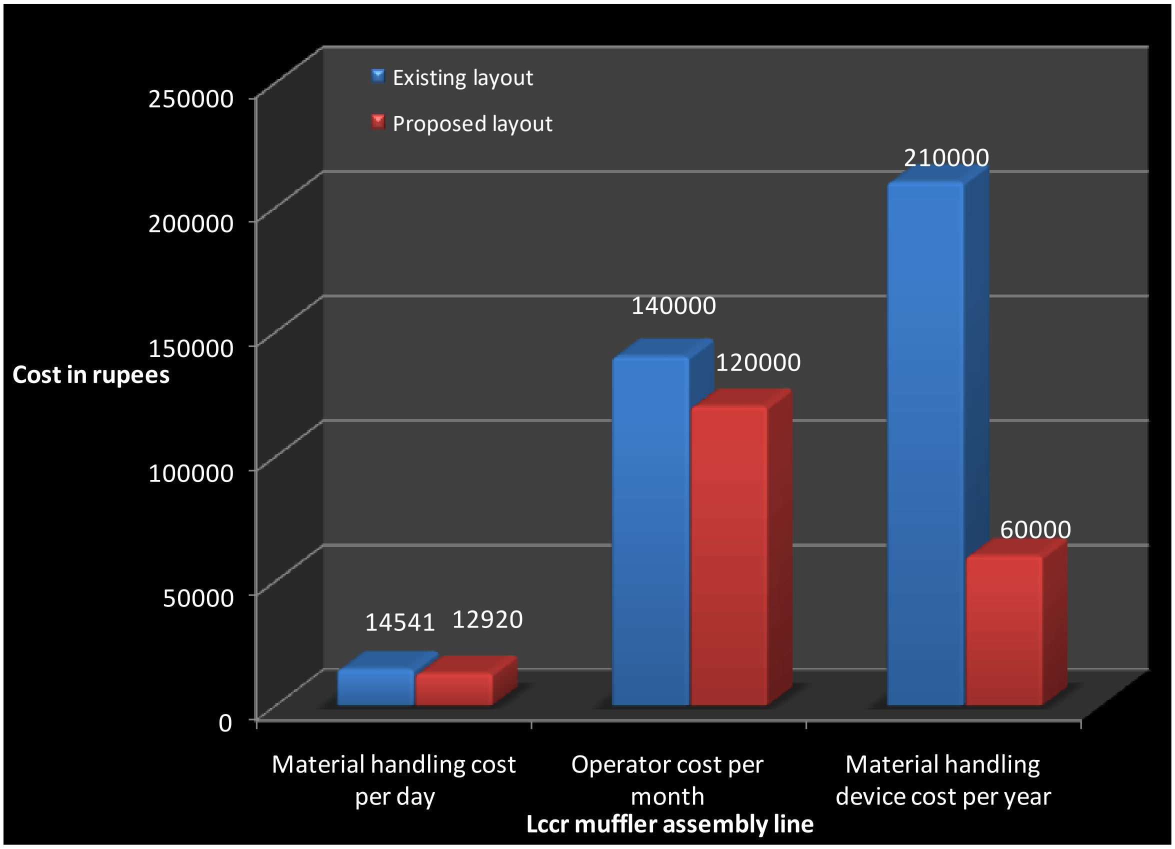

Figure 4.19 Cost factor associated with Scorpio lccr muffler line

For proposed assembly line, total cost incurred will be decreased by Rs.1,621 for material handling per day, Rs. 20,000 for labour cost per month and Rs.1,50,000 for material handling equipments per year. Total cost per annum decreases by Rs. 8,37,396.

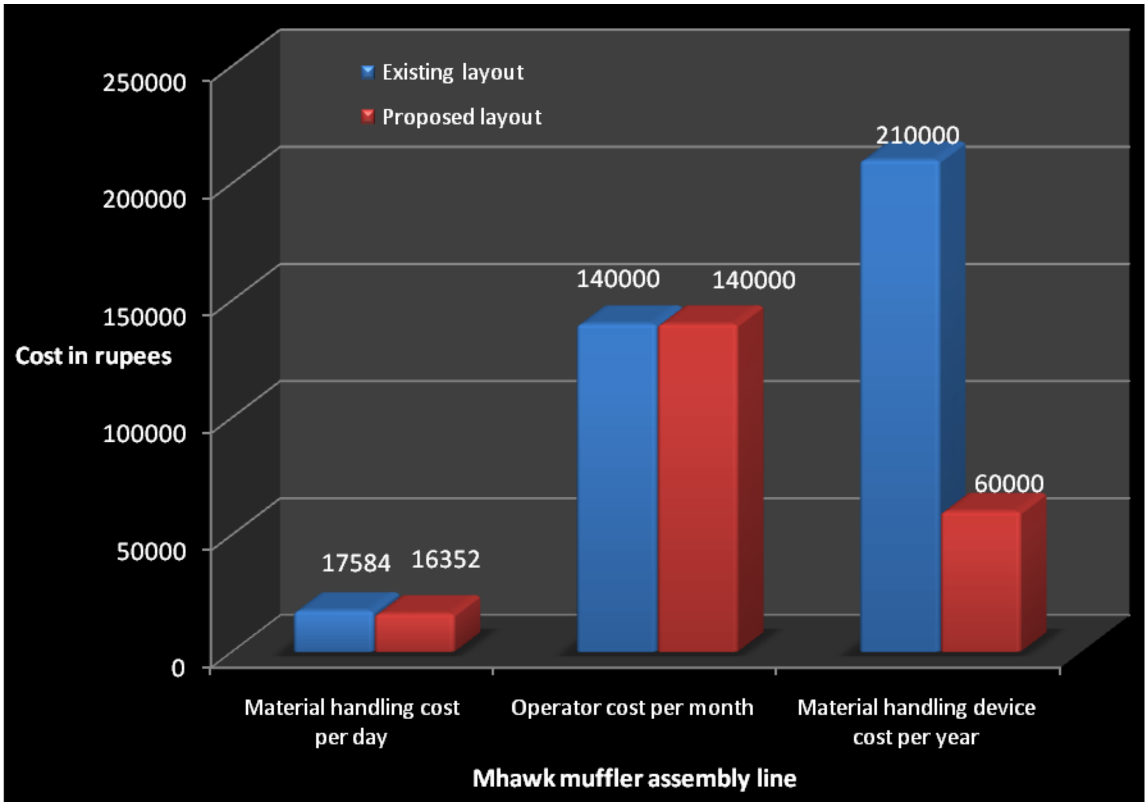

Figure 4.20 Cost factor associated with Scorpio mhawk muffler line

For proposed assembly line, total cost incurred will be decreased by Rs.1,232 for material handling per day and Rs.1,50,000 for material handling equipments per year. Total cost per annum decreases by Rs. 4,90,032 approximately.

Total cost saving per annum will be Rs. 5,59,752 for lccr assembly line and Rs. 1,30,968 for mhawk muffler assembly line.

4.3 Case study no. 03- Xylo exhaust system assembly layout

a. Manpower utilization

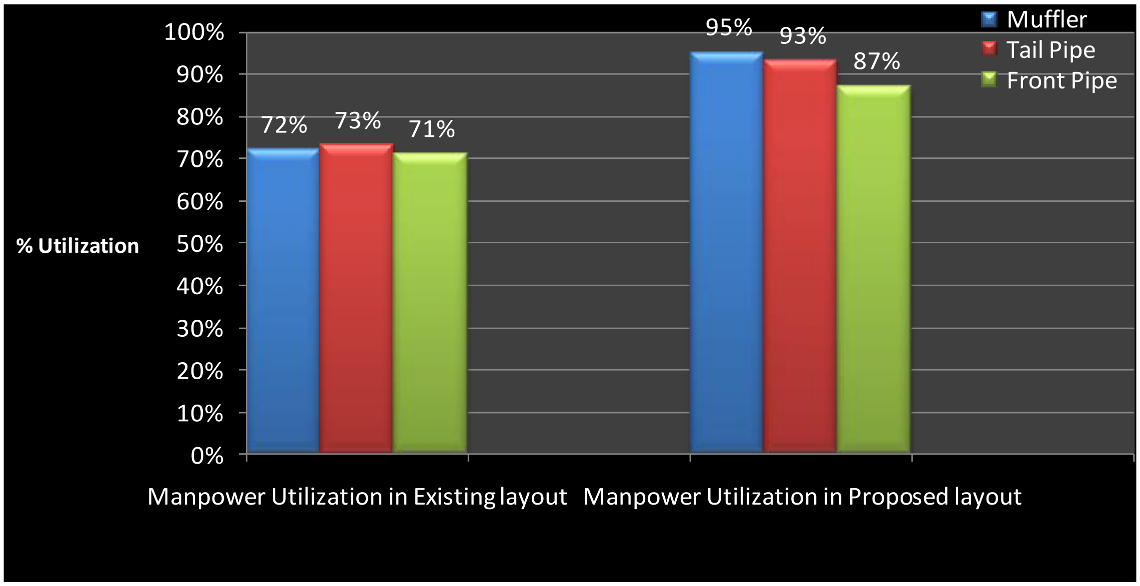

Figure 4.21 Comparison of Manpower utilization for Xylo exhaust system assembly line

Reduction of operators = 05 per shift

Cost saving = 05 X 02 shift X Rs.20000 per operator = Rs. 200000 per month

Above graph shows average manpower utilization increase by 31%, 28% and 23% for muffler, tail pipe and front pipe respectively.

