Study of Batch Manufacturing Techniques

FINAL YEAR PROJECT THESIS

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Declaration

I certify that this research work titled
"**Study of Batch manufacturing Techniques**"
is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged.

Signature of Students

Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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Project Aim

Reduction of Batch size aimed at Flow Optimization through Bottleneck Identification and Work In Process (WIP) Inventory Reduction

Project Abstract

A batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input raw materials to an ordered set of processing activities over a finite period of time using one or more equipment. It is used when there are greater varieties of the product being produced with correspondingly smaller volumes. It involves machinery and equipment to carry out operations on a no. of different products.

Starco Fans, a local fan industry in Gujrat, which was used as a case study, practices Batch Production to meet their customer demand. They manufacture a batch of 500 fans daily. Each fan consists of five parts: Body, Plate, Armature, Rotor Ring and Blades. In total 21 processes are applied to make one complete fan.

The main problems which were identified in their production system included huge level of Work In Process (WIP) Inventory which existed due to Bottleneck Processes, Flow Interruptions due to simultaneous manufacturing of two or more fan models, and Large Batch Size.

Main aim of the project was to reduce the batch size in order to reduce the level of WIP inventory and optimize the product flow through Bottleneck Identification.

Process Cycle Time Study was carried out and the Takt Time was calculated in order to identify the Bottlenecks. To address the bottlenecks, Line Balancing Methods and Production Flow Analysis were used and the current Flow Line was converted into multiple cells and this conversion helped to attain a single piece flow within cells which caused the WIP to reduce by 63% and also the Batch Size was reduced from 500 units per day to 400 units per day. According to proposed cellular layout, in each cell two models can be processed in parallel thus eliminating the problem of flow interruptions.

Keywords: Work In Process (WIP) Inventory, Cycle Time, Takt Time, Bottleneck, Line Balancing, Flow Optimization.

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Introduction

Our Project was mainly divided into 3 parts:

Part 1: First Part involved Background Research regarding the project in order to get some know- how about the basic concepts and terminologies used in the field of manufacturing, in particular, Batch Manufacturing. It helped to make a sound foundation on which project was further built.
It also involved visits to the Starco Fans Gujrat, the project case study, in order to get a deeper understanding of fan making processes and the entire production system of the factory.

Part 2: Second Part involved some more visits to the factory in order to identify the key problems associated with their production system and efforts were made to generate best possible solutions to cope with those problems.

Part 3: In the third Part best solutions were finalized and theoretically implemented and the results were analyzed and project aim was accomplished.

Part One-Chapter No. 01

1.1. Background Research

1.1.1. Different Types of Production System

There are four aspects of manufacturing that fall under the headings of [1]:

a- Customer Service
b- Product Structure
c- Manufacturing Process
d- Factory Layout

a- Customer Service:
Important factor considered by the customer is that how long it will take for the order to be delivered.
An important distinction from the manufacturer's point of view is that between making-to-stock and making-to-order

Making-to-Stock:
Manufacturer makes to stock finished goods unless stocks run out. Customers can be supplied from these finished goods stock.

Making-to-Order:
Customer places an order for delivery at a specified date in future. Then production is planned to ensure that the customer receives delivery at that date.
An important factor in this context is the lead time.

Lead Time:
Planned delay before something can take place.

Types of Lead Time

Delivery Lead Time:
Time taken for the delivery of product to customer after the product has been made.

Operation Lead Time:
The time it takes to complete a single operation.

Manufacturing Lead Time:
The time necessary for completion of all manufacturing operations for a product.

Supplier Lead Time:
The time a supplier takes after an order is placed to deliver raw material or components.

Making-to-Stock : Delivery Lead Time
Making-to-Order : Sum of all Lead Times

b- <u>Product Structure</u>
Involves looking at flow of material within production system
Simplest Type: Serial Production in which raw material is at one end and finished product at the other.
More complicated cases can be viewed through Assembly Operations and Common Parts. [1]

Assembly Operations and Common Parts
Involves putting together of parts into an assembly. Parts may also be assemblies and in this case may be referred as sub-assemblies. These subassemblies may also be an assembly, called sun-subassemblies and so on.
Best way is to represent all this on a diagram:
The information on which bits go together is called product's 'Bill Of Materials' (BOM).
Assembly Operations produce a product structure which either converges or diverges.[1]

Converging Product Structure:
No. of parts or components are large in number than the final products.

Divergent Product Structure:
No. of parts or components are less in number than the final products. Rather than having assembly operations, the manufacturing process involves parts or assemblies which are common to a no. of products. This produces divergent product structure.

Mixture of Convergent and Divergent:
Most of the production systems are usually a mixture of convergent and divergent product structure.

c- <u>Manufacturing Process</u>
It is characterized by volume of items produced and variety of items produced. Volume of items increases at the expense of decreasing variety

Mass Production:
Involves producing large number of products in a hard variety
One characteristic of mass production is that operations are linked together in a line, when one operation is finished on a product, it moves directly to the next operation. Therefore also called 'Continuous Production'

Batch Production:
It is used when there are greater varieties of the product being produced with correspondingly smaller volumes.
It involves machinery and equipment to carry out operations on a no. of different products.
The no. of items in a batch depends partly on the expense associated with setting up machinery to process different parts and partly on the size of individual customer needs.

One-off-Production
Is used when individual customers each require an individual product which is different from any of the product company made in the recent past
This implies low volume and high variety
For large and complicated items, it is project based.

<u>d- Plant Layout</u>

In a mass production or line manufacture the factory layout depends on production processes.
For Batch production, there are two approaches to organize physical layout of factory:
a- Functional Layout
b- Group Technology

Functional Layout:

In this layout similar machines are grouped together on the factory floor.
Group of identical machines is called **work center.**

Advantage:

Machine operators at a particular work center can be expert at the operation and setting up of those machines and they do not need to concern themselves with the operations of other machines.

Disadvantage:

Production of a single part requires movement from one end to the other many times hence time consuming.
Not easy for the people working on the shop floor to relate what they are doing to the progress of a particular part.
Lack of visibility: No idea what is going on in the factory as a whole?

Group Technology:

In this, production is organized on the basis of parts being made rather than functions needed to make them.
As batch manufacturing makes a large variety of parts, similar parts are grouped together on the basis of operations needed to make them or on similar physical appearance. This group of similar parts is called **'part family'.**

Group technology is a principle, which decomposes a global system into several subsystems, which are easier to manage than the entire system. Applied to manufacturing, this principle is the base for the design of production cells [14].

Advantage:
Formation of team, helping one another.
Lead time can be much shorter.
Better use of space.

Disadvantage:
Grouping of parts is often problematic.
Balance of workload on a cell is difficult.

1.1.2. Flexible Manufacturing Systems (FMS)

It is important to distinguish between hard automation and flexible automation (or soft automation) [1].

Hard Automation:
Hard automation refers to a process in which fixed equipment, often custom made, is used to automate manufacture of a specific product. It represents the best way to make a product which is sold in large volumes and which will not change substantially in design for many years at a time e.g. production of light bulbs. The problem with hard automation is that it is very difficult to cope with significant changes in the product design.

Requirement of Flexibility in Manufacturing:
1- Change in product designs is now required at increasing rates due to high competitive pressure.

2-The ability to use the same plant for the manufacture of variety of products reduces the risk of equipment becoming redundant because of obsolescence of a primary product.

3- The ability to change quickly from the manufacture of one product to another enables smaller batches to be economical. This in turn has numerous benefits: less money tied up in work in progress; a shorter lead time which can be offered to the customer; and a factory which is not littered with half completed work, so that everyone has a better chance of understanding what is going on and consequently making well-informed decisions.

4- Ability of quickly responding to the change in customer demand.

5- Reduction in cost of machinery failure. If a machine for the production of one part breaks down, some other machine can be used to take over production and the customer can still be supplied.

Flexible Automation:

The next step towards flexible automation is to link more than one NC machining center together into a Flexible Manufacturing Cell. Something involving up to half a dozen machines would be called a cell while anything substantially bigger than this would be called Flexible Manufacturing System (FMS).

Difficulties in achieving FMS:

Major difficulties arise from the software and control aspects.

Partly a difficulty arises due to compatibility issues especially when existing machinery is to be incorporated in an automated cell. The machine controllers on the various machines will all have their own protocols, methods of message handling, communication standards and so on.

Some difficulties arise due to sheer complexity of the control tasks required for unmanned and flexible operation.

Some are related with detecting and coping with exceptions and faults.

Automatic probing for faults and careful monitoring to check the wear of tools can be used to overcome such difficulties.

To achieve more completely automated factories in FMS it is necessary to have some system for automatically and flexibly transferring parts between different machines or cells. Rail Mounted Conveyors or Automatically Guided Vehicles (AGVs) can be used for this purpose.

1.1.3. Materials Requirement Planning (MRP)

MRP is the planning of production of specific parts according to some fixed schedule or fixed time period. The choice of period length is called time bucket. The aim of the MRP system is to determine the operations to be carried out on a particular machine or group of machines for any given period within a fixed time horizon (the Planning horizon). Information presented in this way on a period by period basis is called time phased information.

The length of period may vary within the planning horizon e.g. one month is dealt on day to day basis, the next two months are dealt on week to week basis, and the rest of the plan is made on month to month basis [1].

The starting point for an MRP system is Master Production Schedule (MPS).

Master Production Schedule (MPS):
The MPS shows how many of the various products are expected to be made in each of the periods under consideration.
The first issue that arises is of the length of time horizon over which MPS is to be drawn which crucially depends on the manufacturing lead time. If we plan to make production for the next six months then we need to plan for it six months in advance.
Changes in the MPS will make changes in the production schedule and too many changes can be expensive. To avoid this many companies have a system of keeping a few weeks at the start of the production as frozen: only in extreme circumstances will the MPS be altered in this region. An extension of this idea is to specify one or more time fences which determine the type of change which can be made to the MPS at a certain time in future.
One circumstance in which MPS will not correspond to the final products is when there are customer options or a large number of different variants of a product produced from a much smaller number of assemblies. A different production plan for each variant is not possible to be made. Instead the MPS will be drawn for each of the different subassemblies. This means that a separate plan has to be made for the final assembly stage in which the product is put together in its particular customer option. This is called final assembly schedule.

1.1.4. Lean Production

What is Lean?
The Toyota Production System is often called Lean Manufacturing and Lean Production [2]. It is called Lean because, in the end, the process can run:

- Using less material
- Requiring less investment

- Using less inventory
- Consuming less space and
- Using less people

The TPS and Lean Manufacturing Defined:

TPS is a manufacturing system that [2]:

1. Has a focus on quantity control to reduce cost by eliminating waste
2. Is built on a strong foundation of process and product quality
3. Is fully integrated
4. Is continually evolving
5. Is perpetuated by a strong healthy culture that is managed consciously, Continuously, and consistently

The Two Pillars of the TPS:

Lean manufacturing has two pillars [2]:

1-Just In Time

JIT, one pillar of lean manufacturing is the technique of supplying the right quantity, at the right time, and at the correct location. *It is quantity control*.

JIT has following aspects [1]:

1- Reduction of set up times
2- Reduction of batch sizes
3- Reduction of buffer inventories
4- Short lead times
5- Teamwork and a motivated workforce
6- Workers responsible for the quality of their own work
7- Visibility of performance
8- Simple Material flows and reduced floor space
9- Long term relationships with suppliers
10- Frequent deliveries from suppliers

2-Jidoka

Jidoka, the second pillar of lean manufacturing is a series of cultural and technical issues relating to the use of machinery and labor and using people for unique tasks they are capable of accomplishing and allowing machines to self-regulate the quality.

Jidoka uses tactics such as *poka-yoke*, (methods of fool proofing the process) andons (visual displays such as lights to indicate process status especially process abnormalities), and 100 percent inspection by machines. The concept here is that no bad parts are allowed to progress down the production line. It is not only necessary to protect the customer and reduce the costs of scrap, it is a tool for continuous improvement and is a key element in making work Kanban. It is a breach of kanban to allow bad parts to carry [2].

1.1.5. Cellular Manufacturing:

The Definition of a cell

A cell is a group of people, equipment, and workstations, organized in the order of process flow and is meant to manufacture all or part of a production unit. The implication of a cell is that it:

- Has one-piece or small lot flow
- Is often used for a product families
- Has specific equipment
- Is usually arranged in a C or U shape so the incoming raw materials and outgoing finished goods are easily monitored but cells can be in shape of L too.
- Has cross-trained people for flexibility [2].

