KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Bhuvaneshwaran Shunmugam

INVESTIGATION OF FACILITY LAYOUT IN LEAN MANUFACTURING

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Rasa Mankutė

KAUNAS, 2015

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M5106L21 Industrial Engineering and Management (621H77003)

Supervisor
(signature) Assoc. Prof. Dr. Rasa Mankutė
(date)

Reviewer
(signature) Lect. Dr. Virginija Gylienė
(date)

Project made by
(signature) Bhuvaneshwaran Shunmugam
(date)

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KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

(Faculty)

Bhuvaneshwaran Shunmugam

(Student's name, surname)

M5106L21 Industrial Engineering and Management (code 621H77003)

(Title and code of study programme)

INVESTIGATION OF FACILITY LAYOUT IN LEAN MANUFACTURING

DECLARATION OF ACADEMIC HONESTY

29 May 20 15

Kaunas

I confirm that a final project by me, **Bhuvaneshwaran Shunmugam**, on the subject "Investigation of Facility Layout in Lean Manufacturing" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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Approved:
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Production engineering
Department

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Investigation of facility layout in lean manufacturing

Approved by the Dean on 15th of May, 2015, Order No. Nr. ST17-F-11-2

2. Aim of the project

To analyze the peculiarities of facility layout in lean manufacturing and application of project management tools for implementing facility modifications.

3. Structure of the project

Summary, Introduction, 1. Peculiarities of facility layout in lean manufacturing, 2. Analysis of facility layout in manufacturing enterprise, 3. Recommendations for facility layout, 4. Production improvement possibilities for the plant, Conclusions, References, Annexures

4. Requirements and conditions

To prepare final project according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2015 June 1st.

Given to the student Bhuvaneshwaran Shunmugam

Task Assignment received Bhuvaneshwaran Shunmugam ______________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor Assoc. Prof. Dr. Rasa Mankutė ______________________
(*Position, Name, Surname*) (*Signature, date*)

Bhuvaneshwaran Shunmugam. Investigation of facility layout in lean manufacturing. *Master of Industrial Engineering* final project / supervisor Assoc. Prof. Dr. Rasa Mankutė, Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Department of Production Engineering.

Kaunas, 2015. 68 pages.

SUMMARY

The main objective of this work is to analyze the peculiarities of facility layout in lean manufacturing and application of project management tools for implementing facility modifications.

Facility layout design plays a major part in a manufacturing enterprise and the aspects involved in designing a layout affects the overall efficiency of a plant. Usage of lean manufacturing tools like production smoothing, value stream mapping and others are used while designing or modifying such a layout. The company with layout problems is inspected and suggested for improvements with new designs according to various determinants like cycle time, takt time and process lead time. Comparison between the existing and the proposed designs using operator balance chart and flow process chart helps in efficiency improvement possibilities in the plant shows the results of modification in terms of operator needed for the whole cycle.

The development and implementation of the new design plan with various objectives, improves the revenue generating process of a company. Project management is the technique used in analysis of situations where cost and time is involved. One of its tools, Earned Value Management (EVM) is used is in this work to investigate the progress of the new project design's construction phase. Using Earned Value Management, the possibilities of highs and lows during the progress of the project is being analyzed. The application of project crashing concept and evaluating the critical activities in the project helps in increasing the value of the project and also benefits the company in a long run.

Key words:
facility layout, lean manufacturing, value stream mapping, takt time, earned value management, project crashing, critical activity

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SANTRAUKA

Pagrindinis tikslas – išanalizuoti įrenginių išdėstymo taupioje gamyboje ypatumus ir projektų valdymo taikymo aspektus kaičiant gamybos sąlygas.

Pirmame skyriuje "Įrenginių išdėstymo ypatumai taupioje gamyboje" analizuojami gamybos sąlygų ir įrenginių išdėstymo principai modernioje gamybos sistemoje, apžvelgiami taupios gamybos apsektai.

Antrame skyriuje "Įrenginių išdėstymo gamybinėje įmonėje tyrimas" pateikiama informacija apie gamybinę įmonę, analizuojamos operacijos ir procesai bei esamo įrenginių išdėstymo ypatumai ir dėl to kylančios problemos.

Trečiame skyriuje "Rekomendacijos įrenginių išdėstymui" pateikiami pasiūlymai, kaip patobulinti įrenginių išdėstymą, analizuojamos ir vertinamos dvi galimybės 1) įrenginių vietos pakeitimas esamose patalpose; 2) įrenginių išdėstymas naujose patalpose.

Ketvirtame skyriuje "Gamybos tobulinimo galimybės įmonėje" pateikiami pasiūlymų įdiegimo (įrenginių išdėstymo atitinkamų pakeitimų) kainos ir laiko skaičiavimai bei rekomendacijos.

Reikšminiai žodžiai:

Įrenginių išdėstymas, taupi gamyba, vertės srauto žemėlapis, takto laikas, uždirbtos vertės valdymas, projekto valdymas.

CONTENTS

INTRODUCTION

In a recent advancement, it is essential for a manufacturing industry to adapt some modern methods of production. Facility layout with its various designs and unique features provides the required features for the industry to carry out its operations in a systematic manner. Implementation of lean manufacturing, made a revolutionary change in the production processes with its time consuming and cost reducing method along with elimination of waste. Renovation or construction of a plant has its own methods of evaluation and exercising them involves appropriate management. This can be achieved using a tool Earned Value Management from project management while planning or performing or in between or while completion of a project or combining all together.

Aim: To analyze the peculiarities of facility layout in lean manufacturing and application of project management tools for implementing facility modifications.

Tasks:

1. To study about layouts and analyze the situations in an existing layout looking for productivity improvements.
2. To investigate about lean manufacturing and assess the factors involved in developing a facility layout according to lean manufacturing.
3. To determine the situations while implementing lean tools in the layout.
4. To review and determine the progress of the project using Earned Value Management.

1. PECULIARITIES OF FACILITY LAYOUT IN LEAN MANUFACTURING

1.1. Facility Layout in Modern Manufacturing

In a plant, the physical arrangement of equipment and facilities is a facility layout. In order to improve productivity, safety and quality of products, optimization of facility layout is necessary. In manufacturing, facility layout includes setting up the plant site with lines, work areas, major facilities, aisles, buildings, and other appropriate features such as department boundaries. Though facility layout for various purposes always follow the basic principles for desired output from the service. Because of its relative perpetuation, facility layout is one of the most crucial elements that affects the overall efficiency. A facility is a system that facilitates the performance of any work assigned. It may be a work centre, a machine tool, a manufacturing cell, a warehouse, a machine shop, a department, etc. A facility layout is an arrangement of everything needed for production of goods or delivery of services. A well-designed facility layout results in efficient material handling, small transportation times, and short paths. This, in turn, leads to low work-in-process levels, effective production management, decreased cycle times and manufacturing inventory costs, improved on-time delivery performance, and consequently, higher product quality [1].

1.1.1. Consideration factors for facility layout development

While developing a facility layout, there are certain elements to be followed and they are discussed below [2].

Physical arrangements

A physical arrangement of departments that minimizes the movement of material and personnel between departments, and thereby decreases material-handling costs, increases a system's efficiency and productivity. Some of the factors are:

- Reducing congestion to permit smooth flow of people and material;
- Utilizing the available space effectively and efficiently;
- Facilitating communication and supervision;
- Providing a safe and pleasant environment for personnel.

Location decisions

Decisions for location play a vital role in a facility layout demanding huge financial expenses which includes permanent, tangible and intangible factors as follows:

- Proximity to source of raw materials
- Cost and availability of energy and utilities.
- Cost, availability, skill, and productivity of labour.
- Construction costs and land price.
- Transportation system
- Technical expertise
- Environmental regulations at the federal, state, county, and local levels
- Support services
- Community services – schools, hospitals, recreation, and so on.
- Weather
- Proximity to customers
- Business climate
- Competition – related factors

Data requirements:

Since the cost of moving material and people is a major factor in a layout plan, these elements assist in designing a valuable facility layout. Some of the factors are:

1. Frequency of trips or flow of material or some other measure of interaction between departments.
2. Shape and size of departments.
3. Floor space available.
4. Location restrictions for departments, if any.
5. Adjacency requirements between pairs of departments, if any.

1.1.2. Facility layout modifications

Facility layouts in a facility significantly affect the productivity of a business, and a proper layout planning can be critical in building good working relationships, increasing the flow of information, and improving communication [3]. Therefore, it is essential to make efforts on designing a good facility layout in the very beginning, and expect the well-designed facility layout contributes to highly productive organizations all the time. Decisions about the arrangement of resources in a business are not made only when a new facility is being designed, they are made any time there is a change in the arrangement of resources, such as a new worker being added, a machine being moved, or a change in procedure being implemented. Also, layout planning is performed any time there is an expansion in the facility or a space reduction [3]. So, facility layout planning is a work appears at any moment in an organization's running. There are lots of operation problems in any organization, some can be solved easily, and some are not. But all these problems give chances for an organization to improve.