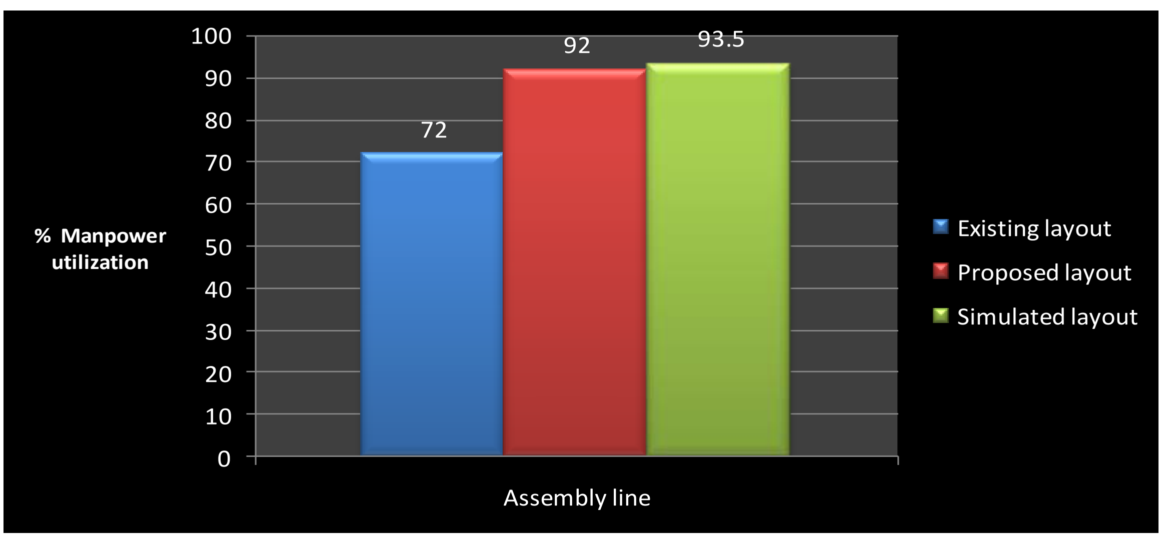

Figure 4.22 Average manpower utilization for Xylo exhaust system assembly line

Average manpower utilization increases from 72% to 92% for proposed Xylo exhaust system assembly line and 72% to 93.5% for simulated Xylo exhaust system assembly line.

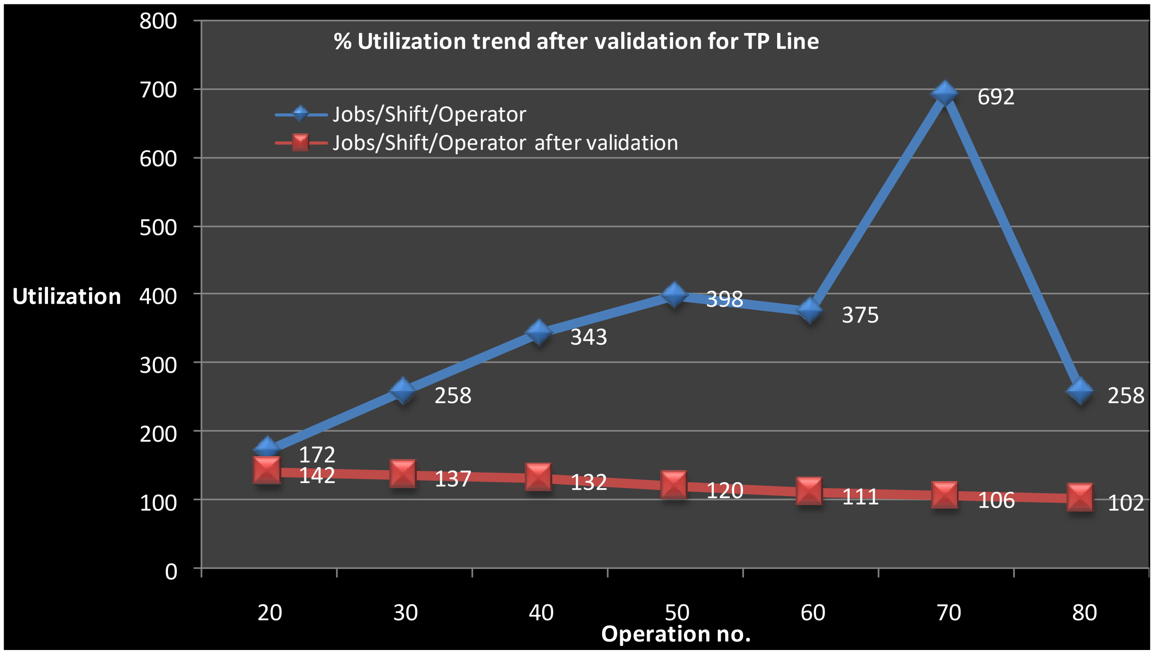

Figure 4.23 Percentage utilization trend after validation for tail pipe assembly line

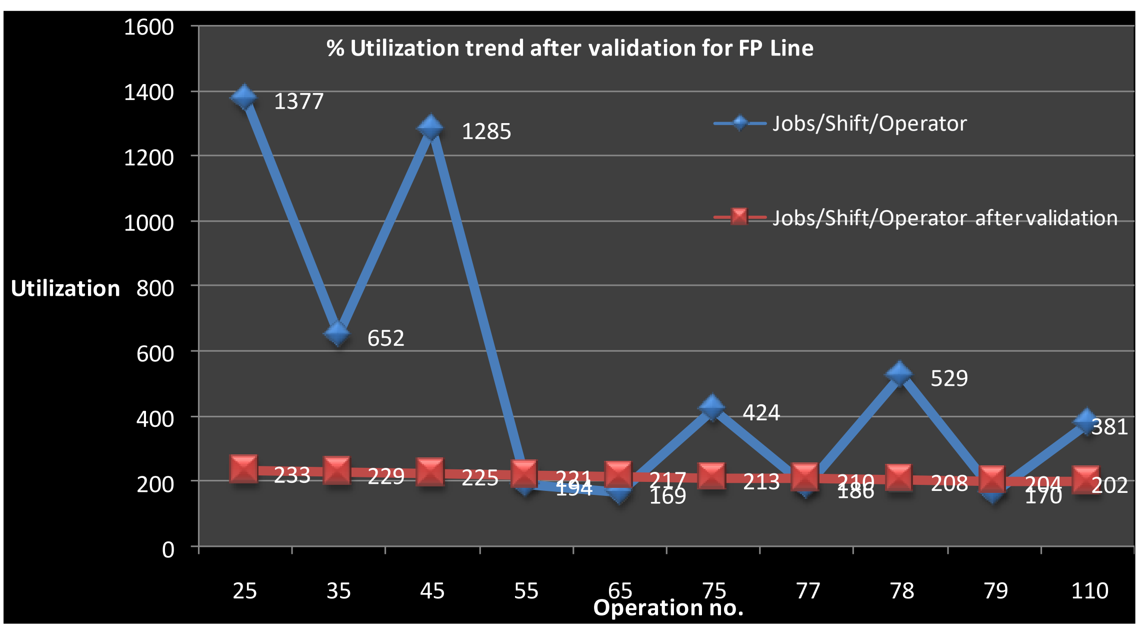

Figure 4.24 Percentage utilization trend after validation for front pipe assembly line

From above values, average manpower utilization for proposed line is equal to average manpower utilization for simulated assembly line after validation.