The Advantages of Cells

Cells are an integral part of Lean manufacturing. The cells work perfectly for TPS but may or may not work for others. So merits and demerits of cells should be kept in mind before conversion to cells.

The primary purpose of a cell, is to reduce wastes in the manufacturing system. The seven wastes again are

- Transportation
- Waiting
- Overproduction
- Defects
- Inventory
- Movement
- Excess processing

It is easy to see that cells reduce transportation due to the close coupled nature of the workstations. They do nothing directly to reduce waiting since that is a function of work balancing and variation. However, cells make the

balancing much easier to manage. Cell; also do nothing directly to prevent overproduction or defects. They do minimize the WIP inventory when one-piece flow is achieved. They produce efficient movement within a cell which depends on cell design and do nothing to reduce excess processing.
Thus, cellular production is designed so that transportation and inventory waste can be reduced. Consequently, it speeds up the process. Cells almost always do this, which results in production advantages such as:

- The reduction of first-piece lead time
- The reduction of lot lead time. So the reduced lead times gives greater flexibility and responsiveness.

Both of these advantages can be achieved with a flow line. A flow line is straight, rather than a U-shaped arrangement or C-shaped. To achieve these benefits in a flow line, there should be the same approach to low inventory and to ensure that the stations are coupled as in a cell. But there are other advantages of a cell over flow line [2].

Cells or Flow Lines?
The question is whether to choose cell or flow line? Often the largest reason to select cells over flow lines is the production rate flexibility possible with cells. The TPS is a batch destruction system. The rate modulation by modifying staffing is not practical to do with a flow line.

When the cells are arranged in a U or C shaped, the worker communication is facilitated. For example, all workers are close to each other, so that the interaction of workers is encouraged. Interaction of workers to help cross-training and interaction of workers to help solve problems are just two of these benefits.. This proximity just makes communication much simpler. They communicate better but also assist better.
The typical U-cell situates the first and last work stations near each other This makes monitoring easier and gives everyone a better idea of completion .In addition, in the typical U-cell, workers sit or walk to the center of the cell in general. This frees up the exterior of the cell to supply materials to the cell more easily.

Two Hidden Benefits of Cells

There are several benefits of cells but the two of great significance are:
First cell creates a team with a sense of flow and synchronization not seen in flow lines. In the flow line, you have two neighbors; in the cell, everyone is in close proximity. The personal dynamics are changed considerably, leading to a feeling of a group, of a team. The team concept is very powerful and there is a real sense of assisting each other. In the cell, since the process is all around the worker, there is a sense of flow and a sense of synchronization that is not present in the flow line. This sense of flow and synchronization actually creates faster pace in the cell with reduced cycle times.. So cycle time is reduced and also cells can reduce the variations. Consequently cells improve the production [2].

Cell Formation Approaches

1-Rank Order Cluster Algorithm

Rank Order Clustering Algorithm is a well-known clustering technique that makes a block diagonal form by repetitively moving the columns and rows of a machine/part matrix according to their binary values [14]

Step 1: Start from the last column, move the rows with positive entries to the top of the matrix.
Step 2: Repeat step1 for all the columns.
Step 3: Start from the last row, move the columns with positive entries to the left of the matrix.
Step 4: Repeat step 3 for all rows.

2-Line Balancing Methods

Line Balancing is leveling the workload in a cell or value stream to eliminate bottlenecks and excess capacity [10].
Line Balancing means balancing the production line, or any assembly line. The aim of line balancing is to evenly distribute the tasks over the work station so that idle time machine can be minimized. It aims at grouping the facilities or workers in an effective manner in order to obtain an efficient balance of the capacities and flows of the production or assembly processes [13].

a. Largest-Candidate Rule (LCR)

Step 1: List all Processes in descending order of Cycle Time value, largest Cycle Time at the top of the list.
Step 2: Processes are grouped considering their precedence and such that each cell does not exceed its maximum allowable time [10].

b. Kilbridge and Wester's Method (KWM)

Step 1: Construct the precedence diagram so those nodes representing work elements of identical precedence are arranged vertically in columns.
Step 2: List the elements in order of their columns, column A at the top of the list. If an element can be located in more than one column, list all columns by the element to show the transferability of the element.
Step 3: Assign elements to workstations, start with the column I elements. Continue the assignment procedure in order of column number until the maximum allowable time for each cell is reached [10].

c. Ranked Positional Weight (RPW) Method

Step 1 and 2: Calculate the RPW for each element by summing the Process Cycle Times together with the Cycle Times for all the Processes that follow it in the arrow chain of the precedence diagram. . Rank the RPW in Descending Order.
Step 3: Assign processes to stations according to RPW, avoiding precedence constraint and maximum allowable time violations [10].

1.1.6. <u>Batch Production in Detail:</u>

Batch Process:
1- A process is considered to be a batch process if, due to arrangement of the equipment, the process consists of a sequence of multiple steps that must be performed in a defined order. And, on completion of the sequence of the steps a fixed quantity of the finished product is produced.

2-A batch process involves production of finite quantities of material by subjecting raw materials to a set of processing activities over a fixed period of time using one or more equipment [3].

Why Do We Batch?
Batching has a deep impact on the features of any process and substantial benefits can be made through it. Batching can be done in either quantity of material or quantity of time. They seem substitutable but most often one is considered variable and the other invariable. Batching once a week; means time is invariable and material is variable. Batching a full load; means material is invariable and time is variable [17].

Increased batch size affects **work-in-process inventory** levels, **manufacturing lead time** and finished goods inventory levels by increasing them. Increased batch size affects quality and **throughput** by decreasing them.

Work In Progress (WIP)
Material that has entered the production process but is not yet a finished product is called Work in progress (WIP). WIP therefore refers to all materials and partly finished products that are at various stages of the production process. WIP excludes inventory of raw materials at the start of the production cycle and finished products inventory at the end of the production cycle [17].

Manufacturing Lead Time and Batch Size
Manufacturing lead time can be broken down into its component parts i.e. set-up time, run time, move time, and queue time (also known as non-instant availability). Queue time is generally much larger than the sum of the other times. The only number that determines the size of the batch order is the run time. Run time can also be broken down into process time and wait time for each individual piece in the batch [17].

Manufacturing Lead Time	
Division	**Subdivision**
Set-up Time	
Run Time	Process Time
	Wait Time
Move Time	
Queue Time	

Figure 1.1(a) Manufacturing Lead Time [17]

Queue - time spent waiting before operation
Setup - time to prepare the work center
Run - time to make the product
Wait - time spent after the operation
Move - transit time between work centers

The amount of waiting during run time can be reduced by following mechanisms:

1- Transfer Batch Reduction (Operation Overlapping)

The first mechanism is transfer batching. As mentioned in Figure 1.1(b), in the first case a job goes through four operations with no queue time. Each operation takes 4 hours for a total of 16 hours. In the second case as soon as half of the first operation is completed it is transferred to the second operation. As soon as that half is completed on the second operation it is forwarded to the third operation and so forth. The total duration is decreased from 16 to 10 hours. In the third case, one quarter of the job is transferred as soon as it completed at each stage. Total duration is compressed from 16 hours to just 7. This can be done at no cost of additional set-ups [17].

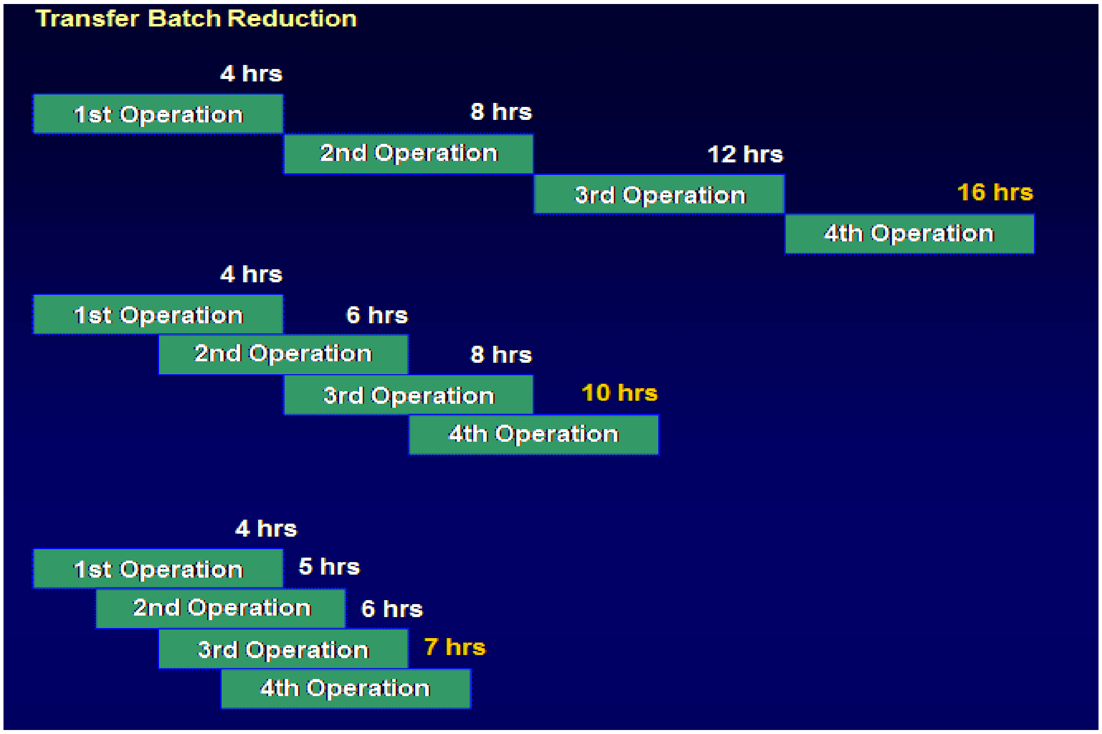


Figure 1.1(b) Transfer Batch Reduction [17]

2- Process Batch Reduction (Operation Splitting)

The second mechanism is process batching. As mentioned in figure 1.1(c), in the first case, again, a job goes through four operations with no queue time. Each operation takes 4 hours for a total of 16 hours. In the second case the numbers of set-ups have been doubled and this halved the duration from 16 hours to 8 per batch. In the third case the numbers of set-ups were quadrupled and it halved the duration once again from 8 to 4 hours per batch. Again duration of the wait time can be reduced considerably but at the cost of additional set-ups [17].

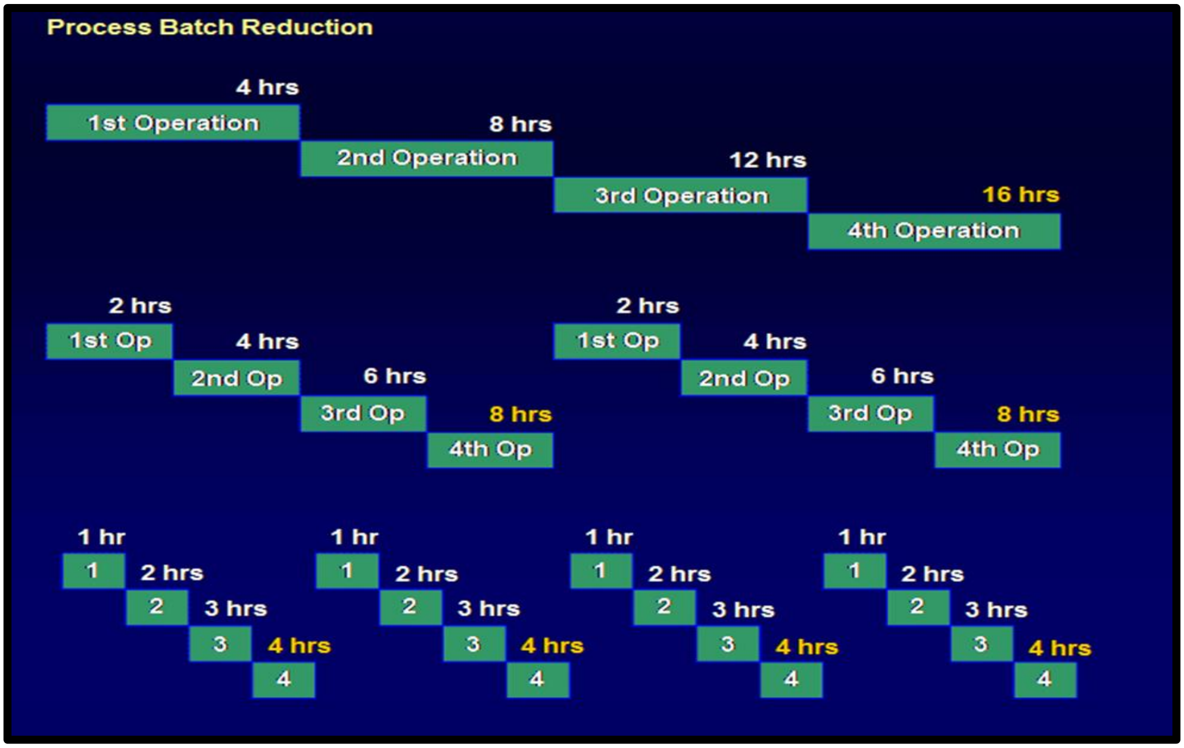


Figure 1.1(c) Process Batch Reduction [17]

However, reducing process batch size is the key factor in reducing finished goods inventory, and reducing finished goods inventory is the key factor in reducing forecast dependency and stock-outs. Reducing process batch size, however, is also a key factor for increasing set-up frequency and thus decreasing productivity on the constraint.