Some of the operation problems that might indicate the need for facility layout modifications, such as [4]:

1. Congestion.
2. Poor utilization of space.
3. Excessive amounts of materials in the workflow.
4. Bottlenecks occurring in one location simultaneously with idleness in another.
5. Skilled workers doing excess unskilled work.
6. Long operation cycles and delays in delivery.
7. Anxiety and strain among workers.
8. Difficulty in maintaining operational control of work and staff.

Most of the facility layouts are originally designed efficiently, but as the organization grows and changes to accommodate a changing environment, the facility layout becomes less efficient, and until eventually a facility layout modification is necessary. The facility layout modifications repeats as long as the organization is under operation, and each modification action signifies an effort to attain the best layout design.

1.1.3. Types of layouts

There are several alternative layout types that are appropriate for different product mixes and production volumes. Determination of the layout type is a major design decision because it impacts on so many other aspects of the production system [5].

Process Layout

Process layouts are found primarily in job shops, or firms that produce customized, low-volume products that may require different processing requirements and sequences of operations. Process layouts are facility configurations in which operations of a similar nature or function are grouped together. As such, they occasionally are referred to as functional layouts. Their purpose is to process goods or provide services that involve a variety of processing requirements. A manufacturing example would be a machine shop (Fig. 1.1). A machine shop generally has separate departments where general-purpose machines are grouped together by function (e.g., milling, grinding, drilling, hydraulic presses, and lathes). Therefore, facilities that are configured according to individual functions or processes have a process layout. This type of layout gives the firm the flexibility needed to handle a variety of routes and process requirements. Services that utilize process layouts include hospitals, banks, auto repair, libraries, and universities.

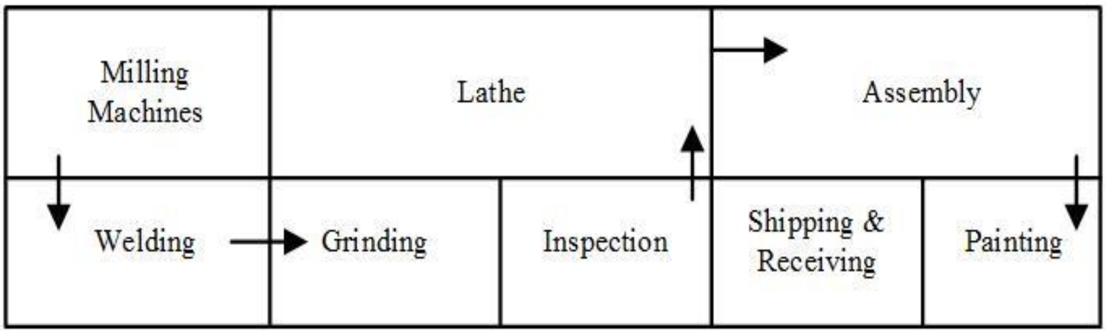


Fig. 1.1 Process layout [6]

Product Layout

Product layouts are found in flow shops (repetitive assembly and process or continuous flow industries). Flow shops produce high-volume, highly standardized products that require highly standardized, repetitive processes. In a product layout, resources are arranged sequentially, based on the routing of the products. In theory, this sequential layout allows the entire process to be laid out in a straight line, which at times may be totally dedicated to the production of only one product or product version. The flow of the line can then be subdivided so that labor and equipment are utilized smoothly throughout the operation. Example of product layout is provided in Fig. 1.2.

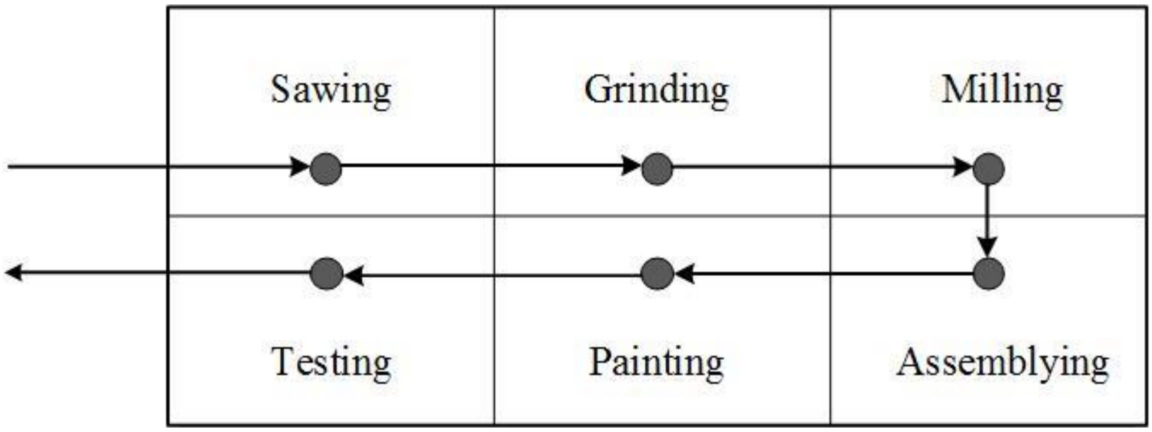


Fig. 1.2 Product layout

Two types of lines are used in product layouts [5]:

1) Paced
2) Non-paced.

Paced lines can use some sort of conveyor that moves output along at a continuous rate so that workers can perform operations on the product as it goes by. For longer operating times, the worker may have to walk alongside the work as it moves until he or she is finished and can walk back to the workstation to begin working on another part (this essentially is how automobile manufacturing works).

On a non-paced line, workers build up queues between workstations to allow a variable work pace. However, this type of line does not work well with large, bulky products because too much storage space may be required. Also, it is difficult to balance an extreme variety of output rates without significant idle time. Product layout efficiency is often enhanced through the use of line balancing [5]. Line balancing is the assignment of tasks to workstations in such a way that workstations have approximately equal time requirements. This minimizes the amount of time that some workstations are idle, due to waiting on parts from an upstream process or to avoid building up an inventory queue in front of a downstream process.

Fixed-position layout

A fixed-position layout is appropriate for a product that is too large or too heavy to move. For example, battleships are not produced on an assembly line. For services, other reasons may dictate the fixed position (e.g., a hospital operating room where doctors, nurses, and medical equipment are brought to the patient). Other fixed-position layout examples include construction (e.g., buildings, dams, and electric or nuclear power plants), shipbuilding, aircraft, aerospace, farming, drilling for oil, home repair, and automated car washes. In order to make this work, required resources must be portable so that they can be taken to the job for "on the spot" performance [5].

Combination layouts

Many situations call for a mixture of the three main layout types. These mixtures are commonly called combination or hybrid layouts [5]. For example, one firm may utilize a process layout for the majority of its process along with an assembly in one area. Alternatively, a firm may utilize a fixed-position layout for the assembly of its final product, but use assembly lines to produce the components and subassemblies that make up the final product (e.g., aircraft).

Cellular layout

Cellular manufacturing is a type of layout where machines are grouped according to the process requirements for a set of similar items (part families) that require similar processing. These groups are called cells. Therefore, a cellular layout is an equipment layout configured to support cellular manufacturing. Processes are grouped into cells using a technique known as group technology (GT) [5]. Group technology involves identifying parts with similar design characteristics (size, shape, and function) and similar process characteristics (type of processing required, available machinery that performs this type of process, and processing sequence). Workers in cellular layouts are cross-trained so that they can operate all the equipment within the cell and take responsibility for its output. Sometimes the cells feed into an assembly line that produces the final product. In some cases a cell is formed by dedicating certain equipment to the production of a family of parts without actually moving the equipment into a physical cell (these are called virtual or nominal cells). In this way, the firm avoids the burden of rearranging its current layout. In some cases of layout design, physical cells are more common [5].

1.1.6 Problems in layout

It is common to identify layout problems in different varieties of production systems. These kind of problems affect the whole manufacturing process and some of the problems are discussed below.

No standardized work procedure

Standardized work is one of the most powerful but least used lean tools. By documenting the current best practice, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so on. Improving standardized work is a never-ending process. Establishing standardized work relies on collecting and recording data on a regular basis. These information are used production supervisor to design the process and by operators to make improvements in the jobs. Basically, standardized work consists of three elements [7]:

1. Takt time, which is the rate at which products must be made in a process to meet customer demand.
2. The precise work sequence in which an operator performs tasks within takt time.
3. The standard inventory, including units in machines, required to keep the process operating smoothly.

Large inventory

An effective inventory management system starts with analysis and design. More thorough analysis and development of better design, helps in the managing an efficient inventory system. Due to inaccurate needs analysis, the gaps between requirements and design are not filled, affecting the whole production process. In a new inventory system, a needs analysis should identify, fully evaluate and prioritize system needs. Decentralized design of inventory not only relies on timely and accurate data entry to determine inventory levels but is also more likely to cause bottlenecks in production causing delay in critical time. Lack of system optimization is a common design problem that makes it more difficult to accurately plan and forecast future inventory needs. The current inventory system is not capable of capturing the right data at the right time to avoid ordering mistakes that result in inaccurate inventory levels. Optimization is especially important as a cost-control measure in a manufacturing business, because it functions both to reduce waste and improve serviceability. This not only can assist in maintaining accurate inventory levels but also signal when it might be time to look for another supplier due to inferior raw material quality [8].

Poor housekeeping

Improper maintenance of housekeeping led to troublesome working environment in the plant which directly or indirectly influences the efficiency of the workers. It also affects the ease in maintaining accurate count of inventories.