b. Operation time

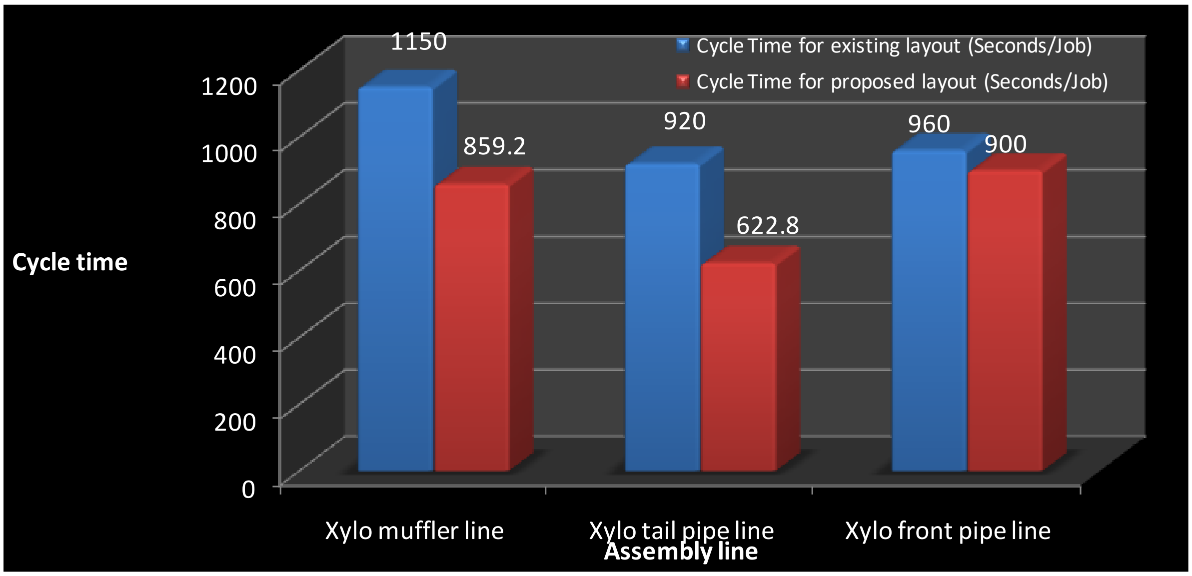

Figure 4.25 Cycle time for Xylo assembly line

Operation time decreases by 25.29 %, 32.30 % and 6.25 % for Xylo muffler model, tail pipe model and front pipe model respectively.

c. Production volume

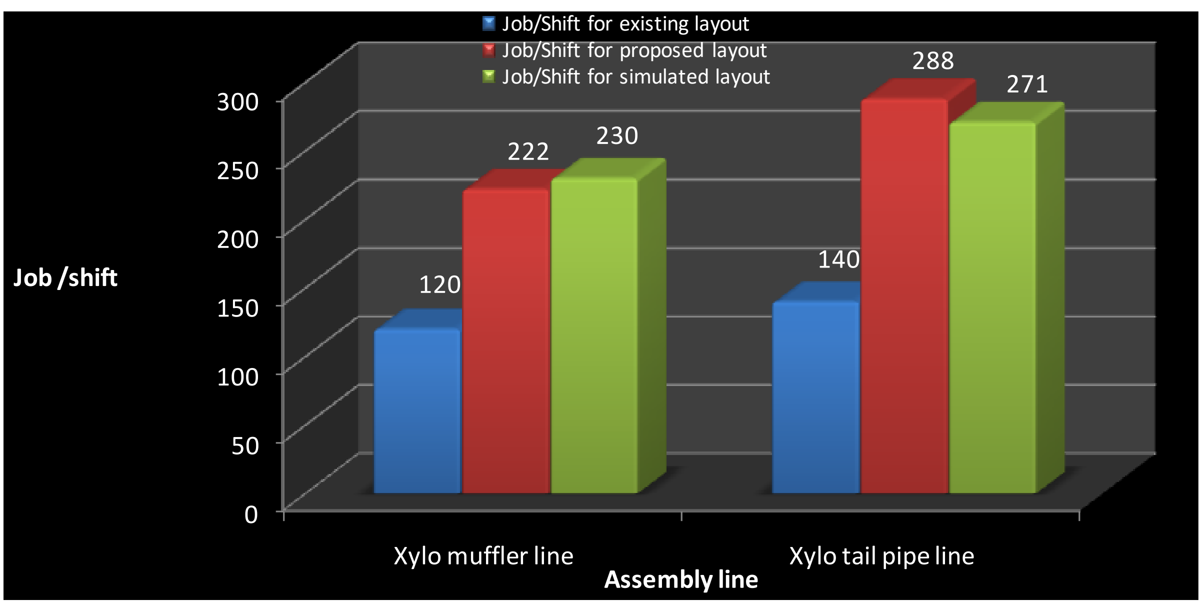

Figure 4.26 Job per shift for Xylo assembly line

Production volume increases by 85% and 105% for proposed xylo muffler and tail pipe line respectively.

Production volume increases by 91.66 % and 93.57 % for simulated xylo muffler and tail pipe line respectively.

From above values, production volume for proposed line is equal to production volume for simulated assembly line after validation.

d. Machine capacity utilization

Chart shows optimized space utilization for new layout compared to existing layput.

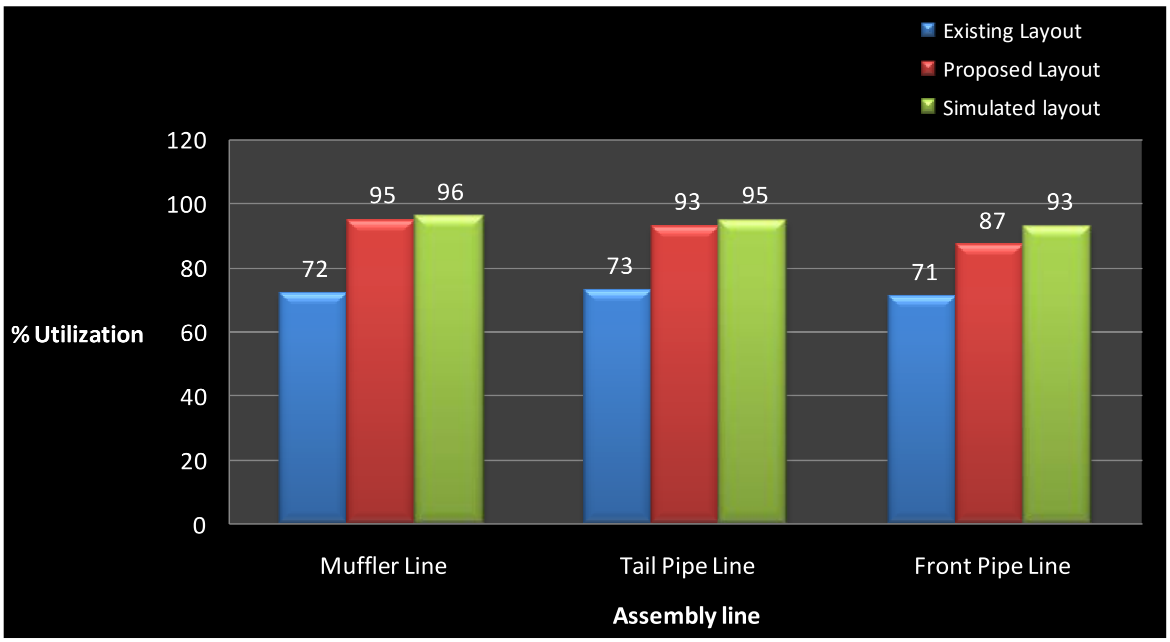

Figure 4.27 Machine capacity utilization for Xylo assembly line

Above graph shows average machine capacity utilization increases by 32%, 27% and 16% for muffler, tail pipe and front pipe respectively in case of proposed layout.

Above graph shows average machine capacity utilization increases by 34%, 30% and 31% for muffler, tail pipe and front pipe respectively in case of simulated layout.