Furthermore, the companies that are most likely to benefit from reduced finished goods stock are those with the largest inventories of make-to-stock items. Because they make so many stock items, and their lead times are so long, they need significant amounts of finished goods [17].

Bottleneck

"A facility, function, department, or resource whose capacity is equal to or less than the demand put upon it."[18]

Bottleneck and non-bottleneck machines should be managed from different perspectives. The production demand at a non-bottleneck machine is often determined by the capacity of the bottleneck machine [11].

Hence, the efforts in increasing production capacity of non-bottleneck machines may not be necessary. However, production capacity matters much at the bottleneck machine since it determines the system output.

Throughput and Bottleneck

The total volume of product passing through a facility is called throughput.
Bottlenecks control the throughput:
Work centers feeding bottlenecks will build inventory.
Work Centers fed by bottlenecks have their throughput controlled by the bottleneck.

Nature of batch processes:

Batch processes have the following characteristics [3]:

- Batch processes deal with discrete quantities of raw materials or products.
- Batch processes allow the tracking of these discrete quantities of material or products.
- Batch processes allow more than one type of product to be processed simultaneously, as long as the products are separated by the equipment layout.
- Batch processes involve movement of discrete product from one processing area to the other.
- Batch processes have recipes (or processing instructions) associated with each load of raw material to be processed into product.
- Batch processes have more complex logic associated with processing than is found in continuous processes.
- Batch processes often include normal steps that can fail, and thus also include special steps to be taken in the event of a failure.

Classification of batch processes

Batch processes can be classified on the basis of two criteria [3]:

1. The quantity of output produced
2. The structure of batch process plant.

1- The number of products produced:

Single-product batch process: Same amount of raw materials are used and same operations are performed on each batch to produce same product.

• **Multi-grade batch process:** Same operations are performed on each batch with different amount of raw materials and/or under different processing conditions to produce similar but not identical products.

• **Multi-product batch process:** Different methods of operations or control are performed on different amount of raw materials under different processing conditions to produce different products [3].

2- The structure of batch process plant:

Batch Processes can be structured as [3]:

Single-path batch process: In a process with single-path structure, the batch passes sequentially in a predefined path from one unit to another, as shown in the Figure 1.1(d).

• **Multi-path batch process**: In a process with multi-path structure, there may be several batches active at a time and the equipment may be of different physical characteristics. For example, as shown in Figure 1.1(d), a reaction operation may be handled by one unit in one path of the process and by two units in the other path of the process.

• **Network batch process:** In a process with network structure, the sequence of the units may be pre-assigned, or determined prior to execution of the batch or during the execution of the batch. In network structure process, an appropriate path is determined at the time of execution depending on constraints like recipe requirements and equipment capabilities. A typical network process is shown in the Figure 1.1(d). Control of network process is complex due to the need for allocation of equipment and the arbitration of requests for the equipment.

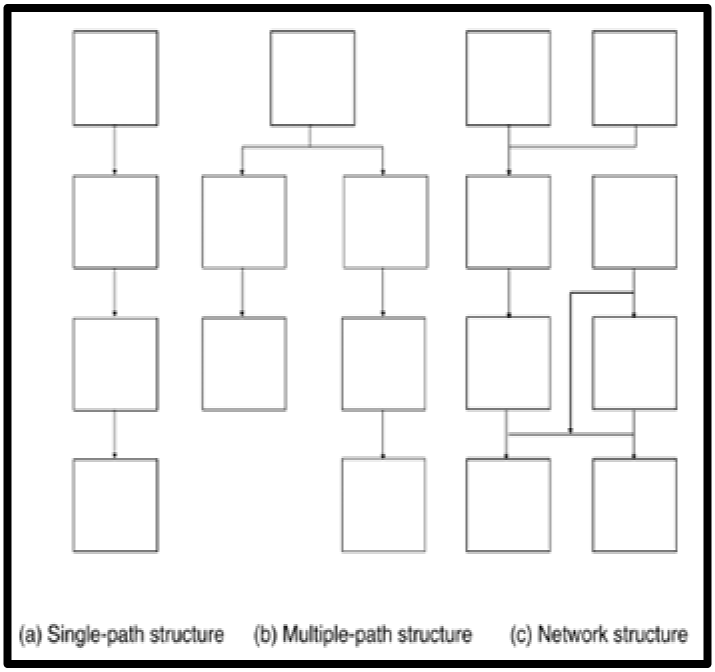


Figure 1.1(d) Structure of Batch Process [3]

1.1.7. Batch Size Calculation Techniques

1-EOQ Lot Sizing

In EOQ, an ordering policy is proposed for raw materials to meet the requirements of a production system which, in turn, must deliver finished products demanded by outside customers at some specific date in future.
It considers the tradeoff between ordering cost and storage cost inventories.
The EOQ Lot Size Formula is as follows:

$$Q^* = \sqrt{\frac{2 \times K \times D}{h}}.$$

Where Q* is the lot size, D is the Demand Rate, h is inventory holding cost, K is fixed order cost [15].

2-Minimum Cycle Time Lot Sizing

Cycle Time, T, of a particular process can be calculated if the lot size Q is known, time to process one part , t, and the set up time s.

T = Qt + s

include queue time must also be included. From the VUT equation of Factory Physics,

CT = VUT + T

The form of the U factor for a single station is

$$U = \frac{u}{1-u}$$

where u is the utilization of the station. The utilization was obtained by first computing the arrival rate to the station.

ra= Annual Demand/(no. of shifts*utilization*working hours*Days per year)

The arrival rate of the batches is simply the arrival rate of the single parts divided by the lot size, ra=Q. Then the utilization will be the arrival rate of the batches multiplied by the time it takes to do a batch, T. [9]

$$\begin{aligned} u &= (r_a/Q)T \\ &= (r_a/Q)(Qt+s) \\ &= r_a t + r_a s/Q \end{aligned}$$

$$\begin{aligned} u &= r_a t + r_a s/Q < 1 \\ &\text{or} \\ r_a s/Q &< 1 - r_a t \\ Q &> \frac{r_a s}{1 - r_a t} \end{aligned}$$

3-Capacity Given Batch Sizes

Capacity = [Total Working Hours – Setup Time]/Cycle Time of Cell

Capacity for a given Batch Size= (Batch Size)/Setup Time * Batch Size

Hence if the capacity is known of a workstation, then the batch size relative to that workstation can easily be determined [5].

1.1.8. Value Stream Mapping

Value Stream Mapping (VSM)
Special type of flow chart that uses symbols known as "the language of Lean" to depict and improve the flow of inventory and information is called Value Stream Mapping (VSM) [6].

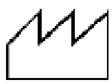
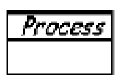
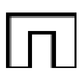
Value Stream Mapping Purpose
Provide optimum value to the customer through a complete value creation process with minimum waste in:
– Design (concept to customer)
– Build (order to delivery)
– Sustain (in-use through life cycle to service) [6]

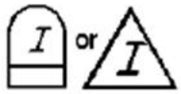
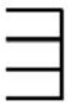
Many organizations pursuing "lean" conversions have realized that improvement events alone are not enough. Improvement events create localized improvements, value stream mapping & analysis strengthens the gains by providing vision and plans that connect all improvement activities. Value stream mapping & analysis is a tool that allows you to see waste, and plan to eliminate it [6].

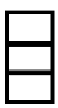
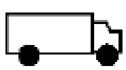
What Is Value Stream Analysis?
Planning tool to optimize results of eliminating waste is called Value Stream Analysis [6].

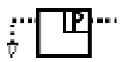
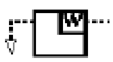
Value Stream Mapping Process Symbols

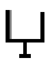
Value Stream Mapping Process Symbols

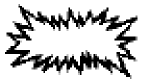
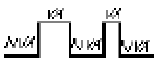
	Customer/Supplier Icon: represents the Supplier when in the upper left, customer when in the upper right, the usual end point for material
	Dedicated Process flow Icon: a process, operation, machine or department, through which material flows. It represents one department with a continuous, internal fixed flow.
	Shared Process Icon: a process, operation, department or workcenter that other value stream families share.
	Data Box Icon: it goes under other icons that have significant information/data required for analyzing and observing the system.
	Workcell Icon: indicates that multiple processes are integrated in a manufacturing workcell.

	Inventory Icons: show inventory between two processes
	Shipments Icon: represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers
	Push Arrow Icon: represents the "pushing" of material from one process to the next process.
	Supermarket Icon: an inventory "supermarket" (kanban stockpoint).
	Material Pull Icon: supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal.

	FIFO Lane Icon: First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input.
	Safety Stock Icon: represents an inventory "hedge" (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures.
	External Shipment Icon: shipments from suppliers or to customers using external transport

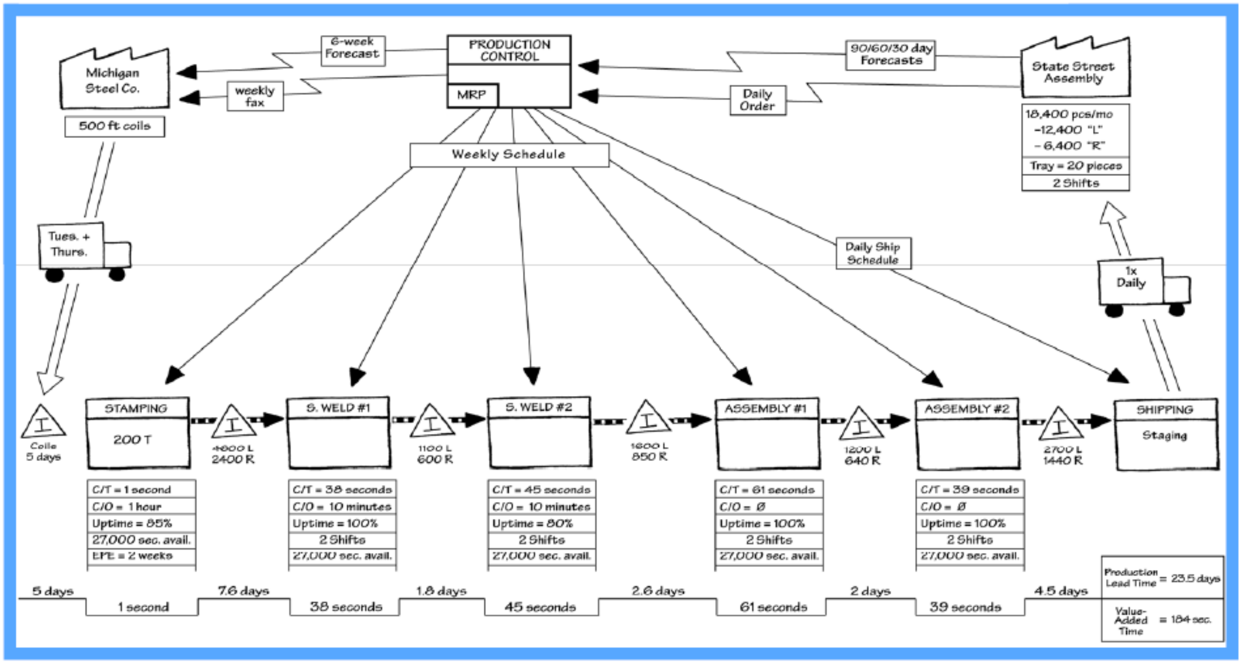
	Production Control Icon: This box represents a central production scheduling or control department, person or operation.
	Manual Info Icon : A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant.
	Electronic Info Icon : This wiggle arrow represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged.
	Production Kanban Icon : This icon triggers production of a pre-defined number of parts. It signals a supplying process to provide parts to a downstream process.
	Withdrawal Kanban Icon : This icon represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.