No benchmarking time

Benchmarking time is associated with continuous evaluation of practices in organizations and adapting standard processes to integrate better processes. It is an ongoing activity of comparing the company's process or product against similarly effective ones, to attain realistic goals in a reasonable time. As a result of failing to follow benchmarking time, the plant is not able to drive its performance to higher levels. Lack of identifying inefficient practices, and improving on them, led to increase in waste. Inadequate measures to overcome complacency and implementation of better work practices contributed to weak benchmarking time.

Backtracking and bypassing

An effective flow within a facility includes the progressive movement of materials, information, or people between departments. The following principles have been observed to frequently result in effective flow: maximize directed flow paths and minimize flow. A directed flow path is an uninterrupted flow path progressing directly from origination to destination. An uninterrupted flow path is a flow path with no backtracking and that does not create congestion, undesirable intersections with other paths, and bypassing. Backtracking, as shown in Fig. 2.3, is the movement of a part from one facility to another preceding it in the sequence of facilities in the flow-line arrangement and increases the length of material flow path [9].

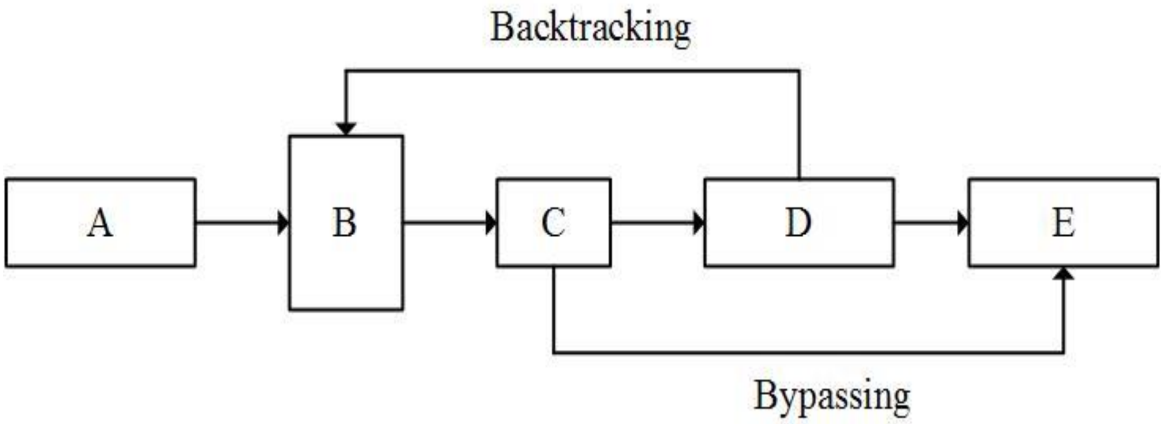


Fig. 1.3 Backtracking and bypassing in layout [9]

1.2. Aspects of Lean Manufacturing

1.2.1. Lean manufacturing principles

Lean manufacturing, also known as the Toyota Production System (TPS) means doing more with less time, less space, less human effort, less machinery, less materials - while giving customers what they want.

The definition of the TPS is a manufacturing system that [10]:

1. Has a focus on quantity control to reduce cost by eliminating waste;
2. Is fully integrated;
3. Is continually evolving;
4. Is perpetuated by a strong healthy culture that is managed consciously, continuously, and consistently.

The industry determines cost, based on the principles of cost accounting and a profit margin. In most industries, price is fixed (or falling). Customers are more powerful than ever before. They have a wealth of choices, unprecedented access to information, and demand excellent quality at a reasonable price. In such an environment, the only way to improve profit is to reduce cost. The great challenge the industries are facing is cost reduction.

But the cost must be reduced without:

- Decimating the team members;
- Cannibalizing the maintenance budgets;
- Weakening the company in the long term.

The only sustainable way of reducing cost is to involve the team members in improvement. The Toyota system relentlessly attacks ‘muda’ (waste) by involving team members in shared, standardized improvement activities. A virtuous cycle ensues: The more team members are involved, the more success they enjoy. In Table 1.1, the comparison between conventional and Toyota/lean model is provided.

Table 1.1

Comparison between Conventional and Toyota/Lean model [10]

Features	Conventional model	Toyota/Lean model
System	Follows ‘push system’	Follows ‘pull system’
Process	Making big batches and moving them slowly through the system	Making things one at a time and moving them quickly through the system
Standards	Only engineers form the standards	Personnel closest to the work develop standards
Methods	Always concentrates on repeating the process	Follows Plan-Do-Check-Adjust (PDCA)

1.2.2. House of lean production

The House of Lean Production (Fig. 1.3), clearly shows that the foundation of the lean system is stability and standardization [12]. The pillars are just-in-time delivery of parts of products and *jidoka*, or automation with a human mind. The goal (the roof) of the system is customer focus: to deliver the highest quality to the customer, at the lowest cost, in the shortest lead time. The heart of the system is involvement: flexible motivated team members continually seeking a better way.

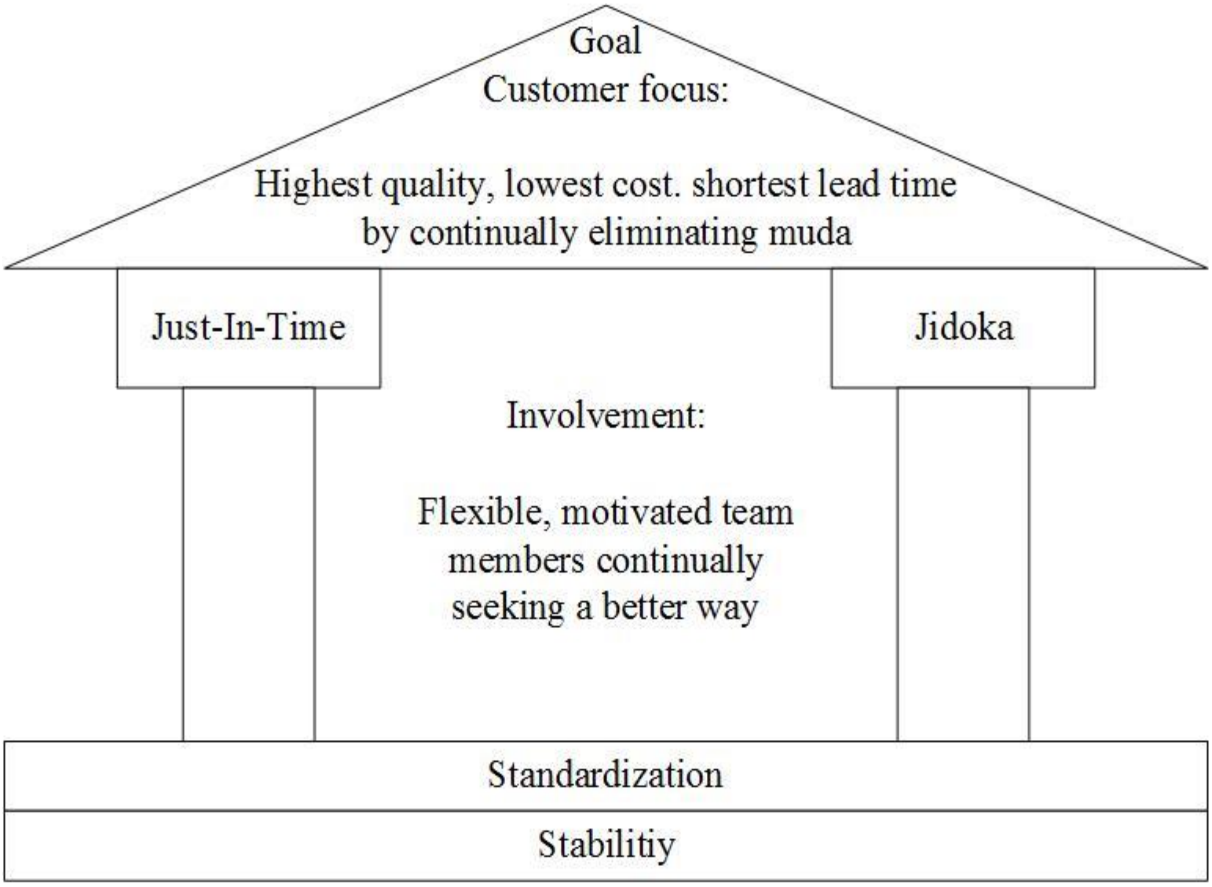


Fig. 1.3 Basic image of Lean Production [11]

Just In Time (JIT)

The first pillar is *Just In Time* (JIT) [11]. This is the technique of supplying exactly the right quantity, at exactly the right time, and at exactly the correct location. *It is quantity control*. It literally is at the technical heart of the TPS. Most people envision this pillar as inventory control, and this is a part of it. However, JIT is much more than a simple inventory control system.

Jidoka

The second pillar is *jidoka*. This is a series of cultural and technical issues regarding the use of machines and manpower together, utilizing people for the unique tasks they are able to perform and allowing the machines to self-regulate the quality. Technically, *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. It is the concept that no bad parts are allowed to progress down the production line [11].