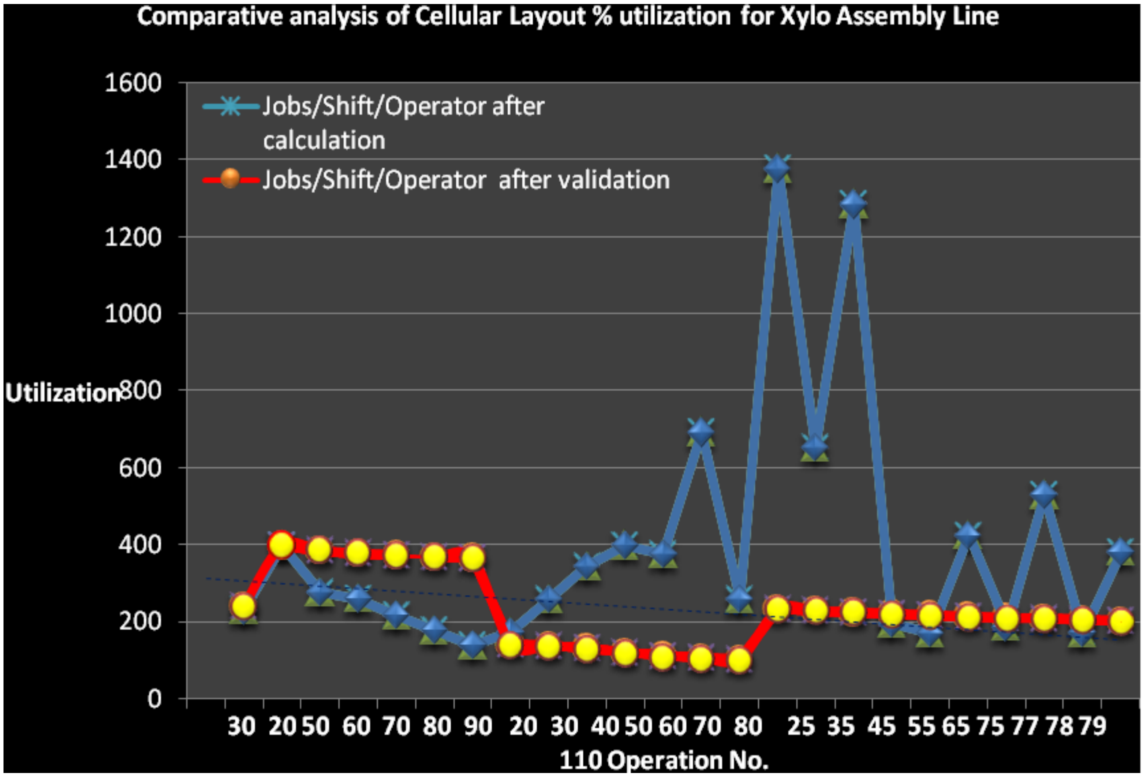

Figure 4.28 Comparative analysis of percentage utilization for Xylo Assembly Line

Analysis shows % Utilization trend after validation is positive and synchronized to cell capacity to meet demand as per customer requirements.

e. Material handling

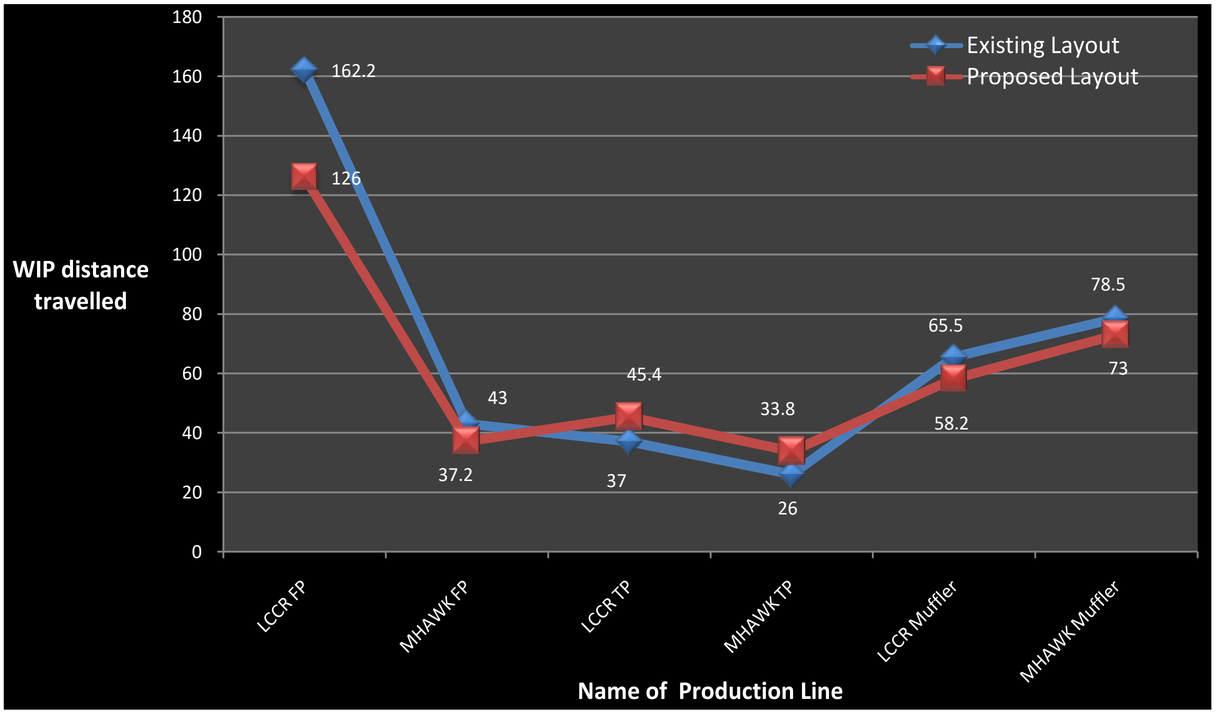

Figure 4.29 Distance travelled by work-in-process for various models

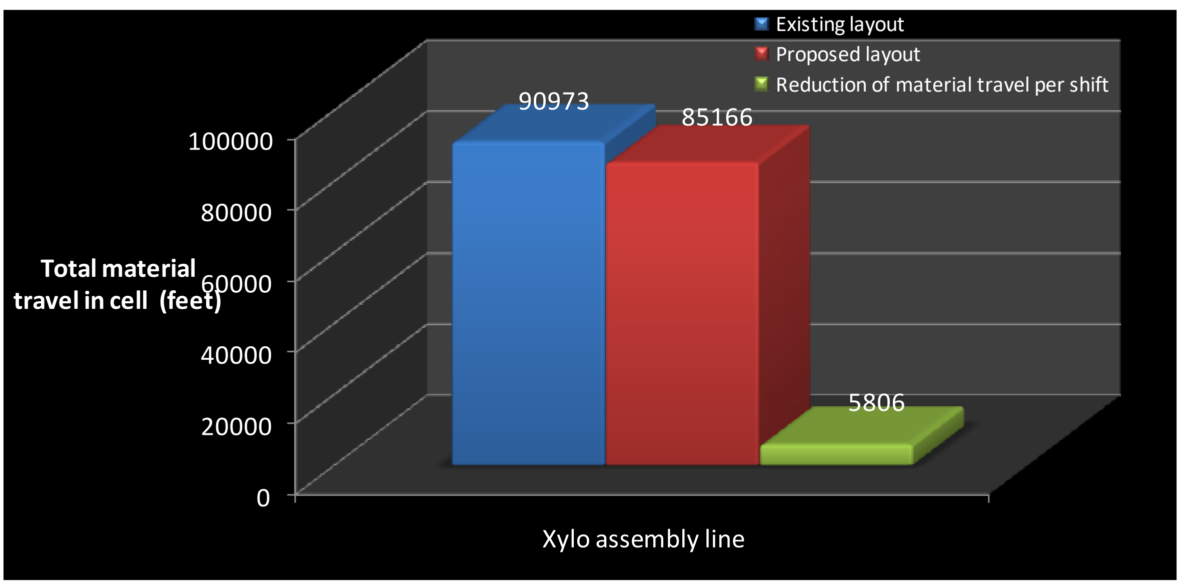

Figure 4.30 Distance travelled by work-in-process in Xylo Assembly Line

Maximum distance travelled by job= 70 feet.

Total material handling cost saving per shift = 5806 X 0.50 per feet =Rs.2903 per shift

Distance travelled by component from starting point to end point is reduced for Lccr front pipe, Mhawk front pipe, Lccr muffler, Mhawk muffler but slightly increased for Lccr tail pipe, Mhawk tail pipe to avoid backtracking of work-in-process material within cell.

In assembly line, trolleys are required for storing of a component after processing on each machine. Separate trolley is required for each operation in existing layout. In cellular layout, one trolley is required for inlet and outlet store considering roller conveyor system in proposed layout. Due to cellular layout trolleys are minimizing as compare to existing layout.