	Signal Kanban Icon : used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. It is also referred as "one-per-batch" kanban.
	Kanban Post Icon : a location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.
	Sequenced Pull Icon: represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket.
	Load Leveling Icon : a tool to batch kanbans in order to level the production volume and mix over a period of time.
	MRP/ERP Icon : scheduling using MRP/ERP or other centralized systems.

	Kaizen Burst Icon: used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.
	Operator Icon : represents an operator. It shows the number of operators required to process the VSM family at a particular workstation.
	Other Icon : other useful or potentially useful information.
	Timeline Icon : shows value added times (Cycle Times) and non-value added (wait) times. Use this to calculate Lead Time and Total Cycle Time.

	Go See Icon : gathering of information through visual means.
	Verbal Information Icon: represents verbal or personal information flow.

Current State Value Stream Map Example



<u>Figure 1.1(e)</u> VSM Example [4]

Part One-Chapter No. 02

1.2. Visit to the Starco Fans Factory and Understanding of its Production System

1.2.1. Introduction of Starco Fans

Starco fans Gujrat is a local fan industry which was used as a case study for this project. It is working on more than 50 models of the fans which includes ceiling, pedestal and exhaust fans. But the industry focuses on the most selling models which are almost 10.

1.2.2. Components of a Ceiling Fan

Ceiling Fan is an assembly of the following components:

Component	Function
Plate	Upper part or covering of the ceiling fan.
Body	Lower part or covering of the ceiling fan.
Armature	Set of thin sheets group together to form an armature Copper or silver wire is wounded on this armature to make rotor.
Axle	Axle along with armature having copper or silver wire as a coil wounded on it forms the rotor that helps the fan to rotate.
Rotor Ring	Armature is placed in a rotor ring to make a complete rotor.
Blades	Help in Circulation of Air

Table 1.2 (a) Components of a Ceiling Fan

After completely understanding how these components join together and make a ceiling, processing, machining and assembling of components to result in to the ceiling fan were investigated.

1.2.3. Sections of Ceiling Fan Workshop

Sections	Work done
Casting Section	Here casting of body and plate is done.
Machining Section	Machining of body and plate is done here.
Armature Section	Here sheets are cut into shape of the armature and a number of sheets are riveted here to form armature.
Blade Section	Here sheets of metal are bent and riveted to form blades.
Winding Section	Coil is wounded on armature here.
Assembly Section	Assembly of all components of fan is done here.
Testing Section	Assembled Fans are tested here.
Painting Section	Fans are painted here in this section. It is on 2nd floor of the factory.
Packaging Section	Fans are packed here in this section. It is on the 1st floor of the factory.

Table 1.2 (b) Sections of a Ceiling Fan

1.2.4. Processing Schedule

Prior to the details of fan manufacturing processes, time sequence in which fans are manufactured is discussed. Starco fans works on a Batch of 500 fans, and this Batch is processed according to the following Schedule:

Day 1: Casting of 500 bodies and 500 plates and Winding of 500 Armature is done on day 1.

Day 2: On day 2, casted bodies and plates are transferred to machining shop and are subjected to machining processes.

Day 3: On day 3, machined bodies and plates are transferred to assembly sections. Here plate, body, axle and armature with coil wounded on it are assembled to make a complete fan and are then tested.

Day 4: On day 4, assembled and tested fans are transferred to painting section on the 2nd floor of the factory.

Day 5: On day 5, painted fans are transferred to packaging section, where fans are first subjected to final testing and are then packed in cardboard boxes.

So a batch of 500 is completed and ready for delivery in approximately 5 days.

1.2.5. Ceiling Fan Manufacturing Processes

Listed below are processes and operations performed to make a ceiling fan.

- Casting
- Machining, which includes:
  - Facing of body /Plate
  - Threading od the Body/Plate
  - Rotor Seat sizing
  - Bearing sizing in Body/plate
  - Rotor Seat turning
  - Rotor Seat Fitting in body
  - Rotor seat internal turning
  - External Turning of Body
  - Finishing of the body/plate
  - Grinding /buffing of the body/plate
  - Drilling in Body/ Plate
  - Balancing of the Body/Plate
  - Winding of coil on armature
  - Axle fitting in armature
  - Blade making
  - Armature making
- Wiring of the coil
- Assembly
- Testing
- Painting
- Packaging

1.2.6. Time Study all Processes

As a preliminary step, it was important to know the time taken by each process in the workshop, in order to know how long it takes to manufacture one fan. Time Study included the calculation of the following times:

- Setup time
- Queue time
- Operation time
- Wait time
- Move time

Setup Times

Serial Number	Operation	TIME (Minutes)
1	Casting	40
2	Grinding (Grinding machine)	20
3	Facing and threading(lathe)	20
4	Rotor Seat sizing(lathe)	20
5	Rotor Fitting(Hydraulic Press)	20
6	Finishing(lathe)	20
7	Screwing	20
8	Drilling (Drilling Machine)	20
9	Axle winding	20
10	Blade Bending (Mechanical press)	20

Table 1.2 (c) Setup Times

Queue Time

Queue Time for all processes was between 30-40 minutes.

Wait and Move Time

Move time mainly constituted loading and unloading of fans on and from the trolley. Loading and unloading took almost 8 to 9 minutes.

Operation Time

CASTING:

BODY/PLATE NUMBER	TIME(Seconds)
1	36
2	34
3	34
4	35
5	44
6	44
7	30
Average	**38**

GRINDING ON GRINDING MACHINE:

Plate/body Number	TIME(seconds)
1	23
2	18
3	17
4	30
5	16
6	16
7	20
8	16
9	19
Average	**19.4**

FACING AND THREADING ON LATHE

BODY/PLATE NUMBER	TIME(Seconds)
1	37
2	32
3	39
4	38
5	33
6	36
7	32
8	31
Average	34.75

ROTOR SEAT SIZING ON LATHE:

BODY NUMBER	TIME(Seconds)
1	14
2	14
3	13
4	13
5	14
6	12
7	16
8	14
Average	13.75

Drilling

BODY/PLATE NUMBER	TIME(Seconds)
1	11
2	8
3	10
4	8
5	9
6	11
7	9
8	10
Average	9.5

ROTOR FITTING ON HYDRUALIC PRESS

BODY NUMBER	TIME(Seconds)
1	6
2	8
3	7
4	7
5	8
6	8
7	8
Average	7.42

Rotor Seat Internal Turning,
Body External Turning and Boring for bearing:

BODY (WITH ROTOR SEAT)NUMBER	TIME(Seconds)
1	27
2	26
3	26
4	25
5	25
6	26
7	28
8	26
Average	26.1

SURFACE FINISHING OF PLATE

PLATE NUMBER	TIME(Seconds)
1	56
2	54
3	101
4	54
5	47
6	58
7	52
8	52
Average	52

ASSEMBLY:

BODY (WITH ROTOR SEAT)NUMBER	TIME(Seconds)
1	43
2	56
3	47
Average	49.3

SURFACE FINISHING OF BODY:

BODY NUMBER	TIME(Seconds)
1	65
2	68
3	90
4	61
Average	**71**

Screw threading:

BODY /PLATE NUMBER	TIME(Seconds)
1	5
2	4
3	5
4	6
5	5
6	4
7	6
8	6
Average	**5.1**

AXLE FITTING IN ARMATURE

ARMATURE NUMBER	TIME(Seconds)
1	11
2	12
3	12
4	13
5	11
6	12
7	13s
Average	**12**

TESTING

FAN	TIME(Seconds)
1	22
2	15
3	24
4	20
5	21
6	18
7	19
8	19
Average	**19.75**

ARMATURE FINAL GRINDING

ARMATURE	TIME(Seconds)
1	16
2	16
3	20
4	16
Average	**17**

WIRING OF ARMATURE:

ARMATURE	TIME(Seconds)
1	16
2	24
3	15
Average	**18.3**

Averaged Operation Times

Process	Op. Time	Process	Op. Time
Grinding (Body & Plate)	19.4 s	Winding Of Coil on Armature (4 sections)	700 s
Body Facing & Threading	34.7 s	Axle Fitting	12 s
Bearing Rotor Sizing (Body)	13.7 s	Armature Tuning	19 s
Fitting of Rotor in Body	7.4 s	Wiring of Armature	18.3 s
Rotor Int. and Body Outer facing	26.1 s	Assembly	49.3 s
Surface Finishing of Body	71 s	Blade Hole and riveting	18 s
Drilling	9.5 s	Testing	19.7 s
Screwing and threading	5.2 s	Paint	41.1 s
Plate Facing Threading	19.4s	Packing	48 s
Bearing Rotor Seat Sizing (Plate)	13.75 s	Balancing	12s
Surface Finishing of Plate	59.2 s	Casting	34s

Table 1.2 (d) Averaged Operations Time

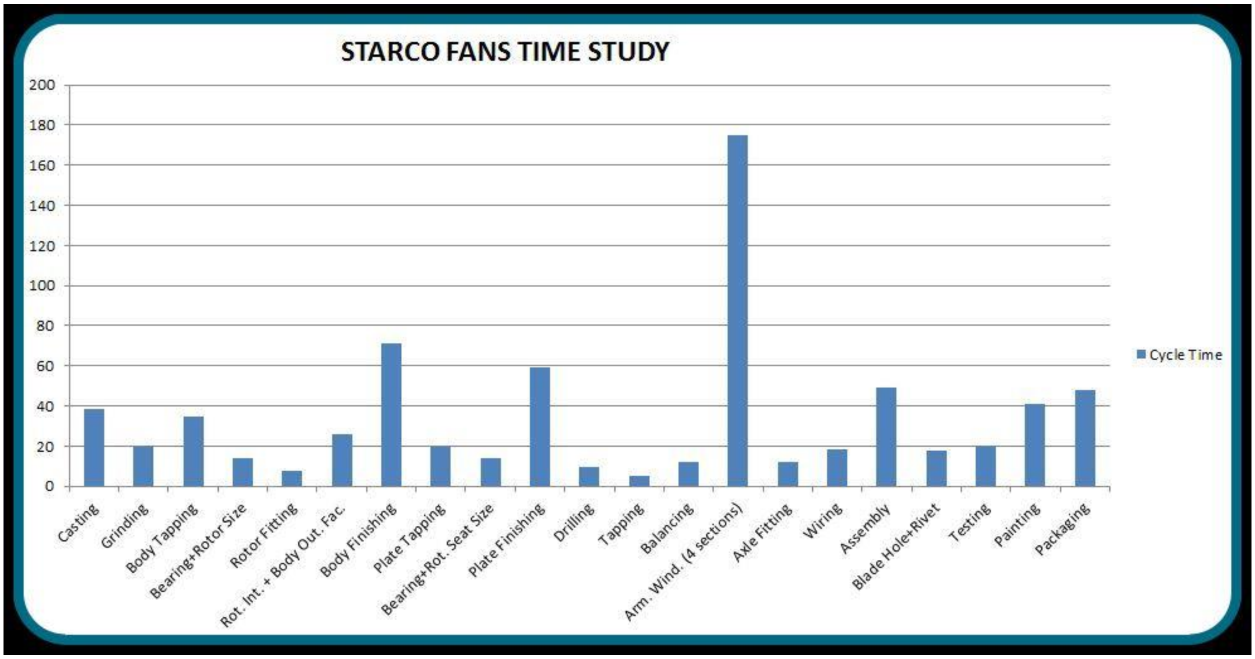


Figure 1.2 (e) Time Study

Part Two-Chapter No. 01

2.1. Identification of Key Problems Associated with the Manufacturing System

2.1.1. Value Stream Mapping

In order to highlight key issues within the production system of ceiling fan workshop, value stream map of the entire workshop was first made and then areas that needed improvements were highlighted.