Waste sources are all related to each other and getting rid of one source of waste is to whether elimination of, or reduction in others. Perhaps the most significant source of waste is inventory. Work-in-process and finished parts inventory do not add value to a product and they should be eliminated or reduced. When inventory is reduced, hidden problems can appear and action can be taken immediately. There are many ways to reduce the amount of inventory, one of which is reducing production lot sizes [13]. It is clear that when inventory is reduced other sources of waste are reduced too. Reduction in setup times as a means to reduce inventory simultaneously saves time, thus reducing time as a source of waste.

Transportation time is another source of waste. Moving parts from one end of the facility to another end does not add value to the product. Thus, it is important to decrease transportation times within the manufacturing process. One way to do this to utilize a cellular manufacturing layout [13] to ensure a continuous flow of the product, this also helps eliminate one other source of waste, which is energy. When machines and people are grouped into cells, unproductive operations can be minimized because a group of people can be fully dedicated to that cell and this avoids excess human utilization. Another source of waste is defects and scrap materials. Total productive maintenance is one way to eliminate defects and scrap.

1.2.3. Lean manufacturing tools and techniques

If waste is identified in a production process of a company, it is important to find the tools to eliminate waste. With the help of various tools, finding the exact type of waste and its location is crucial in lean manufacturing. Some of the tools and their methods of usage are as follows [2, 11, 12, 15]:

1) Value stream mapping
2) Flow process chart
3) Standardization of work
4) Production smoothing

1) Value stream mapping

Value Stream Mapping (VSM) is a process of examining the entire chain of events that must happen from the time an order for a product is received until it is delivered [2]. VSM maps the process as it presently exists, and suggests, via examination, improvements that are needed. It displays material flow, product flow, and information flow for the process. The mapping starts when the order for the product is received and ends when the product is delivered to the customer. Ideally, all in-between stages that a product or a partial product must pass through must ass value to the product and non-value added activities should be eliminated.

A value stream map starts by creating a current state diagram, which serves as the basis for a successfu; design. For each product it is possible to draw an independent value stream diagram or combine all the information in one diagram. Value stream mapping is appropriate when the production is in high volume and predictable with a limited variety and limited components. Takt time and takt time is used to verify production balance, by ensuring the smoothness of production rate. It also displays the storage points and the minimum and maximum inventory maintained and the process symbols used in designing a value stream map are found in Annex.1.

2) Flow process chart

Flow process chart is a tool which is used in service oriented operations [11]. It helps in optimizing processes in terms of their necessity or efficiency. Using apt symbols, it helps in recording the events and their sequence of flow of materials. Understanding the overall nature of the system and eliminating unsuitable flow patterns are the key feature of this chart. From flow process chart it is possible to study the frequency, duration, type and sequence of operations. Flow process chart is highly useful in determining improvement possibilities and delay in processes [12]. The symbols used in flow process chart designing and their descriptions are presented in Annex 2.

3) Standardization of work

A very important principle of waste elimination is the standardization of worker actions. Standardized work basically ensures that each job is organized and is carried out in the most effective manner. No matter who is doing the job the same level of quality should be achieved. This includes the time needed to finish a job, the order of steps to follow for each job, and the parts on hand, which leads to ensure:

1) Line balancing is achieved,
2) Unwarranted work-in-process inventory is minimized
3) Non-value added activities are reduced.

‘Takt time’ is the tool used to standardize work while implementing lean in a layout. It mentions the frequency of a part’s production in a product family based on the customer demand.

Takt time (*TT*) is calculated based on the following formula [12]:

$$TT=\frac{WT}{D} \tag{1.1}$$

where

WT - available work time per day, h;

D - customer demand per day, units.

4) Production smoothing

Production smoothing is one of the major tool to achieve lean manufacturing method in a company. Heijunka, the Japanese word for production smoothing, is where the manufactures try to keep the production level as constant as possible from day to day [15]. Heijunka is a concept adapted from the Toyota production system, where in order to decrease production cost it was necessary to build no more cars and parts than the number that could be sold. To accomplish this, the production schedule should be smooth so as to effectively produce the right quantity of parts and efficiently utilize manpower. If the production level is not constant this leads to waste (such as work-in-process inventory) at the workplace [15].

1.2.4. From lean manufacturing to lean enterprise

Elimination of waste is an operation that helps in examining the whole production process. It refers to paying attention to independent segments of a company or a plant starting from raw materials to distribution and sales of finished products. A lean enterprise is a group of individuals, functions, and legally separate but operationally synchronized companies [15]. By managing the entire system, it is likely to manage the value adding activities not as a sum of separate parts but holistically. When an enterprise becomes lean, it recognizes the workers, managers, and customers as dynamic assets of the company.

Lean enterprise which is a development of lean manufacturing.contribute value to the customer, by focusing on the firm, its partner, its suppliers and especially its employees. The lean enterprise aims to line up and integrate the value creating process for a finished good or service along the value stream. All processes are continually examined against the customer's definition of value, non-value added activities and waste are forcefully and methodically eliminated.

There are three different types of activities that exist in almost all organizations [16]:

1. *Value added activities:* These include all the activities that the customer envisions as valuable either in a product or as a service. Examples include converting iron ore (with other things) into cars, forging raw material, and painting a car body. To define a value adding activity, one should ask if a customer would be willing to pay for the activity.
2. *Necessary non-value adding activities:* These are activities that in the eye of the final customer do not make a product or service more valuable but are necessary under the current operating conditions. Such waste is difficult to remove immediately and should be targeted for longer-term change. Examples include walking long distances to pick up parts, or unpacking vendor boxes. These can be removed by changing the current layout of a line or organizing vendor items to be delivered unpacked.
3. *Unnecessary non-value adding activities:* These include all the activities that the customer envisions as not valuable either in a product or as a service, and are also not necessary under the current circumstances. These activities are pure waste and should be targeted for immediate removal. Examples include waiting time, stacking of products and double transfers.

2. ANALYSIS OF FACILITY LAYOUT IN MANUFACTURING ENTERPRISE

2.1. Characteristics of Company

Company X was established in 1987 and has been manufacturing pumps and motors (Fig. 2.1) for the past two decades [17]. The company’s products are known for its impeccable quality, affordability, trouble free performance, reliability and longer life. It concentrates on corrosion-resistant and erosion-resistant pumps for industrial and domestic purposes. The focus area of the house is not only cost reduction and maintaining its competitive edge, but also to ensure that the business is sustainable.

Though the company is manufacturing high quality products, it was finding some issues in facing the growing customer demands in one of its plants involved in manufacturing pumps for industrial purposes, for the past few years. The management is keen about improving the situation and finding a solution to rectify it. Since the company’s material flow method is growing old, it requires innovation in its production methods. In order to develop its production and increase its revenue, it is essential to identify and implement modern processes for improvement. Innovation of production process not only involves machinery or manufacturing methods, it also include the skill set of the workers associated with the whole system.

Fig. 2.1. Jet and submersible pumps manufactured [17]

The company comes under a public charitable trust which nurtures educational institutions in the field of engineering sciences and technology, and health. The trust is being controlled by a board of directors followed by general managers in the hierarchy who execute the demands and commands of the board through the mangers below them. Operations in the plants are carried out by the operators who are being directed by the production supervisors for the weekly demands. Currently the plant produces 60 motors every day, with a net profit of 96 000 € each month.

2.2. Investigation of Existing Layout

The design of manufacturing facility plays a vital role in the overall operation and productivity of an industrial plant. With all supporting facilities, the plant is spread for about a total area of 5500 m^2. It is equipped with an effective metrology lab and a machine shop with improved technology. The plant is supplied with machining facilities like CNC Vertical/Horizontal Machining Centres, Special Purpose Machines, Conventional Machine Tools, CNC Machining Centres (Deckel Maho) and so on. The Quality Control department is incorporated with Spectrovac Metal Analysis equipment Coordinate Machining Machine (CMM), Optical Profile Projector and other equipment. The plant structure is designed according to product layout principles aiming for the flow of material in a streamline. Since the design follows a particular form of layout type, the flow of material or the product is carried according to the standards to the quality of the products. The pump manufacturing involves a systematic and a step-by-step process in each stage of operations. It requires to follow certain standards for the operations involved in each workstation, for example winding in a motor has to be according to the international standards for safety reasons. With respect to the norms for developing a facility layout, workstations like winding and pressing are located adjacent to each other. Similar to that, motor assembly and pump assembly also follow the same method. Some parts of the plant require space for storage of varnished parts which comes along the product flow line, whereas the other store serves for machinery parts required during maintenance. According to the traditional model of testing, the plant has separate testing stations after pump assembly, which is connected to electrical connection station. This electrical connection station serves for the final electrical wirings and the connections required to operate by the consumers. The existing facility layout of the plant as shown in Fig 2.2 is the layout to be investigated for improvements.