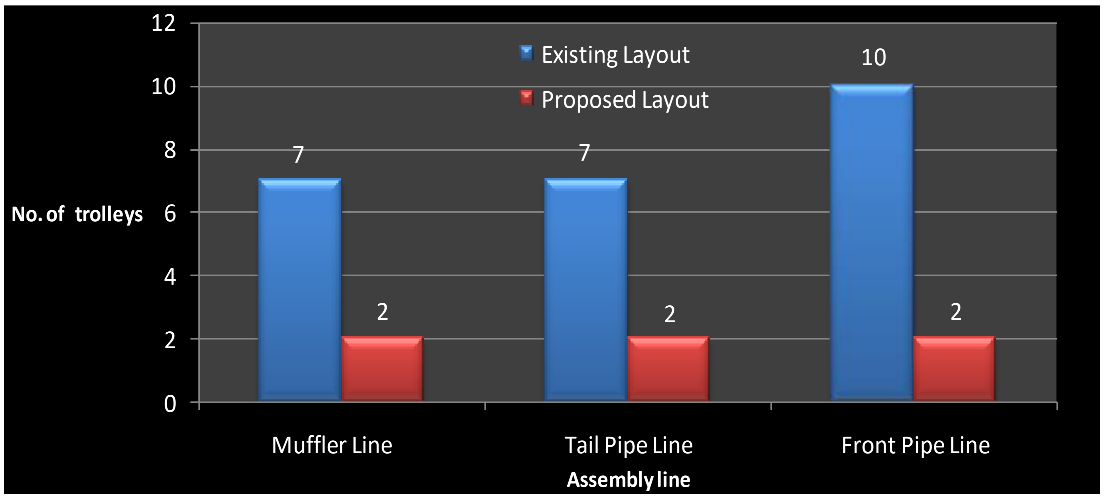

Figure 4.31 Trolley requirement for Xylo Assembly Line

Cost/Trolley = Rs. 30000

Total cost saving for Trolleys in Proposed Layout = Rs. 5, 40, 000.

Total cost saving upto 75 % for Trolleys is possible in proposed Layout.

f. Floor space utilization

In existing layout space required for line is 60meter x 13 meter (i.e. 806 square meter) Due to Proposed, it is reduced to 53 meter x 10 meter (i.e. 530 square meter). Therefore, space saving is 276 square meter = 906 square feet.

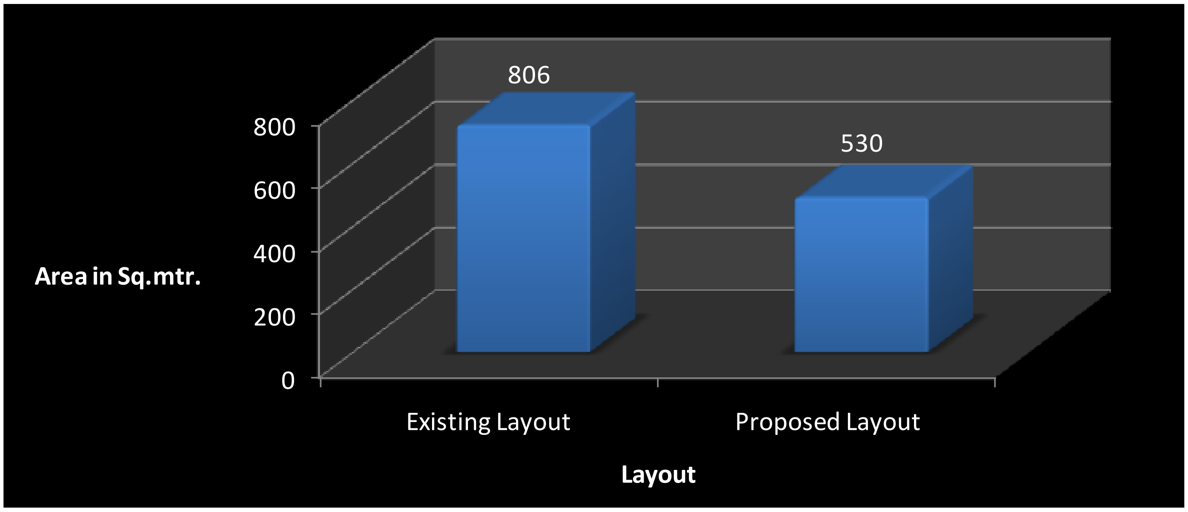

Figure 4.32 Comparison of space requirement for Xylo Assembly Line

Saving in space is 34.24% by proposed layout implementation.

g. Cost factor associated with plant layout

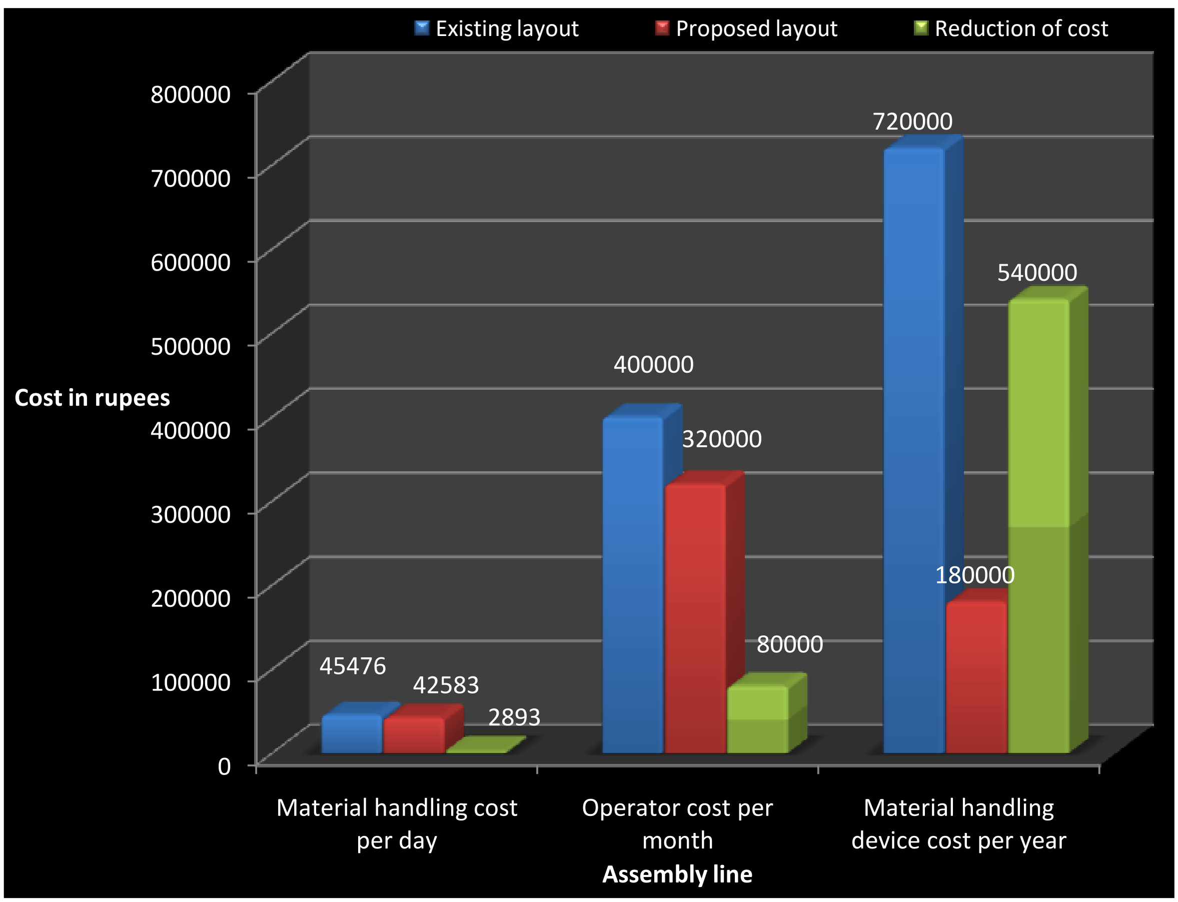

Figure 4.33 Cost factor associated with Xylo Assembly Line

For proposed assembly line, total cost incurred will be reduced by Rs.2893 for material handling per day, Rs. 80000 for labour cost per month and Rs.540000 for material handling equipments per year.

From above results, total cost saving per annum will be Rs. 2323308 approximately.

Cost of reinstallation of the layout is about Rs. 2323308 from payback period calculation the payback period for reinstallation cost is equal to one year and six months, when component manufacturing is based on proposed layout.

4.4 Other parameters

1] Standard time reduces in proposed layout because during auto cycle, operator handles more machines in a cell. Therefore, target for manufacturing the components gets increased and completion of target as per demand.

2] Space saving:

Keep all welding M/C Control Panels on overhead platform and that platform should be accessible to operator results in-

- Free space between 02 M/Cs increases which can be utilised for WIP Trolley.
- Easy for regular maintenance of M/C & Electrical Panels.

Figure 4.34 Sample overhead platform

MIG WELDING M/C KEPT ON THE OVERHEAD STRUCTURE ABOVE DED.