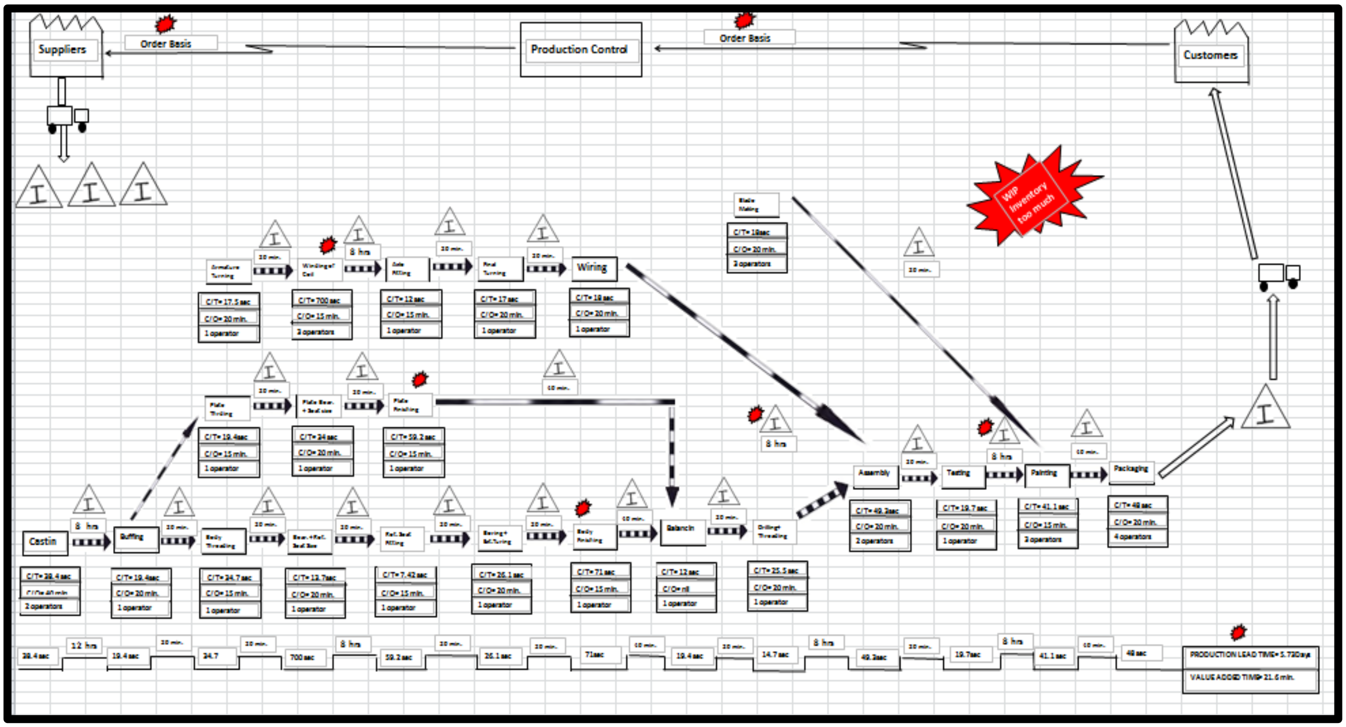


Figure 2.1 (a) Starco VSM

2.1.2. Identification of Problems

1- Bottlenecks Identification

In order to find the bottleneck processes, Takt Time of all the processes was calculated:

$$\text{Takt Time} = \frac{\text{Effective Working Time Per Shift}}{\text{Customer Demand Per Shift}}$$

Takt Time = (8× 3600)/500

Takt Time = 57.6 seconds

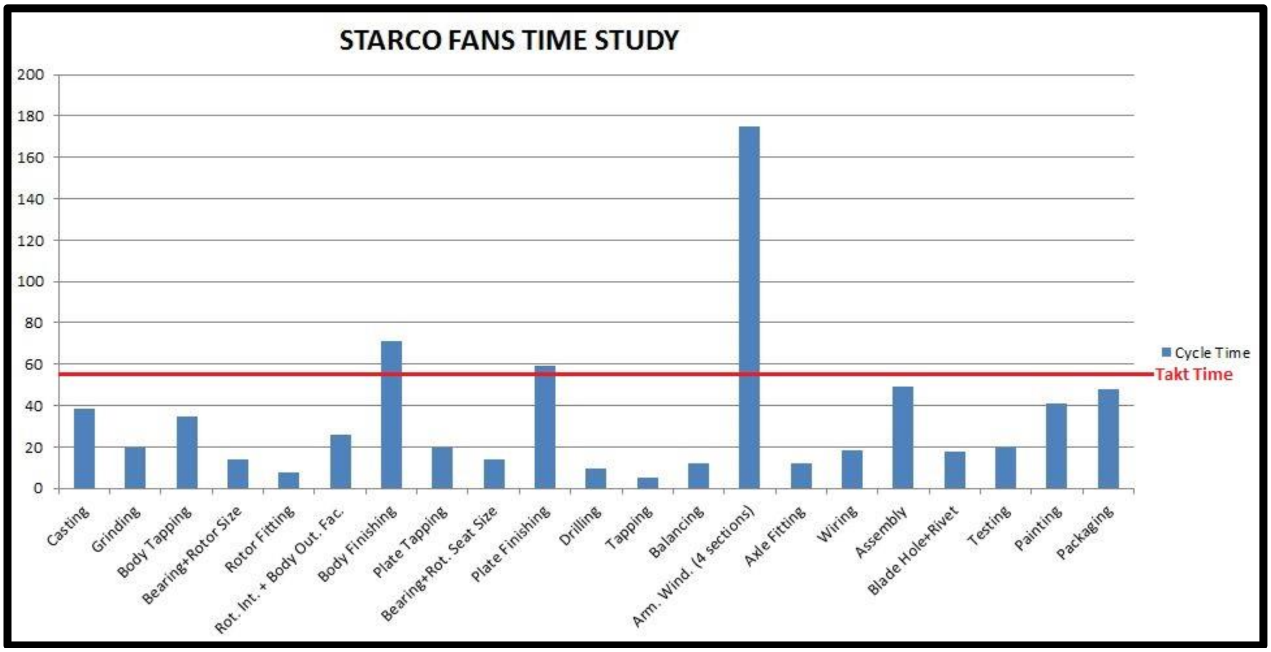


Figure 2.1 (b) Takt Time

Processes with Cycle Times (Operation Times) greater than the Takt Time are the bottlenecks. Hence there are 3 Bottlenecks in Starco Ceiling Fan Workshop:

a- Winding of Coil on Armature
b- Body Finishing
c- Plate Finishing

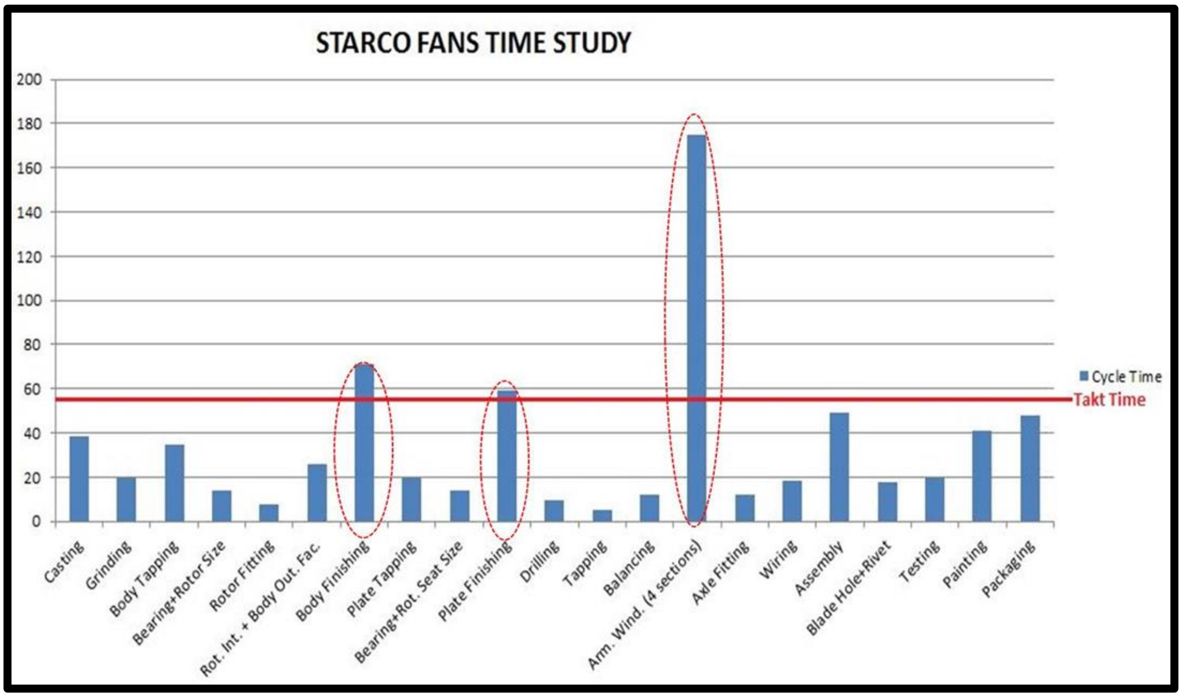
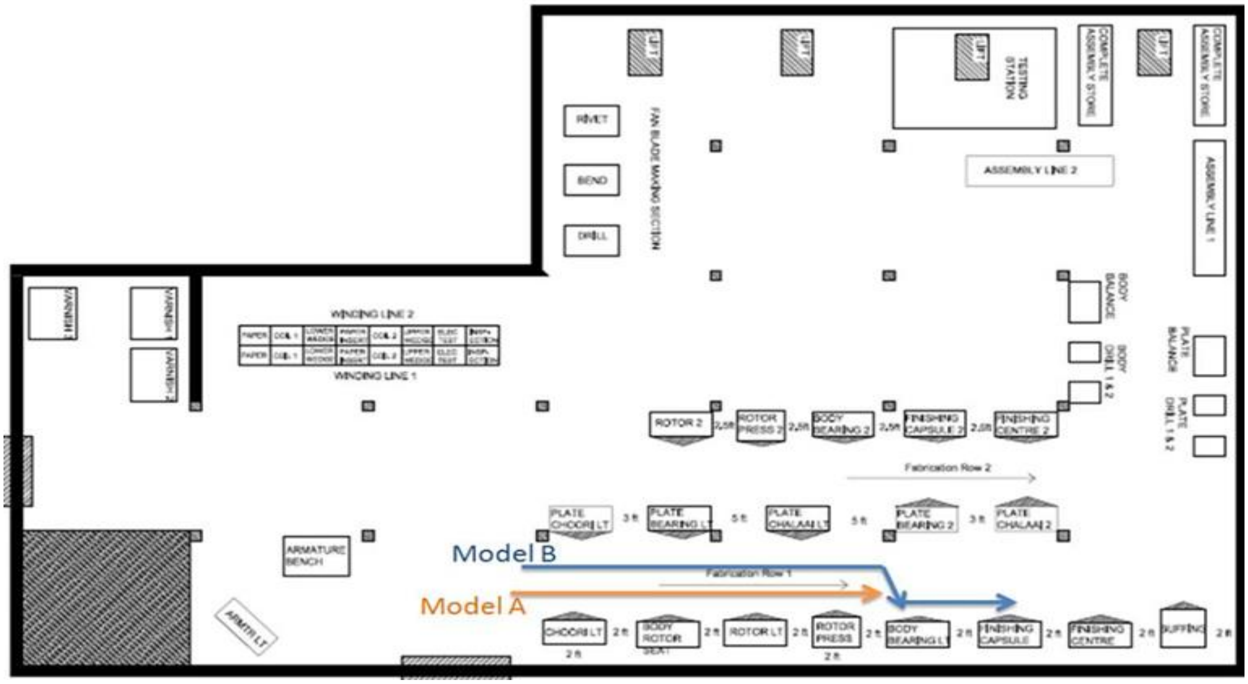


Figure 2.1 (c) Bottleneck Identification

These Bottlenecks are one of the main reasons leading to high level of WIP inventory between the processes.

2- Interruptions in the Flow

The current layout of the factory is designed to process one model at a time. But in actual, 2 to 3 models are being processed simultaneously within the same flow line. When two models reach a certain process, priority is given to the one which has to be delivered earlier. Hence one model is left over and the other flows ahead. Hence these flow interruptions also lead to increased level of WIP inventory.