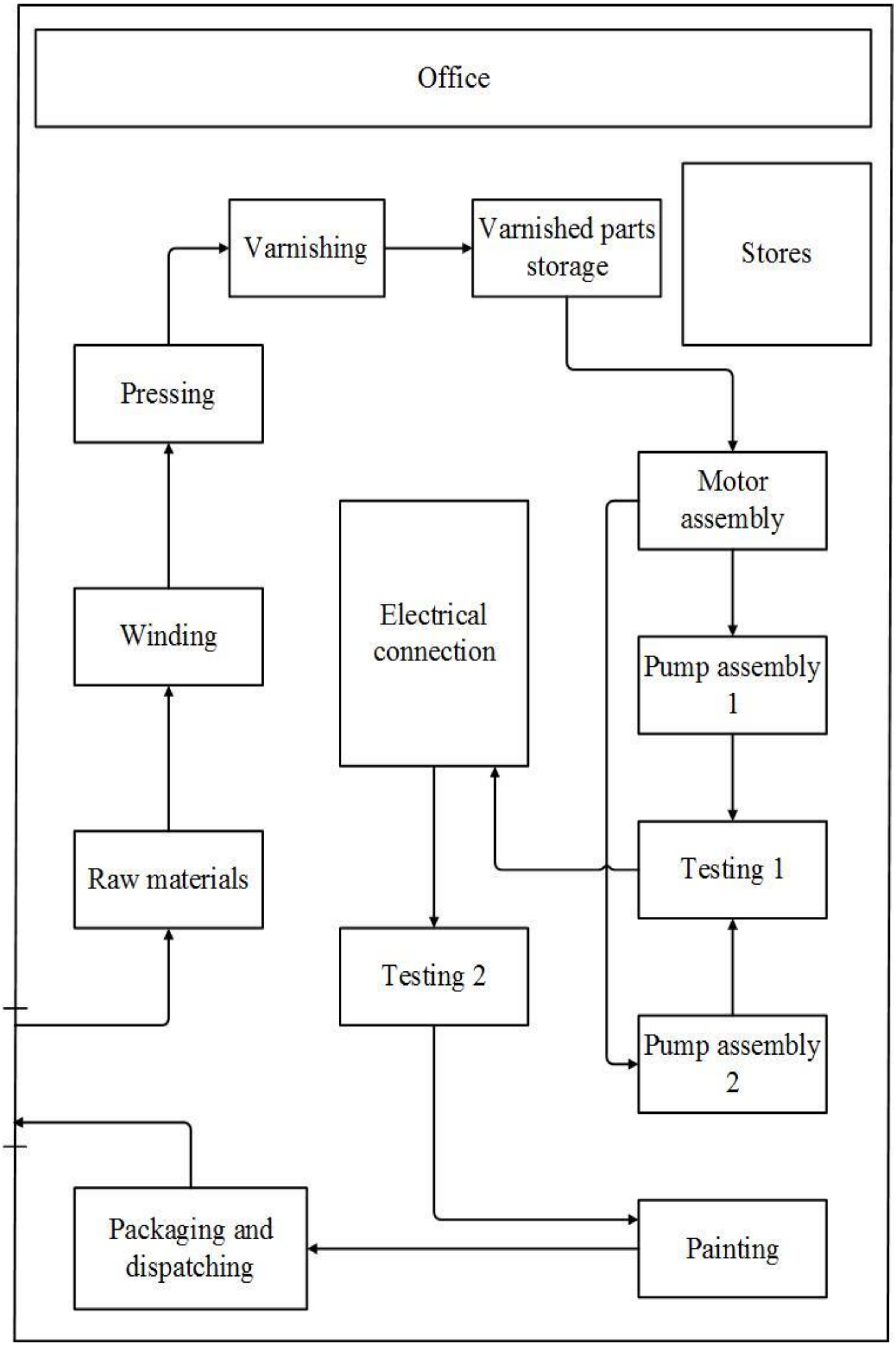


Fig. 2.2 Existing facility layout of the plant

The whole plant consists of various workshops especially for every operation. The process of operation is movement of materials from one workshop to the next after completion at each station. Within the 'Motor Assembly' department, there are two types of assembly stations meant for jet pumps and submersible pumps. The plant operates for 8 hours per day with a net working time of 400 minutes for a shift. According to the plant's current manufacturing capacity, it can produce 60 pumps for a shift (a day), which is capable of fulfilling the customers limited order. The initial level of production starts from the winding department, where the material from the warehouse is brought to the workstation. An office at the north and a store adjacent to it, also cover the floor area of the plant. The whole process of manufacturing starts from the movement of raw materials to the winding station. The winding station, working with 8 operators is one of the most time consuming stations in the entire production planning. The operation time for this station is accounted to be minutes for each pump. Followed by the winding station, pressing and varnishing are the work stations involved in the plan, consuming 2 minutes for their operations, correspondingly. Later the varnished parts are stored in a storage place located close to the motor assembly station. The motor assembly station has 2 operators who work on assembly process for 10 minutes.

Cycle Time (CT) is given as the time required to complete a cycle of operation; also to complete a task or a work from start to finish [2]. The list of operations involved in the production process is given with cycle time and the number of operators required.

Table. 2.1

Operations list with their cycle time and number of operators

No	Operation/workstation	Operators, units	Cycle Time, min
1.	Winding	3	14
2.	Pressing	1	2
3.	Varnishing	1	2
4.	Motor assembly	2	10
5.	Pump assembly	2	11
6.	Testing	12	1

Technological process for product manufacturing

Pump assembly is the station next to the motor assembly (from where movement is directed to jet and submersible pump assembly stations). This part of the layout of the plant is considered to be a section where improvements are necessary. The submersible pump assembly station lies between the 'Testing 1' station and makes it difficult for the material to flow in a streamline. It also involves movement of pumps to the 'Electrical Connection' station for setting the connections and electrical components for the final assembly of the motor. After which the final testing of the pumps take place in the 'Testing 2' station and moved to the painting workshop. Finally packaging and dispatching station takes care of the completed product and moves them through the same exit.

The current state value stream map in Fig. 2.5 shows how the shop floor operates in order to face the weekly customer demands. The customer demand of 1200 pumps for a week and the processes involved in them are clearly depicted in this state map. Daily operations are directed by the production supervisor, according to the demand for the whole week. The tasks carried out in the plant and their individual cycle time are mentioned. It clearly shoes that winding and pump assembly are the operations which consume most of the plant‘s working time. The customers and the supplier are contacted electronically from the plant. It serves as an initial step for the development for the understanding plant's performance and aids in developing the same in terms of production. It helps in analyzing the continuity of material flow and waste management. From the state map, the lead time and the total cycle time of the production process are determined. Takt time plays a pivotal role in the designing of the state map and it serves as a key factor the required number of operators. Takt time is simply the available working time per shift divided by the rate of customer demand per shift (Equation (1.1)).

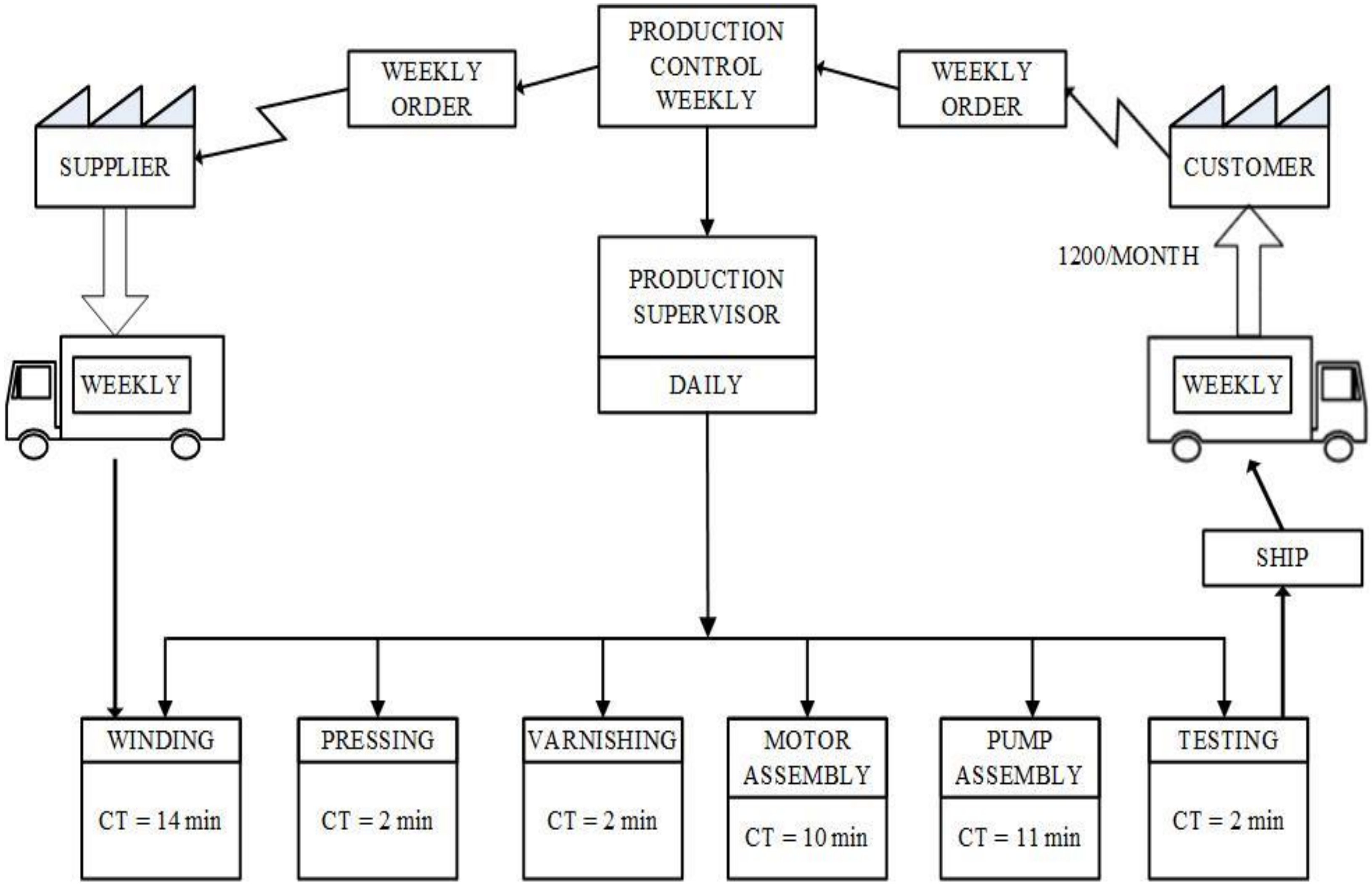


Fig. 2.5 Value stream map with cycle time for weekly operations

2.3. Current Parameters of Operations and Process

Some of the basic information required to analyze the production process are:

Working hours per shift, h	-	8 h
Available Production Time per shift (*APT*), min	-	480 min
Actual Production Time of a machine for a month (APT_m)	-	43200 min
Downtime per shift	-	0 min
Breaks and breakdown Time (*BT*)	-	80 min
Total Cycle Time (*TCT*) or Value Added Time (*VAT*)	-	41 min
Daily Production Requirement (*DPR*), units	-	60 pumps

In order to determine the quality of the operations, it is essential to determine factors like:

- Process Lead Time (*PLT*)
- Takt Time (*TT*)
- Process Ratio (*PR*)
- Uptime (*UT*)

Process Lead Time (*PLT*) is the actual time the plant operates in a day for production which excludes breakdown time, and is expressed in minutes:

$$PLT = APT - BT \tag{2.1}$$

Using (2.1): $PLT = 480 - 80 = 400$ min

Takt time (*TT*) according to (1.1):

$$TT = \frac{480}{60} = 80\ min$$

Process Ratio (*PR*) is used in order to evaluate the overall operating process and its rate of operation. It is the ratio of value added time in a process to process lead time:

$$PR = \frac{VAT}{PLT} \cdot 100 \tag{2.2}$$

With respect to (2.2):

$$PR = \frac{41}{400} \cdot 100 = 10.25$$

Uptime (*UT*) percentage is used to determine the quality of the process with respect to the working time of the machinery along with the value added time:

$$UT = \frac{APT_m - VAT}{APT_m} \cdot 100 \tag{2.3}$$

From (2.3):

$$UT = \frac{43200 - 41}{43200} \cdot 100 = 99.90\ \%$$

Table 2.2

Parameters of whole production cycle

Process Lead Time (*PLT*)	400 min
Takt time (*TT*)	80 min
Process Ratio (*PR*)	10.25
Uptime (*UT*)	99 %

2.4. Problems in Existing Layout

As mentioned in chapter 1.1, possible problems, related with facility layout seeking lean, are [2, 11, 12, 15]:

1. No standardized work procedure
2. Large inventory
3. Poor housekeeping
4. No benchmarking time
5. Backtracking and bypassing

The investigation about the current layout with respect to the discussions in Chapter 2 shows that the production plant encounters problems:

1. Lack of standardized work procedure
2. Poor benchmarking time
3. Backtracking and bypassing
4. Crossing of flow lines

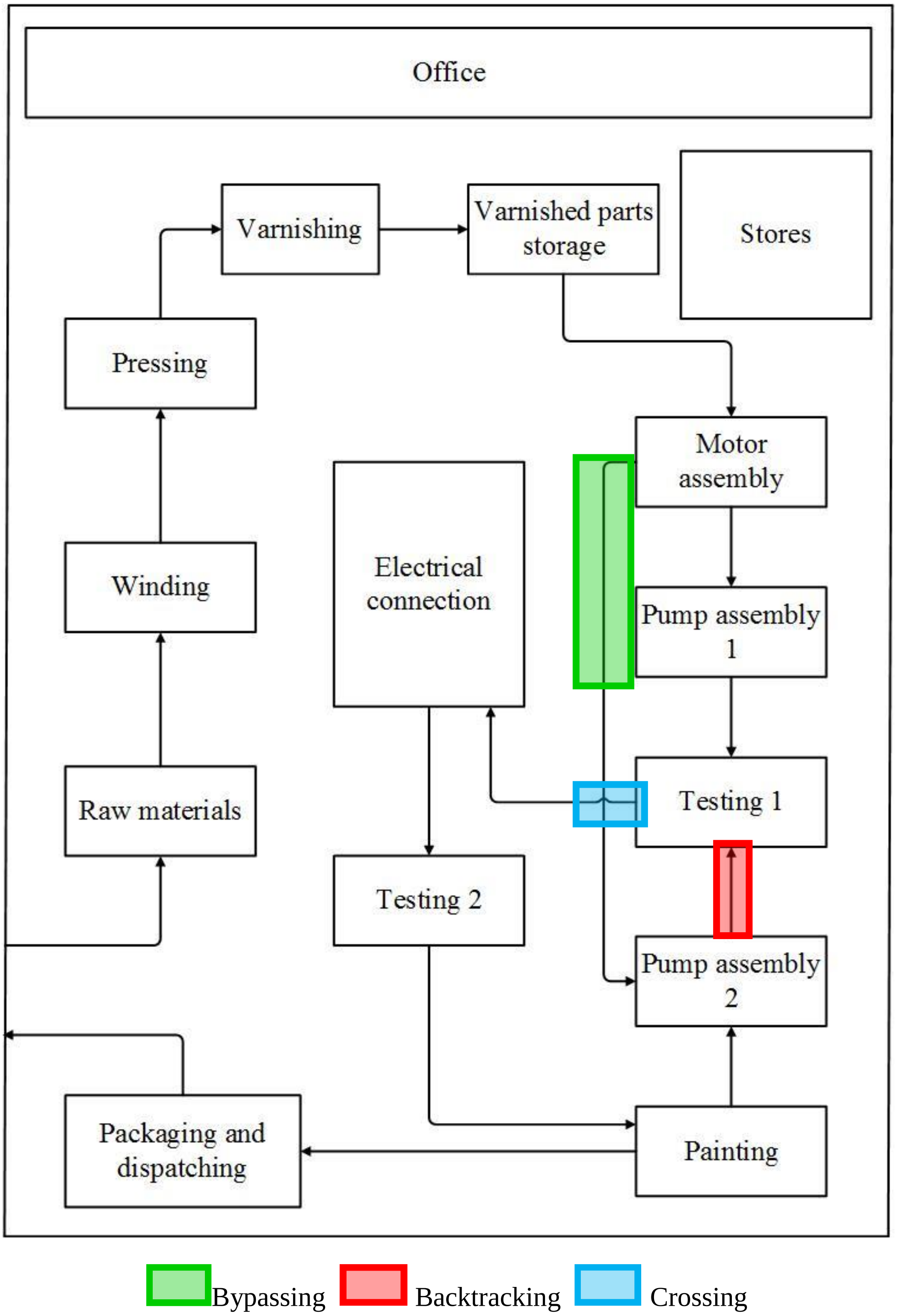


Fig. 2.4 Operation cycle affected by backtracking and bypassing.

Figure 2.4 shows the highlighted area with bypassing and backtracking. From the figure it is clear that the material flow principles (i.e. maximize directed flow paths and minimize flow) are violated. The highlighted areas shows the action of bypassing stations (pump assembly and testing) in between two other stations, prohibit the flow process. The flow of the pump after assembly to the testing station depicts backtracking operation. As backtracking and bypassing flows increase the total distance that a unit load must travel, these movements should be eliminated or minimized. Since the material flow is directly influenced by the layout of the facilities, efficient rearrangement of the placements of the departments may result in significant improvement in terms of the distance that a unit load travels and ease the material flows.

3. RECOMMENDATIONS FOR FACILITY LAYOUT

3.1. Proposed Facility Layout

As the management of the company is keen about improving the productivity of the plant, it is essential for the new design to be more efficient compared to the existing layout. The requirements can be listed as:

1. Reduced distance of material movement
2. Training for workers
3. Minimal transportation time (timespan in shifting the products to next station)
4. Advanced machinery

It is essential to modify such a design and improve the working process. It also causes idle time at working stations, to support the backtracking activity making it a cost and time consuming factor. The existing pattern of the machinery involved in production are being on usage for a very long time, and requires replacement. Each and every workstations in the plant is in need of modernization. For example, the motor assembly station is being a vital support for the entire system which is found to be following traditional methods of working. It needs to be restored for the improvement in the production cycle, hence reducing time and cost of production.