Figure 4.35 Overhead platform in Scorpio muffler assembly line

3] Automation- W105 muffler assembly line

Combine Seal ring welding operation of inter-pipe (M/C No. 01) with DED SPM welding M/C i.e. providing additional welding gun & modification in fixture is required which result in (Refer figure 4.36)

a. Clamp inter-pipe with muffler from top-Left side clamping
b. Weld seal ring by RH torch
c. Clamp on inter-pipe with muffler both side
d. Weld muffler to inter-pipe by middle torch results in
e. M/C No. 01 can be eliminated from line.
f. Scope for reduction of one operator from the cell.
g. WIP movement reduced.
h. Saving of Space for one machine on assembly line.

Figure 4.36 Automation area- W105 muffler assembly line (SMIL)

4] Provide guide ways for trolley on floor within cell for trolley movement & design trolley as per width of guide way for all components.

Figure 4.37 Sample photograph of guide ways on shop floor

Figure 4.38 Sample photograph of guide ways on shop floor

Chapter 05

Conclusions

The conclusions drawn from this research are summarised in this chapter. Recommendations and the direction of further research is also suggested.

5.1 Conclusions

To test and evaluate research approach a comprehensive case study is undertaken at a SMIL Nasik. Restructuring of existing plant layout to new layout results into huge cost saving by improvements in layout like aisles are left open along walls, all goods flow in the same sequence, layout arranged to flow according to processing sequence, job process by First in – First out, eliminated any use of non-value adding space, parts are arranged for easy feeding into line, stock-on-hand for entire line is predetermined, only non-defectives are fed to the first process, factory is divided into areas and line numbers, equipment is laid out for easy maintenance access, processes are brought as close as possible, U-shaped cells are arranged for neat outward appearance and backtracking of WIP material is avoided, analysis shows percentage utilization trend after validation is positive and synchronized to cell capacity to meet demand as per customer requirements, simulation readings proves that proposed layout and parameters associated with layout are within limit to satisfy customer requirements.

Improvements in major parameters are -

5.1.1. Manpower utilization

No. of operator required are reduced by three, three and five for Scorpio front pipe, tail/muffler line and Xylo assembly line respectively. Average manpower utilization increases by 23%, 25 %, 14.28 % and 92% for proposed Scorpio front pipe, tail pipe, muffler line and Xylo assembly line respectively. Analysis shows reduction of eleven operators per shift. i.e. 22 operators per month (for two shift) results in cost saving of Rs. 52,80,000 per annum.

Manpower utilization increases due to cellular manufacturing implementation. This methodology groups together machining and small team of staff directed by a team so all the work on a component can be accomplished in the same cell eliminating resources that do not add value to the manufactured goods.

5.1.2. Operation time

Operation cycle time decreases by 9.39 %, 11.19 %, 10.81 %, 25.29 %, 32.30 % and 6.25 % for Scorpio lccr tail pipe, lccr muffler, mhawk muffer, Xylo muffler, tail pipe and front pipe model respectively.

With reduction waste in terms of setup time, waiting time, work in process inventory results in improvement of productivity. The number of operation per part reduced through the implementation of new machinery/technology that which combine multiple operations in a single operation. Operator devotion allows the workers processing the jobs to become more recognizable with a similar family of components thus potentially reducing the throughput time per component.

5.1.3. Production volume

Production volume increases by 40 %, 21.43%, 105.71 %, 148.57 %, 85 %, 86.67 %, 85% and 105% in proposed Scorpio lccr front pipe, mhawk front pipe, lccr tail pipe, mhawk tail pipe, lccr muffler, mhawk muffler, Xylo muffler and tail pipe line respectively.

Production target increases due to shorter through time which result into the return business from automobile manufacturers who are satisfied due to shorter throughout time.

5.1.4. Machine capacity utilization

Machine capacity utilization increases by 61.68 %, 70.98 %, 65.79 %, 32%, 27% and 16% for proposed scorpio front pipe, tail pipe, muffer line, xylo muffler, tail pipe and front pipe line respectively. Machine capacity increases due to implementation of new technology machinery and automation of existing production system.

5.1.5. Material handling

Total material travel per shift in cell is reduced by 991.8 feet, 1620.6 feet, 1232 feet and 5806 feet for Scorpio front pipe, lccr muffler, mhawk muffler and xylo line respectively.

Total material handling cost saving per shift is Rs. 4825 i.e. Rs. 26,63,400 per annum due to switch over is made from traditional to cellular layout.

Total cost saving for Trolleys in Proposed Layout is Rs. 5,40,000 per annum. In assembly line, trolleys are required for storing of a component after processing on each machine. Separate trolley is required for each operation in existing layout. In cellular layout, one trolley is required for inlet and outlet store considering roller conveyor system in proposed layout. The new layout arrangement together with the installation of roller conveyor, made possible a substantial reduction in material handling the amount of material-in- process and temporary storage handling by means of the hand trolleys and lifting from floor to table will be practically eliminated. Also one piece flow decreases rework and scrap because faulty parts can be quickly identified at the subsequently operation.

5.1.6. Floor space utilization

In existing layout space required for line is 60meter x 13 meter (i.e. 806 square meters) Due to proposed layout, it is reduced to 53 meter x 10 meter (i.e. 530 square meters). Therefore, space saving is 276 square meter i.e. 906 square feet. Saving in space is 34.24% by proposed layout implementation due to redesign of layout and combining multiple operations into single operation using new technology.

5.1.7. Cost factor associated with plant layout

Total cost saving per annum will be Rs. 25,82,880, Rs. 5,59,752, Rs. 1,30,968 and Rs. 23,23,308 for Scorpio front pipe line, lccr assembly line, mhawk assembly line and xylo assembly line respectively. Overall saving is upto Rs. 55,96,908 per annum.The monetary impact is that the cost associated with this project is substantial small in comparison to the benefits derived from the improvement in various parameters.

Second economical impact is reduction of one shift per day to achieve same production target as in existing layout i.e. instead of three shift per day, target achieved in two shift per day results in huge cost saving per annum, 33% approximately.

Third economical impact is that scope for company to run third shift for additional production as per existing or new customer requirement i.e. profit margin will increase by 33 % per annum compare to existing conditions.

5.1.8. Significance of simulation

From results, utilization for proposed line is equal to average utilization for simulated assembly line after validation. Simulation readings proves that proposed layout and parameters associated with layout are within limit to satisfy customer requirements i.e. Job target / shift. Result of the simulation study here clearly indicated that the choice of a alternate layout has impact on the productivity. In real life situation this approach increases the scope of efficient machine cell formation and reduces the complexity of the problem. Simulation study shows that proposed alternative layout optimize various productivity parameters compare to existing layout for auto assembly lines. Simulation of existing layout makes operation simpler for design and increases productivity of planning engineer by using 'Show Flow' simulation software.

5.2. Recommendations for implementation

a. Give training to slowest machine operator.
b. Operator should be capable of performing all operation in cell.
c. Rotate jobs among operators to increase alertness.
d. Operators can share job tasks between work stations within cell to balance output as per customer demand.
e. Use mechanical conveyors, gravity chutes, slides for movement of jobs from operation to operation.
f. Shifting of cross trained operators within different cell as per demand from customers.
g. Instead of reducing the cycle time, decrease the no. of operators because decreasing cycle time result in over production per shift.
h. Material movement within cell- for one piece flow i.e. no pending work between two stations.
i. Provide guide ways for trolley on floor within cell for trolley movement & design trolley as per width of guide way for all components.

Thus, it is concluded that, the design of a layout affects cell performance and thus should be analysed before restructuring or establishing production/assembly line for productivity improvement.

5.3 Issues for future research

The present system can be extended to take care of the following shortcoming;

1. Cell layout and intracellular movement issues can be considered for designing of Cellular Manufacturing Systems.
2. Scheduling issues can be incorporated in design of CMS to bring additional savings in time and money.
3. Still much scope exists for considering more design attributes and developing better simulation layout.
4. More advanced material handling equipments can be used to reduce material travel time within cell.

References

[1]Agarwal A. 2008. Partitioning bottleneck work centre for cellular manufacturing: An integrated performance and cost model, International Journal of Production Economics 111(2):635-647.

[2]Agarwal G.K. 2012. Plant Layout & Material Handling, 8th Edition, Jain Brothers, New Delhi, ISBN 81-86321-78-0.

[3]Andrew G.2008.Using simulation for facility design: A case study, Simulation Modelling Practice and Theory 16:670-677.

[4]Apple J.M. 1997. Plant Layout and Material Handling, Wiley, New York.

[5]Aryanezhada M.B. et al.2011. A new approach for cell formation and scheduling with assembly operation Structure, International Journal of Industrial Engineering Computations 2: 533-546.