<u>Figure 2.1 (d)</u> Flow Interruptions

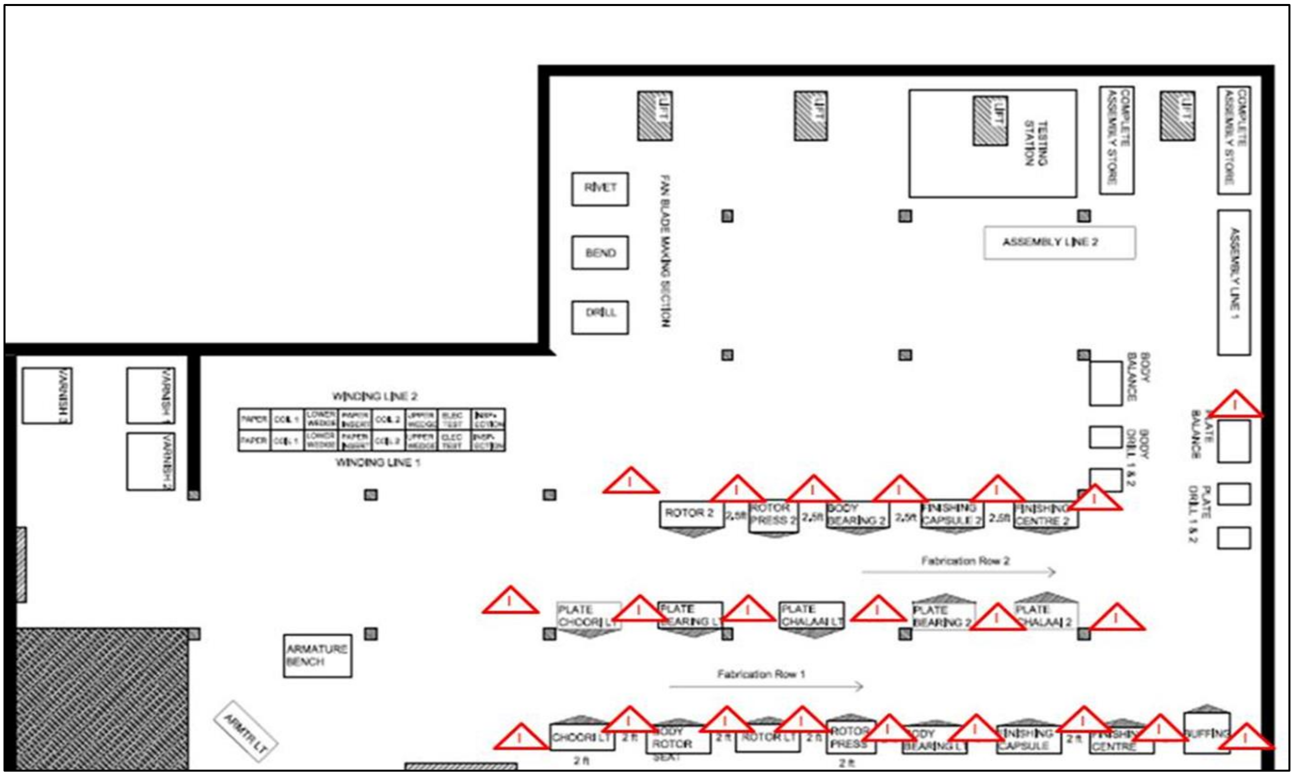
3- WIP Inventory

Due to Bottlenecks and Flow Interruptions, WIP existed between every two processes as shown in the Picture 2.1(a), (b), (c). Also there was no optimized transfer batching which also contributed to high levels of WIP.
Current Layout has 22 WIP Inventory points as shown in Figure 2.1(e). Each point contained almost 80 to 100 fans.

<u>Picture 2.1 (a)</u> WIP at Testing Section

<u>Picture 2.1 (b)</u> WIP at Finishing Section

<u>Picture 2.1 (c)</u> WIP at Rotor Fitting Section



<u>Figure 2.1 (e)</u> WIP Points

Part Two-Chapter No. 02

2.2. Possible Solutions

2.2.1. Constraints for generating Solutions

Whatever solutions were to be generated, the constraints of Area and No. of machines had to be kept in mind.

Area

The Area of the factory was fixed and could not be further increased.
Ceiling Fan Workshop had a total Area of 112 * 26 feet.

No. of machines

Our Solution should be using the existing number of machines as increased number of machines would lead to increased costs.

2.2.2. Increasing Setups at Bottlenecks

To address the Bottlenecks, increasing the setups at the bottleneck processes was thought to be the first option. Winding of Armature Section had already 4 sections and also Winding was done one day prior to the other machining operations.

Even if the number of setups at the Body and plate finishing sections were increased, it only helped to reduce the WIP inventory problem to a small extent.

2.2.3. Single Piece Flow

Attaining single Piece flow throughout the flow line was a good solution but it was practically very difficult to achieve it throughout the flow line as Bottlenecks existed and also there was a lot of variation in the cycle times of all the processes. But some of the processes did have close cycle times which gave a hope.

2.2.4. Conversion of Flow Line into Cells

As the cycle times of some processes were close to each other, grouping those processes in one cell and attaining single piece flow within the cells was an option. By doing this, WIP inventory might not have been eliminated completely but it could be reduced for sure. One thing that was kept in mind was that operations on body and Machine are being done simultaneously and also that the plate reaches the assembly section in about 146 seconds after undergoing all the operations while body reaches assembly section in about 186 seconds due to which plate had to wait for 46 seconds at assembly section.

<u>**Part Three-Chapter No. 01**</u>

3.1. Best Solution

From all the solutions generated, conversion of flow line into Cellular Layout seemed to be the best as it fulfilled the constraint issues and was practically possible and simple which helped to attain single piece flow within the cells and also lead to the reduction of WIP inventory to a great extent.

3.1.1. Flow line Conversion into Cells

To convert the Flow Line into Cells, firstly the processes that could be grouped were observed and the part family that would undergo the cellular layout for manufacturing was to be determined. For that, Rank Order Cluster Algorithm was used to see if it provided with feasible solution.

3.1.2. Rank Order Cluster Algorithm

Rank Order Cluster Algorithm was applied as follows:

Step 1: Assign binary weight and calculate a decimal weight for each row and column

Step 1

Machines	Parts					
	2^4	2^3	2^2	2^1	2^0	
	Body	Plate	Rot. Ring	Armature	Blade	**Weight**
Lathe	1	1	1	1		**30**
Hydraulic Press	1		1	1		**22**
Drilling	1	1				**24**
Mech. Press					1	**1**
Grinding	1	1				**24**

Step 2: Rank the rows in order of decreasing decimal weight values.

Step 2

Machines	Parts					Weight
	Body	Plate	Rot. Ring	Armature	Blade	
Lathe	1	1	1	1		**30**
Drilling	1	1				**24**
Grinding	1	1				**24**
Hydraulic Press	1		1	1		**22**
Mech. Press					1	**1**

Step 3: Repeat steps 1 and 2 for each column.

Step 3

Machines	Parts					
	Body	Plate	Rot. Ring	Armature	Blade	
Lathe	1	1	1	1		**2^4**
Drilling	1	1				**2^3**
Grinding	1	1				**2^2**
Hydraulic Press	1		1	1		**2^1**
Mech. Press					1	**2^0**
Weight	30	28	18	18	1	

Step 4: Continue the preceding steps until there is no change in the position of each element in the row and the column.

Step 4

Machines	Parts				
	Body	Plate	Rot. Ring	Armature	Blade
Lathe	1	1	1	1	
Drilling	1	1			
Grinding	1	1			
Hydraulic Press	1		1	1	
Mech. Press					1

Result of Rank order Cluster Algorithm

Part Family: Body and Plate

According to this method, only one cell should be made consisting of all body and plate operations which is not practically possible as cell size would get too large and this will further increase WIP.

The only positive outcome of this method was the determination of the part family for which the cellular layout was to be designed.

3.1.3. Grouping Based on Close Cycle Times

On the basis of close Cycle Times, the processes for the part family of Body and Plate were grouped as follows:

Facing and Threading === 30.75 seconds

Rotor seat sizing =====15 seconds

Rotor fitting====10 seconds

ONE GROUP

Rotor internal and body external turning ==26 seconds

2^{ND} GROUP

Finishing (2 setups) === 71 (35.5) seconds

Drilling== 8s

Threading==6

Balancing==12

3^{rd} Group

3.1.4. Verification of the Grouping from Line Balancing Methods

As the processes on the basis of close cycle times were grouped, these groups needed to be verified from some authentic method and also it was needed to find if the cells' work load was balanced or not? For that Purpose, three line balancing methods were applied and checked what results did they give? The three Line balancing Methods we applied are:

Largest Candidate Rule (LCR) Method
Kilbridge and Wester Column(KWC) Method
Ranked Positional Weight (RPW) Method

In all three methods, order of flow was considered as they involved process precedence constraints.
As Body and Plate must flow in parallel to each other, and also involve similar operations, hence all 3 processes were applied separately to both.
For each method, maximum allowable time for each cell was determined (Body and Plate each)
Casting and Grinding of both body and plate are done one day prior to the other operations, hence they were not included in calculations.

Calculating maximum Allowable Time for each Cell
Bottleneck Time= 71s
Total Cycle Time= 246s
No. of Cells Required= 278.9/71 = 3.92
Henev minimum 4 cells are needed.
Maximum Allowable Time for each cell= 278.9/4=69.7s

As body and plate flow in parallel and our target is that Body and Plate must reach the Assembly section at the same time, hence Maximum Allowable time for both body and plate cells is kept same.

Body Operations With Assembly

Processes	Cycle time(s)	Preceding By
Threading	34.7	Grinding*
Bearing + Rotor Size	18.7	Grinding*
Rotor Fitting	7.4	Bearing + Rotor Size
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting
Surface Finishing	71	Rot. Int.+Body Out. Facing
Drilling, Tapping, Balancing	26.6	Finishing
Axle Fitting	12	-
Wiring	18.3	Axle Fitting
Assembly	49.3	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring
Testing	19.7	Assembly
Total Cycle Time	**278.9**	-

Plate Operations With Assembly

Processes	Cycle time(s)	Preceding By
Threading	19.4	Grinding*
Bearing + Rotor Seat Size	34	Grinding*
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading
Drilling, Tapping, Balancing	26.6	Finishing
Assembly	49.3	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring
Axle Fitting	12	-
Wiring	18.3	Axle Fitting
Testing	19.7	Assembly
Total Cycle Time	**238.6**	-

1- Largest Candidate Rule (LCR) Method

Step 1: List all Processes in descending order of Cycle Time value, largest Cycle Time at the top of the list for both Body and Plate.

Processes	Cycle time(s)	Preceding By
Drilling, Tapping, Balancing (1 section for 2 models)	26.6*2=53	Finishing
Surface Finishing (2 setups)	71(35.5)	Rot. Int.+Body Out. Facing
Threading	34.7	Grinding*
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting
Testing	19.7	Assembly
Bearing + Rotor Size	18.7	Grinding*
Wiring	18.3	Axle Fitting
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring
Axle Fitting	12	-
Rotor Fitting	7.4	Bearing + Rotor Size

Body

Processes	Cycle time(s)	Preceding By
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading
Drilling, Tapping, Balancing (1 section for 2 models)	26.6*2=53	Finishing
Bearing + Rotor Seat Size	34	Grinding*
Testing	19.7	Assembly
Threading	19.4	Grinding*
Wiring	18.3	Axle Fitting
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring
Axle Fitting	12	-

Plate

Step 2: Processes are grouped considering their precedence and such that each cell doesnot exceed its maximum allowable time for both Body and Plate.