The new design for the plant along with modification it also includes the removal of the electrical connection station, which is one of the outmoded method used in modern manufacturing. It highly affects the full method of production, saving unnecessary costs. The machinery used in the processes after the motor assembly station requires modernization and follow latest trends in the production mechanism. The store located adjacent to the varnished parts storage, which is being used to store tools and the parts for repairs and replacement can also be expanded. This expansion supports the production process during downtime more efficiently and can also be used to store packaging materials. The location of office in new design is similar to the existing one, located at the north side of the plant. Unlike the current design, the entry of raw materials and the exit of finished goods helping the smooth flow of materials. This helps in reducing congestion at the exit, which is happening now.

Following the motor assembly section, the pump assembly for jet and submersible pumps are located adjacent to each other. These stations are equipped with the machinery which includes facilities similar to the electrical connection station, thus reducing the movement of materials. Due to this recent trend, the floor area occupied by the workstation is quite larger than the current one. The modernization of testing stations also help in occupying less floors area contrasting the existing design. The operations in the first testing station includes the detection of defective pump wiring. It involves the examination of all motor and control box wiring. The new design of the plant as shown in Fig. 3.1 is without backtracking and bypassing, leading to decrease in the distance of material movement.

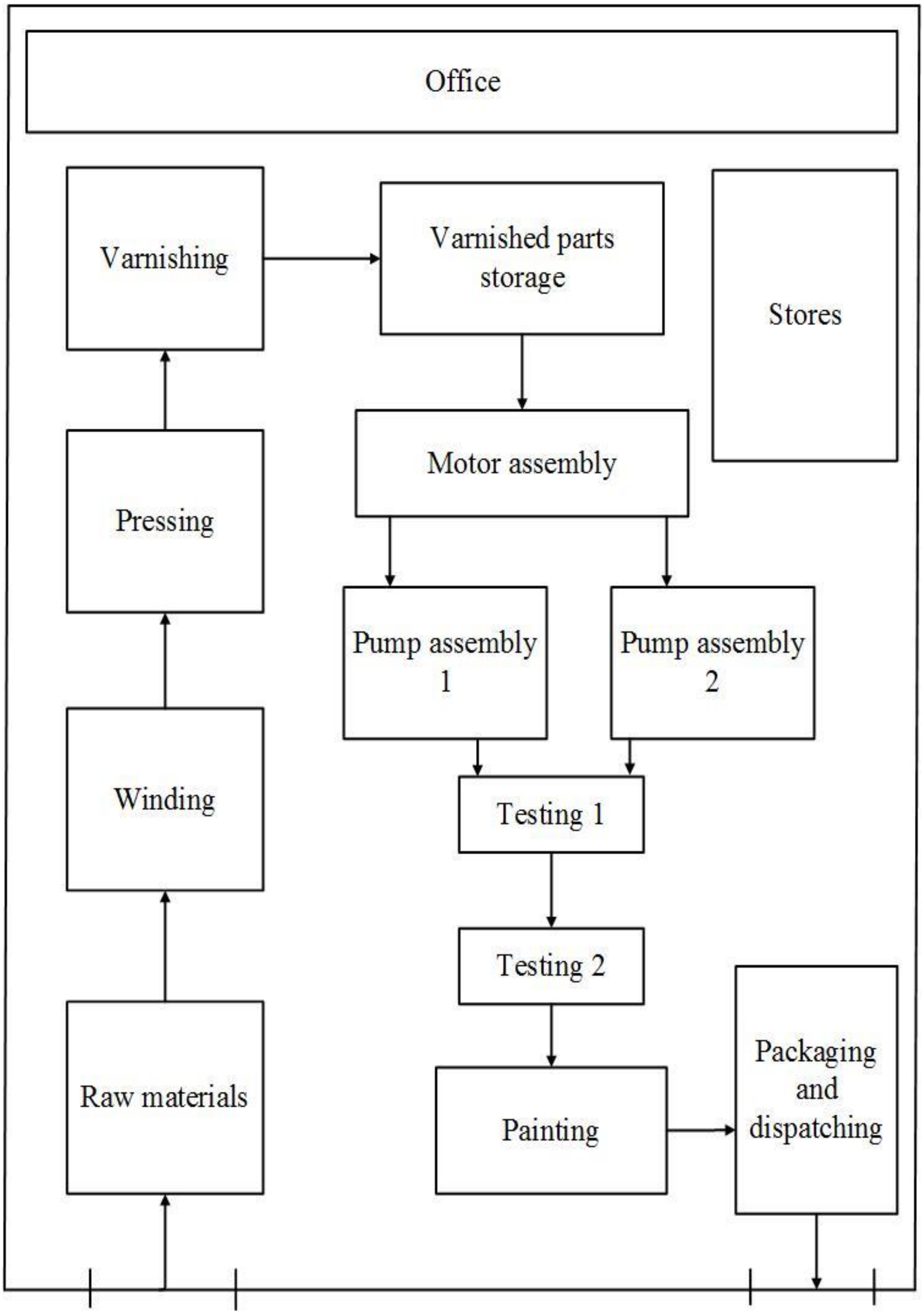


Fig. 3.1 New facility design with modifications

It also includes the resistance checking which indicates the quality of the winding (either shorted or open winding). The second testing station is associated with overloading factors by checking pump line amperage. The workshop with improved painting techniques located next to the testing stations certainly helps in cutting down the timespan in shifting the products to next station. Compared to the current painting station, new design is made corresponding to the recent advancement in the painting process covering involving modern automation. The packaging and dispatching station adjoining the painting station, is located close to the exit. This helps in the continual flow of materials and thus not affecting the incoming material as in the current system.

3.2. Analysis of New Facility Layout

For comprehensive analysis of new facility layout design the following means are used and particular charts developed:

1. Value stream map
2. Operations balance chart
3. Flow process chart

3.2.1. Value stream map

The value stream map of the new layout shows after implementation of lean techniques improves the performance of the production process and the shop floor. This state map provides as the lead for the advancement for the future operations to be carried out in the plant. Elimination of waste to the maximum and continuous flow of material are the primary goals of this map. It also shortens lead-time and also enhances the production cycle through lean techniques. The frequency of the unit completion and takt time are the major factors behind the development of such a mapping.

Fig. 3.2 when compared with the existing layout's state map from Chapter 2 (Fig. 2.5), the operations winding & pressing, varnishing & motor assembly, and testing & pump assembly, are combined together respectively. The cycle time of those combined operations are being carried out under the oversight of the production supervisor on a daily basis, to face the weekly demand from the customers. Following the operations, it is evident that shipping is carried out to the customers and the raw materials for the forthcoming week are brought into the production process. The existence of problems within the operations are highlighted, hence making the entire result in the practice a better one.