[6]Arora P.K. et al.2011. Cell Formation Techniques-A Study, International Journal of Engineering Science and Technology 3:1178-1182.

[7]Askin R. G. and Goldberg J. B. 2002.Design and Analysis of Lean Production Systems, John Wiley & Sons, Inc., New York, ISBN 0-471-11593-2.

[8]Abdinnour S.F., Venkataramanan M.A. and Jacobs F.R. 1993. Models of Various Cell Structures in GT, Modelling, 18(2):35-42.

[9]Agarwal A., and Sarkis J. 1998. Review and analysis of comparative performance studies on functional and cellular manufacturing layouts, Computers & Industrial Engineering, 34(1):77-89.

[10]Ali A. and Soroush H.M. 2008. The significance of reducing setup times/setup costs, European Journal of Operational Research, 187:978-984.

[11]Askin R. and Standridge C. 1993.Modeling and Analysis of Manufacturing Systems, John Wiley & Sons, New York.

[12]Black J.T. 1991. The Design of the Factory with a Future, McGraw-Hill, New York.

[13]Baudin M.2002. Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow ,Productivity Press, New York, ISBN 1-56327-263-6.

[14]Barve S.B. et al. 2011. Research issues in Cellular Manufacturing System, International Journal of Applied Engineering Research 6:291-30.

[15]Bansee J. and Chowdary B. V. 2007. A New Concept of Cellular Manufacturing: A Case Study, Fifth LACCEI International Latin American and Caribbean Conference

for Engineering and Technology (LACCEI'2007) "Developing Entrepreneurial Engineers for the Sustainable Growth of Latin America and the Caribbean: Education, Innovation, Technology and Practice", Tampico, Mexico:1-10.

[16]Bharamgude P.S. And Telsang M.T. 2014. Design, analysis and performance simulation of cellular manufacturing system - a case study, International Journal of Mechanical And Production Engineering, 2(6):74-77.

[17]Bopaya B. et al.2005.Human related issues in manufacturing cell design, implementation, and operation: a review and survey, Computers & Industrial Engineering, 48:507-523.

[18]Benjaafar S., Heragu S.S. and Irani S.A.2002. Next Generation Factory Layouts: Research Challenges and Recent Progress,Interfaces INFORMS 32(6):58-76.

[19]Caputo F., Girimo D.I. and Marzano A. 2006. Ergonomic optimization of a manufacturing system work cell in a virtual environment, ActaPolytecnhnica 46(5):21-27.

[20]Chryssolouris G. et al. 2009. Digital manufacturing: history, perspectives, and outlook, Journal of Engineering Manufacture 223:451-462.

[21]Caputo G., Gallo M. and Guizzi G. 2009. Optimization of production plan through simulation techniques, WSEAS Transactions On Information Science and Applications 3(6):352-362.

[22]Chalapathi P.V. 2012. Complete Design of Cellular Manufacturing Systems, International Journal of Advanced Engineering Technology 3(3):67-71.

[23]Choobineh F.1988. A framework for the design of cellular manufacturing systems, International Journal of Production Research, 26: 1161-1172.

[24]Cesani V.I. and Steudel H. J. 2005. A study of labor assignment flexibility in cellular manufacturing systems, Computers & Industrial Engineering 48: 571-591.

[25]Croci F., Perona M. and Pozzetti A.2000.Work-force management in automated assembly systems, Int. J. Production Economics 64:243-255.

[26]Chenguang L., Wenjuan L., Jie L. and Yong Y.2012.Reconfiguration of assembly systems: From conveyor assembly line to serus, Journal of Manufacturing Systems 31:312-325

[27]Danny J.J. 2003. A Framework for Reducing Manufacturing Throughput Time, Journal of Manufacturing Systems 22(4):283-298.

[28]Dwijayanti K., Dawal S.Z., Jamasri and Aoyama H.2010.A Proposed Study on Facility Planning and Design in Manufacturing Process,IMECS 2:5-8.

[29]Dombrowskia U. and Ernsta S. 2013.Scenario-based simulation approach for layout planning, Procedia CIRP 12:54-359.

[30]Elmaraghy H. et al. 2014. A model for assessing the layout structural complexity of manufacturing systems, Journal of Manufacturing Systems 33:51– 64.

[31]Eric M., Jannes S. and Samantha R.2002.The evolution of a cellular manufacturing system – a longitudinal case study, Int. J. Production Economics 75:305–322.

[32]Farimah M.R. and Aliasghar D.2012.Flexible Labor Assignment in Cellular Manufacturing System (A Simulation and DEA Approach), International Conference on Industrial Engineering and Operations Management Istanbul, Turkey:952-960.

[33]Fitzpatrick E.L. and Askin R.G.2005.Forming effective worker teams with multi-functional skill requirements, Computers & Industrial Engineering 48:593–608.

[34]Fahad A.M., Cem C. and Basheer M.K.2003.A simulation study of focused cellular manufacturing as an alternative batch-processing layout, Int. J. Production Economics 83:123-138.

[35]Greasley A. 2008. Using simulation for facility design: A case study. International Journal of Simulation Modelling Practice and Theory 16:670–677.

[36]Gursel A. S. and Cihan D.2005. Intra-cell manpower transfers and cell loading in labor-intensive manufacturing cells, Computers & Industrial Engineering 48:643-655.

[37]Gaither N. 1992. Production and Operations Management, 5th ed., The Dryden Press, New York.

[38]Gert N. and Durk J. V. 2008.Virtual cellular manufacturing: Configuring routing flexibility, Int. J. Production Economics 112:439-451.

[39]Gallagher C.C. and Knight W.A. 1986. Group Technology Production Methods in Manufacture, Ellis Horwood, New York.

[40]Gerald R.A., John R.O. and Marc J.S.2004. U-shaped assembly line layouts and their impact on labor productivity: An experimental study, European Journal of Operational Research 156:698-711.

[41]Gursel A. S., Jeremy C. and Amanda P.2009. Models for cell loading and product sequencing in labor-intensive cells, Computers & Industrial Engineering 56:97-105.

[42]Ghosh T. et al.2011. Coding and Classification Based Heuristic Technique for Workpiece Grouping Problems in Cellular Manufacturing System, International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 02:53-72.

[43]Hakan G. 2012. Scheduling in flowshops with flexible operations: Throughput optimization and benefits of flexibility, Int. J. Production Economics 140: 900–911.

[44]Harrington J. 1984. Understanding the Manufacturing Process: key to successful CAD/CAM implementation, Marcel Dekker, New York.

[45]Huawei C., Wang A., Ning R. and Shao C. 2011. Layout Planning Technology of Cellular Manufacturing System Based on process interconnection Analysis, Chinese Journal of Mechanical Engineering 24:1-11.

[46]Hu S.J.et al. 2011. Assembly system design and operations for product variety, CIRP Annals - Manufacturing Technology 60:715-733.

[47]Iqbal M. and Hashmi M.S.J. 2001.Design and Analysis of a virtual factory layout. International Journal of Materials Processing Technology 118:403-410.

[48]Jeffrey S. 2003. Survey on the Use of Simulation for Manufacturing System Design and Operation, Journal of Manufacturing Systems 22(2):157-171.

[49]Jeffrey S.2007. Designing and redesigning cellular manufacturing systems to handle demand changes, Computers & Industrial Engineering 53:478-490

[50]Johnson D.J. 2003. Systematic Redesign of Cellular Manufacturing Systems, Journal of Manufacturing System 22(4).

[51]John M.2001.U-shaped production lines: A review of theory and practice, Int. J. Production Economics 70:201-214

[52]Jannes S., Jos A.C.B. and Eric M.2005. Cross-training in a cellular manufacturing environment, Computers & Industrial Engineering 48:609-624.

[53]Joseph B. and Michael M.2004.Multi-objective design of team oriented assembly systems, European Journal of Operational Research 156:326-352.

[54]Jin Y., Yamashita Y. and Nishitani H. 2004. Human modeling and simulation for plant operations, Computers and Chemical Engineering 28:1967-1980.

[55]Korves B. and Loftus M.2000. Designing an immersive virtual reality interface for layout planning, Journal of Materials Processing Technology 107:425-430.

[56]Khusna D. et al. 2010. A proposed study on facility planning and design in

manufacturing process, International MultiConference of engineers and computer scientists 3:5-8.

[57]Karuna K.G., Reddy S.H.K. and Ahmed S.N. 2012. Application of Cellular Manufacturing Concepts in an Automobile Workshop, International Journal of Engineering Research and Applications 2(6):1616-1619.