Processes	Cycle time(s)	Preceding By	
Drilling, Tapping, Balancing (1 section for 2 models)	26.6*2=53	Finishing	3
Axle Fitting	12	-	
Wiring	18.3	Axle Fitting	
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	4
Testing	19.7	Assembly	
Threading	34.7	Grinding*	
Bearing + Rotor Size	18.7	Grinding*	1
Rotor Fitting	7.4	Bearing + Rotor Size	
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting	
Surface Finishing (2 setups)	71 (35.5)	Rot. Int.+Body Out. Facing	2

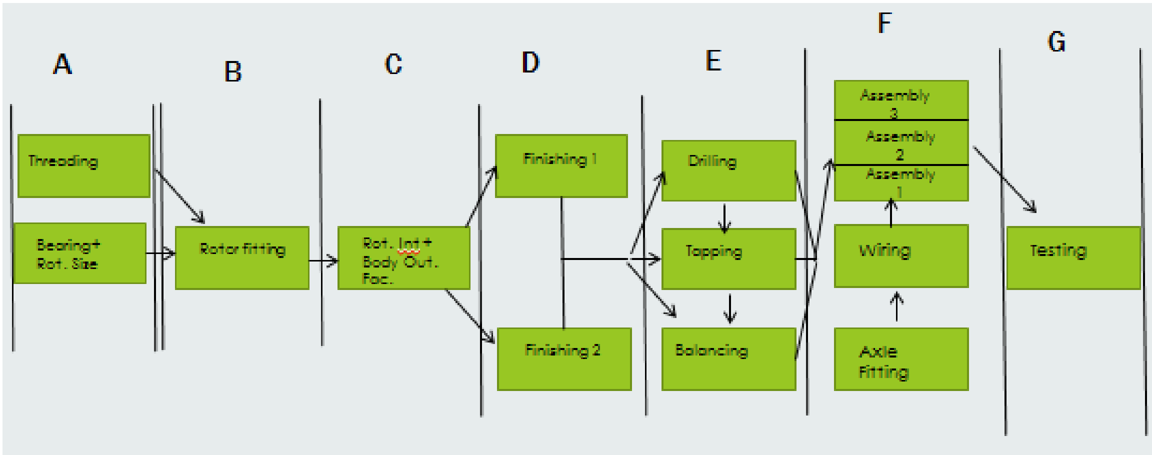
Body

Processes	Cycle time(s)	Preceding By	
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading	2
Drilling, Tapping, Balancing (1 section for 2 models)	26.6*2=53	Finishing	3
Axle Fitting	12	-	
Wiring	18.3	Axle Fitting	
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	4
Testing	19.7	Assembly	
Bearing + Rotor Seat Size	34	Grinding*	
Threading	19.4	Grinding*	1

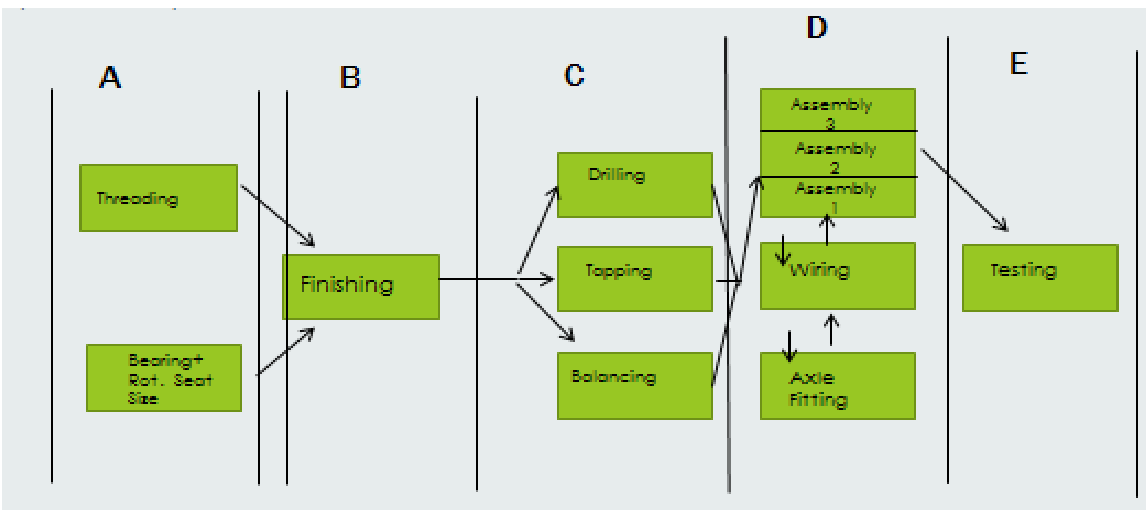
Plate

2- Kilbridge and Wester's Method

Step 1: Construct the precedence diagram so those nodes representing work elements of identical precedence are arranged vertically in columns for both body and plate.



Body



Plate

Step 2: List the elements in order of their columns, column A at the top of the list. If an element can be located in more than one column, list all columns by the element to show the transferability of the element for both Body and Plate.

Processes	Cycle time(s)	Preceding By	Column
Threading	34.7	Grinding*	A
Bearing + Rotor Size	18.7	Grinding*	A
Rotor Fitting	7.4	Bearing + Rotor Size	B
Rot.Int.+Body Out. Facing	26.1	Rotor Fitting	C
Finishing (2 sections)	71(35.5)	Rot. Int.+Body Out. Facing	D
Drilling, Tapping, Balancing	26.6*2=53	Finishing	E
Axle Fitting	12	-	F
Wiring	18.3	Axle Fitting	F
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	F
Testing	19.7	Assembly	G

Body

Processes	Cycle time(s)	Preceding By	Column
Threading	19.4	Grinding*	A
Bearing + Rotor Seat Size	34	Grinding*	A
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading	B
Drilling, Tapping, Balancing	26.6*2=53	Finishing	C
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	D
Axle Fitting	12	-	D
Wiring	18.3	Axle Fitting	D
Testing	19.7	Assembly	E

Plate

Step 3: Assign elements to workstations, start with the column A elements. Continue the assignment procedure in order of column number until the maximum allowable time for each cell is reached for both Body and Plate.

Processes	Cycle time(s)	Preceding By	Column	
Axle Fitting	12	-	F	
Wiring	18.3	Axle Fitting	F	4
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	F	
Testing	19.7	Assembly	G	
Threading	34.7	Grinding*	A	
Bearing + Rotor Size	18.7	Grinding*	A	1
Rotor Fitting	7.4	Bearing + Rotor Size	B	
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting	C	2
Finishing (2 sections)	71 (35.5)	Rot. Int.+Body Out. Facing	D	
Drilling, Tapping, Balancing	26.6*2=53	Finishing	E	3

Body

Processes	Cycle time(s)	Preceding By	Column	
Axle Fitting	12	-	D	
Wiring	18.3	Axle Fitting	D	
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	D	4
Testing	19.7	Assembly	E	
Threading	19.4	Grinding*	A	
Bearing + Rotor Seat Size	34	Grinding*	A	1
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading	B	2
Drilling, Tapping, Balancing	26.6*2=53	Finishing	C	3

Plate

3- Ranked Positional Weight Method

Step 1 and 2: Calculate the RPW for each element by summing the Process Cycle Times together with the Cycle Times for all the Processes that follow it in the arrow chain of the precedence diagram. . Rank The RPW in Descending Order for both Body and Plate.

Processes	Cycle time(s)	Preceding By	RPW
Threading	34.7	Grinding*	166.4
Bearing + Rotor Size	18.7	Grinding*	150.4
Rotor Fitting	7.4	Bearing + Rotor Size	131.7
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting	124.3
Finishing (2 sections)	71(35.5)	Rot.Int.+Body Out. Facing	98.2
Drilling, Tapping, Balancing	26.6*2=53	Finishing	62.7
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	36.1
Testing	19.7	Assembly	19.7
Axle Fitting	12	-	-
Wiring	18.3	Axle Fitting	-

Body

Processes	Cycle time(s)	Preceding By	RPW
Bearing + Rotor Seat Size	34	Grinding*	155.9
Threading	19.4	Grinding*	141.3
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading	121.9
Drilling, Tapping, Balancing	26.6*2=53	Finishing	62.7
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	36.1
Testing	19.7	Assembly	19.7
Axle Fitting	12	-	-
Wiring	18.3	Axle Fitting	-

Plate

Step 3: Assign processes to stations according to RPW, avoiding precedence constraint and maximum allowable time violations for both body and plate.

Processes	Cycle time(s)	Preceding By	RPW	Cell
Threading	34.7	Grinding*	166.4	1
Bearing + Rotor Size	18.7	Grinding*	150.4	1
Rotor Fitting	7.4	Bearing + Rotor Size	131.7	1
Rot. Int.+Body Out. Facing	26.1	Rotor Fitting	124.3	2
Finishing (2 sections)	71 (35.5)	Rot.Int.+Body Out. Facing	98.2	2
Drilling, Tapping, Balancing	26.6*2=53	Finishing	62.7	3
Axle Fitting	12	-	-	4
Wiring	18.3	Axle Fitting	-	4
Assembly (3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	36.1	4
Testing	19.7	Assembly	19.7	4

Body

Processes	Cycle time(s)	Preceding By	RPW	Cell
Bearing + Rotor Seat Size	34	Grinding*	155.9	1
Threading	19.4	Grinding*	141.3	1
Surface Finishing	59.2	Bearing + Rot. Seat. Size, Threading	121.9	2
Drilling, Tapping, Balancing	26.6*2=53	Finishing	62.7	3
Axle Fitting	12	-	-	4
Wiring	18.3	Axle Fitting	-	4
Assembly(3 sections)	49.3(16.4)	Drilling, Tapping and Armature Winding, Axle Fitting, Wiring	36.1	4
Testing	19.7	Assembly	19.7	4

Plate

Result of Line Balancing Method:

As similar results were obtained from all line balancing methods, hence the cellular layout is based on these methods.

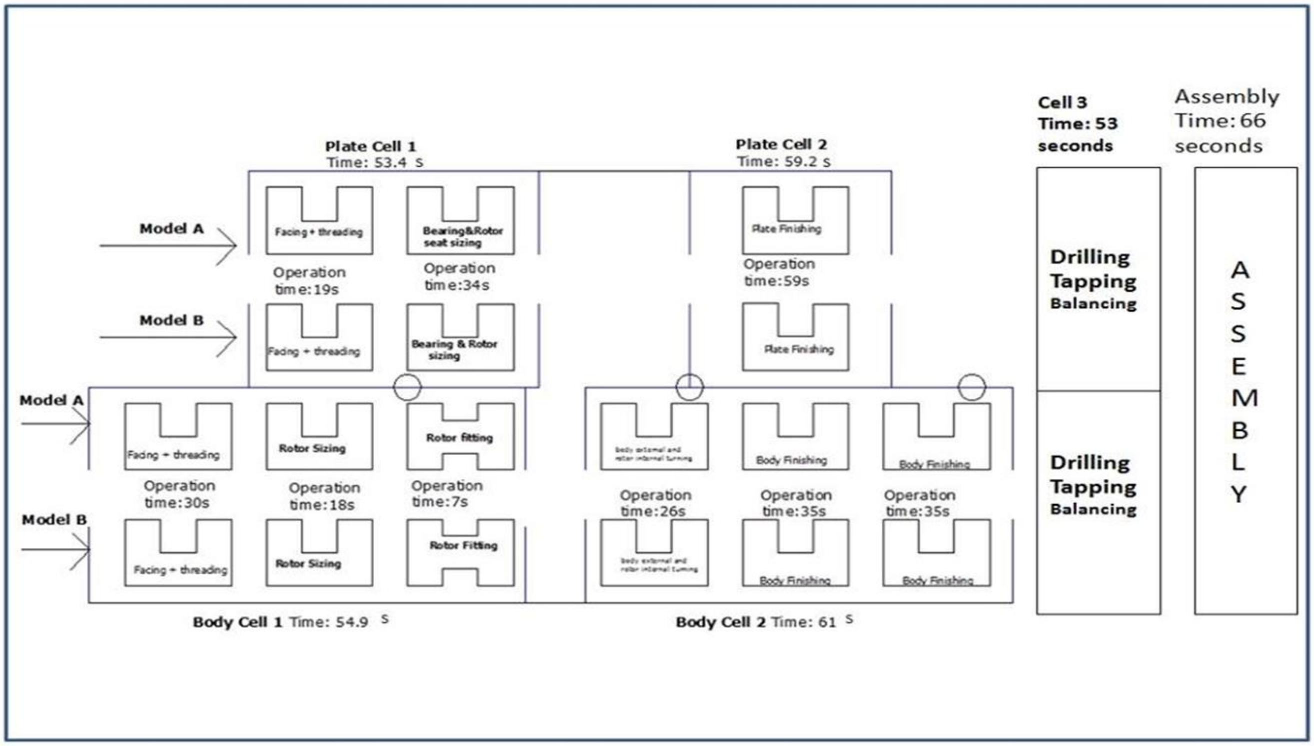
Operations on Body and Plate are grouped into 6 cells before the assembly section, 3 cells for body and 3 for Plate.

Processes with close cycle times have been grouped together within each cell to attain one piece or almost one piece flow and eliminate WIP inventory between the processes.

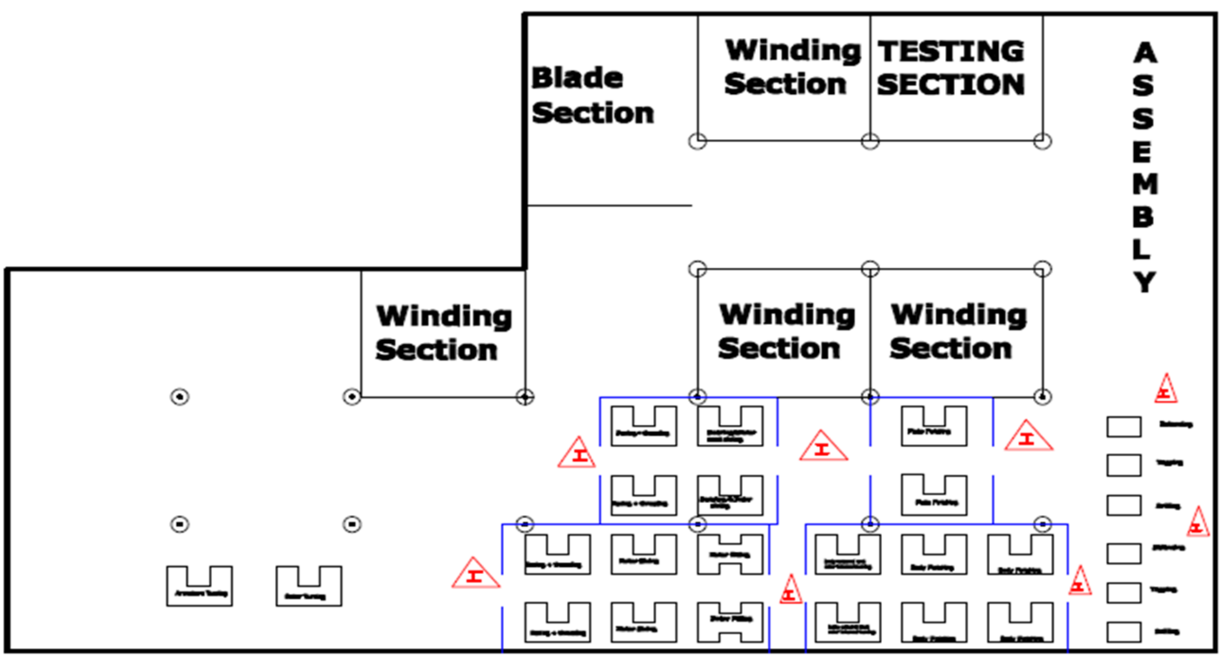
Timings of cells are adjusted such that both Body and Plate reach the assembly section at the same time.

3.1.5. <u>The Cellular Layout</u>

As verified from Line Balancing Methods and grouping according to close cycle times, Cellular Layout for Ceiling Fan Workshop will be;



<u>Figure 3.1(a)</u> Cellular Layout



<u>Figure 3.1(b)</u> Cellular Layout

Each cell is designed to process two models at a time, in parallel to each other in order to avoid any flow interruptions. Cells for both Body and Plates will run Parallel to each other and their timing is adjusted such that both Body and Plate reach the assemble section at the same time.The Plate reaches the Assemly section in 139.2 seconds while the body reaches in 143.2 seconds, hence both reach at almost same time.

3.1.6. Determining the Batch Size

In order to determine the batch size, first the capacity of each working cell was calculated.

Capacity = [Total Working Hours – Setup Time]/Cycle Time of Cell

Setup Time For each cell is assumed to be 30 min.

Cells with their Capacities are:

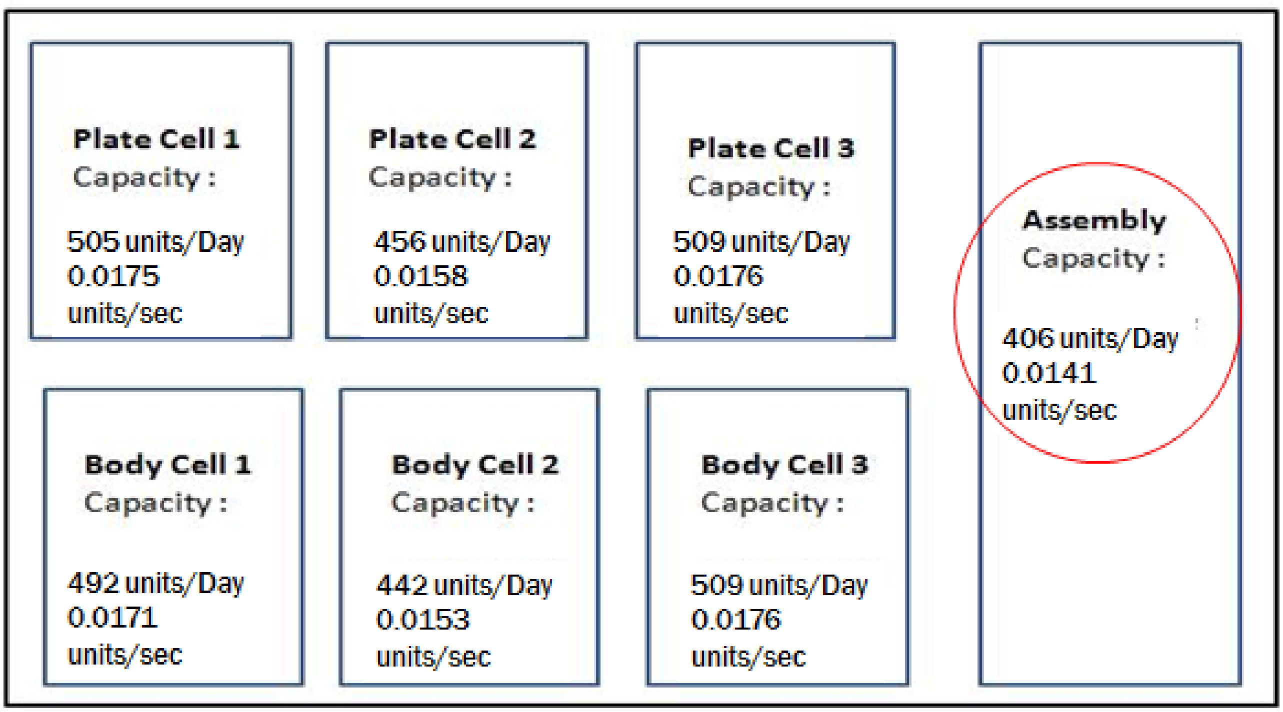


Figure 3.1(c) Capacity Calculation

As assembly section has the lowest capacity, hence it is a determining section for the calculation of batch size.

Now,
Capacity for a given Batch Size= (Batch Size)/Setup Time * Batch Size

As the capacities are known, hence from here, an appropriate Batch Size can be determined.

Capacity for a given Batch Size=(Batch Size)/Setup Time * Batch Size

0.0141= (Batch Size)/1800*Batch Size

Batch Size= 400

Batch With Schedule
Keeping the transfer batch of 100 units between every cell, we get a sunchronized a well scheduled flow within the workshop. This batch will be Scheduled as:

Time	Cell 1	Cell 2	Cell 3	Assembly
8 am	Process starts with 100 units	Process starts with 100 units	Process starts with 100 units	Process starts with 100 units
10 am	100 units Completed	100 units Completed	100 units Completed	100 units Completed
12 pm	100 units Completed	100 units Completed	100 units Completed	100 units Completed
12-1(BREAK)				
3 pm	100 units Completed	100 units Completed	100 units Completed	100 units Completed
5 pm	100 units Completed	100 units Completed	100 units Completed	100 units Completed

Total Production per day= 400 units

Figure 3.1(d) Batch Schedule

Why transfer batch of 100?

If the batch size is kept below 100, it may also work but it will increase the move time between cells.

Again If the Batch size is kept above 100, then WIP will take more space and also loading and unloading of the products would take more time.

The Batch Size of 100 synchronizes well with the working schedule and also it will lead to less move time between cells, with a reasonable loading and unloading time.

3.2. Improvements from the Solution

Proposed cellular layout brought following improvements in the Ceiling Fan Workshop

1- WIP Inventory Reduction

Old Layout had 22 WIP inventory points and each point contained almost 80 to 100 fans whereas new cellular layout contains only 8 of such WIP inventory points. Hence it can be said that with our new Cellular Layout, WIP inventory is reduced by 63%.

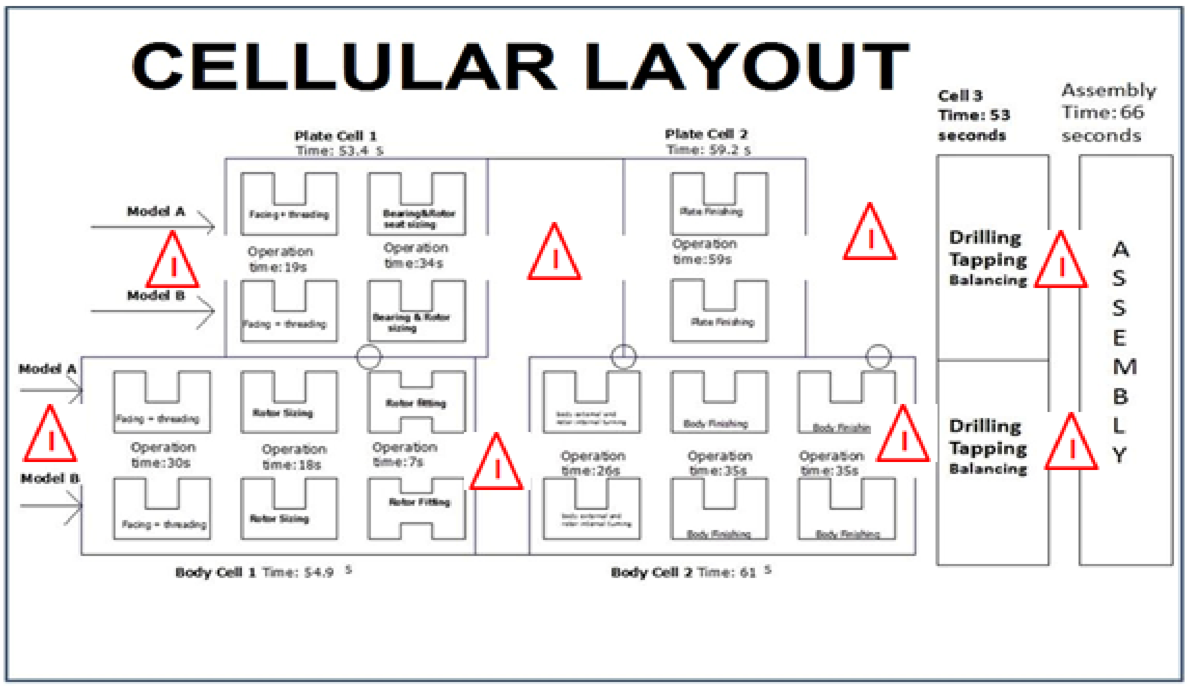


Figure 3.2(a) Cellular Layout

2- No More Flow Interruptions

As each Cell is designed to process two models at time and in parallel to each other, hence there will be no more flow interruptions.

3- Batch Size Reduced

Batch Size has been reduced from 500 units per day to 400 units per day. This will lead to 20% reduction in WIP, Raw Materials and Finished Goods Inventory.

4- 400 Fans per day with Assembly and Testing

Old layout produced 500 bodies and plates per day but their assembly was done on the next day. With this Cellular Layout, Starco fans will be able to produce 400 assembled and tested fans per day.

5- Reduction in Production Lead Time

Including the WIP Inventory times, C/O times and cycle times of all processes, the Production Lead Time according to the old layout was 5.73 days. According to proposed cellular layout, Production Lead Time has reduced to 3.74 days which means 35% reduction in the Production Lead Time.

3.2.1. Feedback From Starco Fans

In the last visit to the Starco Fans Gujrat, solutions were recommended.

Proposed Solutions were seen in detail by the Production Engineer. He appreciated the recommendations and He said:

- The solutions are implementable but with the current labour policies, it seems difficult to practice them effectively.
- Currently, the labour is working on contract basis and it is highly difficult to motivate the contract labour to work in cells.
- The proposed Cellular layout requires highly trained labour but the labour in Starco Fans in not so trained to work in the cells.
- Labour is paid on the basis of daily production, hence they are not motivated to work in teams.
- In future, when the labour will be working on parmanent wages with more motivation to learn and work in teams, this solution can be implemented.

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