[58]Kulak O., Durmusoglu M.B. and Tufekci S. 2005. A complete cellular manufacturing system design methodology based on axiomatic design principles, Computers & Industrial Engineering 48:765-787.

[59]Lashkari R.S., Boparai R. and Paulo J. 2004. Towards an integrated model of operation allocation and material handling selection in cellular manufacturing systems, Int. J. Production Economics 87:115-139.

[60]Lamkull D., Hanson L. and Ortengren R. 2009. A comparative study of digital human modelling simulation results and their outcomes in reality: A case study within manual assembly of automobiles, International Journal of Industrial Ergonomics 39:428-441.

[61]Miltenburg J. 2001. U-shaped production lines: A review of theory and practice, Int. J. Production Economics 70:201-214.

[62]Michael N. and Engelbert W.2013.Method for situation-based Modeling and Simulation of Assembly Systems, Procedia CIRP 7: 413-418

[63]Mohammed O., Nadia B. and Gerard J. G.2012. Integrating workers' differences into workforce planning, Computers & Industrial Engineering 63:1096-1106

[64]Mitala A. and Pennathur A.2004.Advanced technologies and humans in manufacturing workplaces: an interdependent relationship, International Journal of Industrial Ergonomics 33:295-313

[65]Minh D.N. and Soemon T. 2008. Emergence of simulations for manufacturing line designs in Japanese automobile manufacturing plants, Winter Simulation Conference, IEEE: 1847-1855.

[66]Muther R. and Wheeler J. D. 1994. Simplified Systematic Layout Planning, 3rd Edition, Management and Industrial Research Publications, Georgia, ISBN 0-9336-8409-676.

[67]Nikoofarid E. and Aalaei A. 2012. Production planning and worker assignment in a dynamic virtual cellular manufacturing system, International Journal of

Management Science and Engineering Management, 7(2):89-95.

[68]Ortiz C. A. 2006. Kaizen Assembly: Designing, Constructing and Managing a Lean Assembly Line, Taylor and Francis Group, Boca Raton, ISBN 0-8493-7187-2.

[69]Parashar N.B.S. 2009. Cellular Manufacturing Systems- An integrated approach, 1st Edition, PHI Learning Pvt. Limited, India, ISBN 978-81-203-3601-8.

[70]Pasupuleti V.C. 2012. Scheduling In Cellular Manufacturing Systems, Iberoamerican Journal of Industrial Engineering, Florianopolis, SC, Brazil 4(7):231-243.

[71]Penker A., Barbu M.C. and Gronalt M.2007. Bottleneck analysis in MDf-Production by means of discrete event simulation, Int J of Simulation Model 6(1):49-57.

[72]Poornachandra R. P. and Vira C.2005. Design of cellular manufacturing systems with assembly considerations, Computers & Industrial Engineering 48:449–469.

[73]Paul P., Koshy J. and Cherian A.2013. Conversion of Regular Assembly Line into Cellular Manufacturing Layout, International Journal of Engineering and Innovative Technology ,2(7):250-255.

[74]Prod. D.T.1999. Cellular Manufacturing-One Piece Flow for Workteams,1st Edition, Productivity Press, New York, ISBN 1-56327-213-X.

[75]Razman B. and Ali A. 2010. Design and analysis of automobiles manufacturing system based on simulation model, Modern Applied Science 4(7):130-134.

[76]Reiter B.S. and Freitag M. 2007. Autonomous Processes in Assembly Systems, Annals of the CIRP 56(2):712-729.

[77]Riggs J.L. 1987. Production Systems: planning, analysis and control, Wiley, NewYork.

[78]Reza K. 2013. A multi-objective model for designing a group layout of a dynamic cellular manufacturing system , Journal of Industrial Engineering International,9(8):1-14.

[79]Suleyman S. 2010. Using advanced technology in automotive sector and relationship of technology management, Academic Journals - Scientific Research and Essay 5 (1):001-008.

[80]Shahrokhi M. and Bernard A.2009.A framework to develop an analysis agent for evaluating human performance in manufacturing systems, CIRP Journal of Manufacturing Science and Technology 2:55-60.

[81]Slomp J., Bokhorst J. and Molleman E. 2005. Cross-training in a cellular

manufacturing environment, Computers & Industrial Engineering 48:609–624.

[82]Singh N.1993. Design of cellular manufacturing system- An invited review, European Journal of ProductionResearch,69:284-291.

[83]Scholl A. 1999. Balancing and Sequencing of Assembly Lines, 2nd Edition, Physica-Verlag, Heidelberg, ISBN 3-7908-1180-7.

[84]Song B.L. et al.2006. A recursive operator allocation approach for assembly line-balancing optimization problem with the consideration of operator efficiency, Computers & Industrial Engineering 51:585–608.

[85]Schroeder R. G. 2007. Operations Management:Contemporary Concepts and Cases, 3rd Edition, McGraw Hill/Irwin, Singapore, ISBN 007-125436-6.

[86]Slack N., Chambers S. and Jonhston R. 2007. Operations Management, 5th Edition, Pearson Education Limited, Essex, ISBN 978-0-273-70847-6.

[87]Sule D. R. 1994. Manufacturing Facilities: Location, Planning and Design, PWS Publishing Company, Boston, ISBN 0-5349-3435-8.

[88]Saghafianl S. and Jokar M. 2009. Integrative Cell Formation and Layout Design in Cellular Manufacturing Systems, Journal of Industrial and Systems Engineering 3(2):97-115.

[89]Selim H., Askin R. and Vakharia A. 1998. Cell Formation in Group Technology: Review, Evaluation and Directions for Future Research. Computers and Industrial Engineering 34(1): 3-20.

[90]Shahram T. et al.1998.Simulation And Production Planning For Manufacturing Cells, Winter Simulation Conference, 973-978.

[91]Satya S. C. and Douglas N. H.2004. Implications of cell design implementation: A case study and analysis, European Journal of Operational Research 152:602-614.

[92]Spieckermann S., Gutenschwager K., Heinzel H. and Vo S. 2000. Simulation-based Optimization in the Automotive Industry – A Case Study on Body Shop Design, Simulation 75(5):276-286.

[93]Smutkupt U. and Wimonkasame S. 2009. Plant Layout Design with Simulation, International MultiConference of Engineers and Computer Scientists 2:5-11.

[94]Tempelmeier H. and Kuhn H. 1993. Flexible Manufacturing Systems, John Wiley & Sons, New York.

[95]Tillal E. and Ray J.P.1997. Flexible modeling of manufacturing systems with variable

levels of detail, Winter Simulation Conference: 801-808.

[96]Timothy J. G. and Randall P. S.1984. A Review of Cellular Manufacturing Assumptions, Advantages and Design Techniques, Journal of Operatlons Management 4(2):85-97.

[97]Thottungall A.P. and Sijo M.T.2013. Redesign the Layout of a Forging Unit Using Discrete Event Simulation, International Journal of Emerging Technology and Advanced Engineering 3(8):148-154.

[98]Volling T. et al. 2013. Planning of capacities and orders in build-to-order automobile production: A review, European Journal of Operational Research 224:240-260.

[99]Viviana I. C. and Harold J. S.2005.A study of labor assignment flexibility in cellular manufacturing systems, Computers & Industrial Engineering 48:571-591

[100]Willem J. S. and Jalal A. 2001. Manufacturing cell performance improvement: a simulation study, Robotics and Computer Integrated Manufacturing 17:169-176.

[101]Vonderembse M.A. and While G.P. 1991. Operations Management–concepts, methods, and strategies, 2nd ed., West, St. Paul.

[102]Wemmerlov U. and Johnson D. 1997. Cellular Manufacturing at 46 User Plants: Implementation experiences and Performance Improvements. International Journal of Production Research, 35(1):29-49.

[103]Wemmerlov U. and Nancy L. H..1987. Research issues in CMS, International Journal of Production Research,25:413-431.

[104]Williams E.J. and Orlando D.E.1998. Simulation Applied To Final Engine Drop Assembly, Winter Simulation Conference 1:943-949.

[105]Wolfgang K.2007. Digital Factory-Integration of Simulation Enhancing the Product and Production Process Towards Operative Control and Optimization, I.J. Of Simulation 7 (7):27-39.

[106]Wolfgang K.2006.Digital Factory-Simulation Enhancing The Product and Production Engineering Process, Winter Simulation Conference Ieee, 1899-1906.

[107]Yoram K. and Moshe S. 2010.Design of reconfigurable manufacturing systems, Journal of Manufacturing Systems 29:130-141.

[108]Yinhua J., Yuh Y. and Hirokazu N.2004.Human modeling and simulation for plant operations, Computers and Chemical Engineering 28:1967-1980.

[109]http://www.showflow.uk