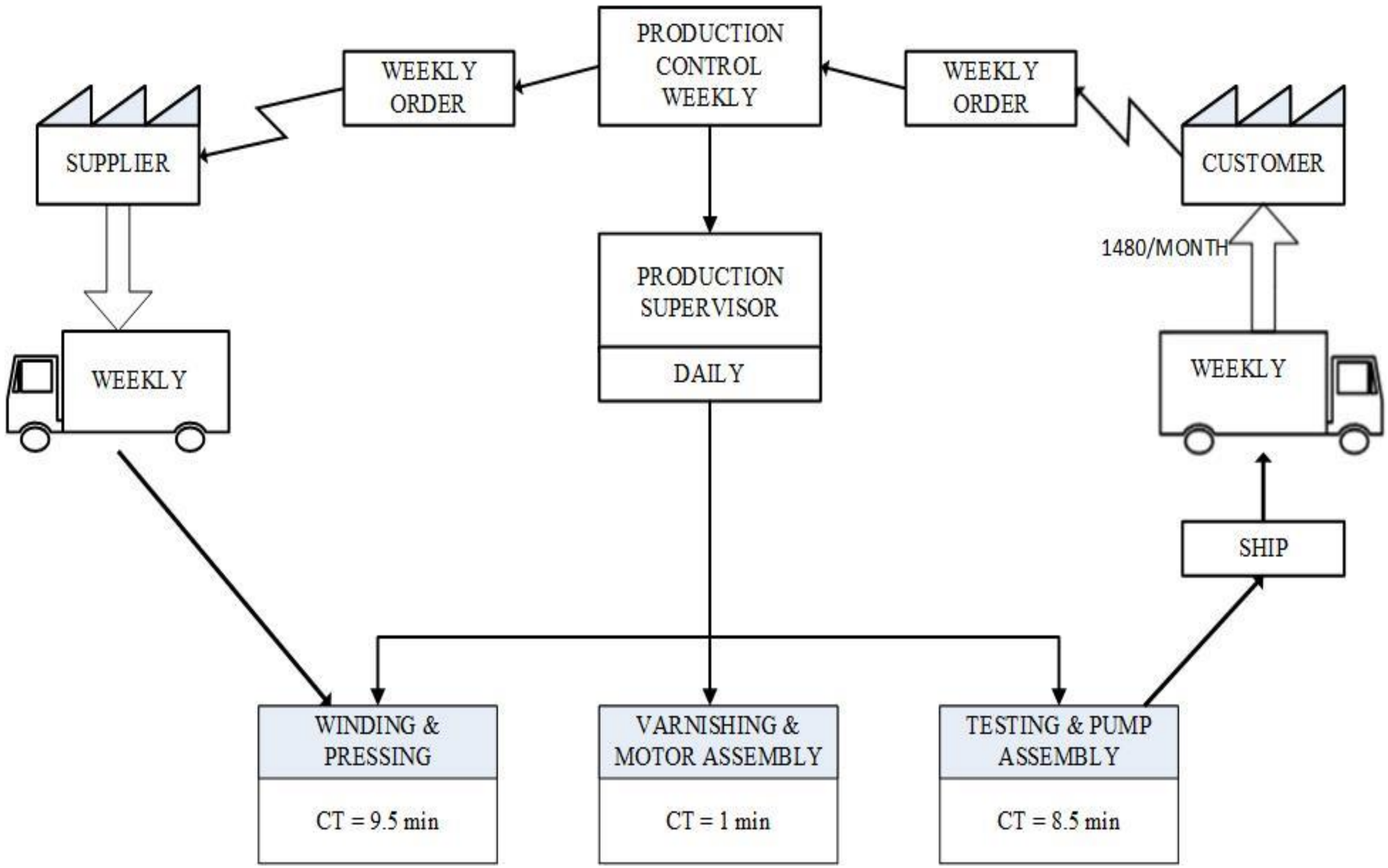
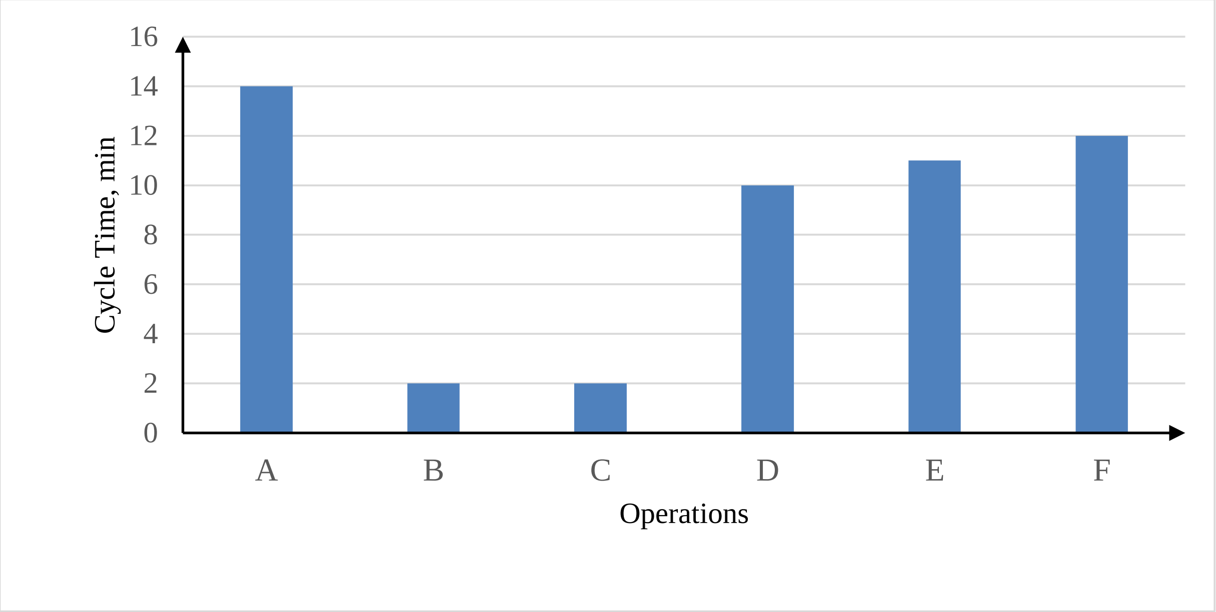


Fig. 3.2. Value stream map for new facility design

3.2.2. Operations balance chart

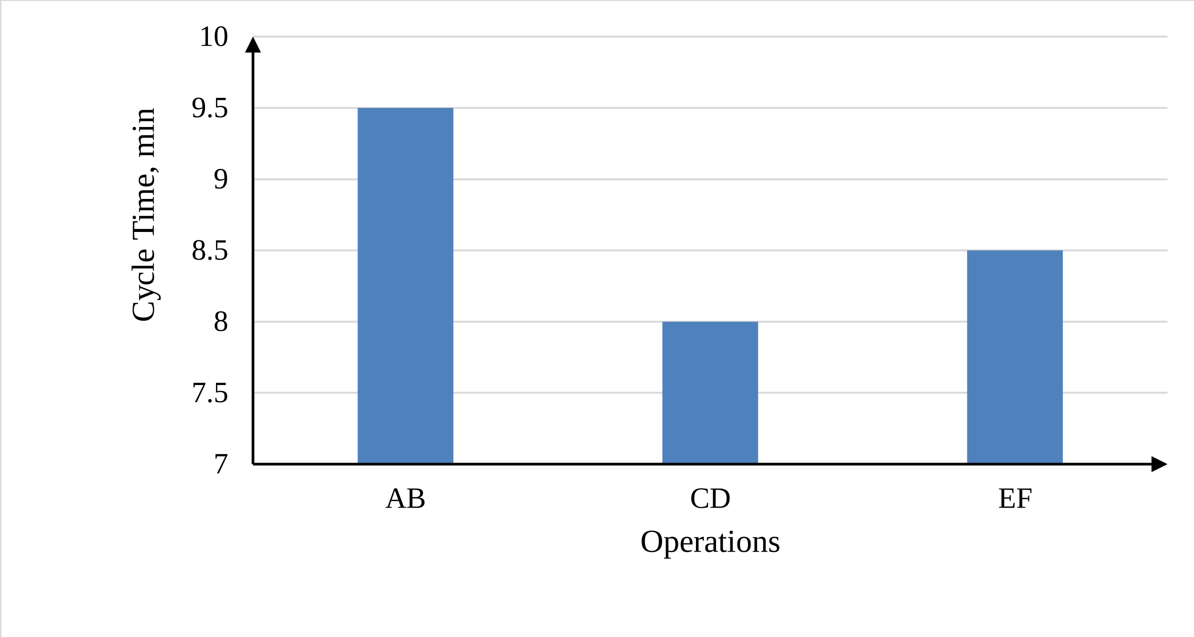
Operator Balance Chart (OBC) is a graphic tool that helps in the creation of regular flow in a multi-operator, multistep process by administering operator task elements in relation to takt time. It is also called an operator loading diagram, assisting in determining the number of operators needed [18]. An OBC uses vertical bars to represent the total amount of work each operator must do compared to takt time. The vertical bar for each operator is built by stacking small bars representing individual work elements, with the height of each element proportional to the amount of time required. This is essential for minimizing the number of operators needed by making the amount of work for each operator very nearly equal to, but slightly less than, takt time [13]. Fig. 3.3 shows the cycle time and the operations in a balance chart along with total cycle time and the total cycle time of all the operations of existing layout is 41 min.



Operations	Winding (A)	Pressing (B)	Varni-shing (C)	Motor assembly (D)	Pump assembly (E)	Testing (F)
Cycle time (min)	14	2	2	10	11	2

Fig. 3.3 Operator balance chart for existing facility layout

Compared to the operator balance chart for the existing design layout, the proposed one shows the reduced total cycle time which is 26 min, and their operations being combined to reduce the operators required. In Fig. 3.4 the operator balance chart for proposed facility layout is presented.



Operations	Winding & Pressing (A&B)	Varnishing & Motor assembly (C&D)	Pump assembly & Testing (E&F)
Cycle time (min)	9.5	8	8.5

Fig. 3.4 Proposed layout design's operator balance chart

The number of operators needed (OP) for the operations as a whole production cycle is given as:

$$OP = \frac{TCT}{TT} \tag{3.1}$$

Using (3.1), for existing production process,

$$ON = \frac{41}{8} = 5.12$$

And for the proposed layout,

$$ON = \frac{26}{8} = 3.25$$

As a result of determination of operator needed, the proposed layout is found to be requiring less number of operators, thus showing that it is efficient in terms of operators needed.

3.2.3. Flow process chart

The flow process chart developed (Fig. 3.5) shows the comparison between the types of actions and the distance of material movements in present and proposed layouts.

Operations	○	⇨	D	□	▽	Distance, m	
						Present	Proposed
1.1 Store					●		
1.2 Raw material unloading		●				12	10
2.1 Winding	●						
2.2 Move to pressing		●				10	9
3.1 Pressing	●						
3.2 Move to varnishing		●				9	9
4.1 Varnishing	●						
4.2 Move to store		●				8	12
4.3 Store					●		
4.4 Move to motor assembly		●				18	12
5.1 Wait for motor assembly			●				
5.2 Move to pump assembly		●				20	8
5.3 Wait for pump assembly			●				
6.1 Move to electrical connection		●				15	10
6.2 Electrical connection	●						
7.1 Move to testing		●				12	2
7.2 Testing				●			
8.1 Move to painting		●				12	12
8.2 Painting	●						
9.1 Move to packaging and dispatching		●				16	12
9.2 Packaging and dispatching (Store)					●		
Total	5	10	2	1	3	136	102

Fig. 3.5 Flow process chart showing the distance of material movement

The point where changes are needed are easily optimized through this chart along with the distance travelled by materials between different stations. It is determined that the movement between pump assembly and testing workstations consume most of the time and distance. Through the new design of facility layout this issue has been rectified, helping the plant management to increase productivity and simplify the work process. It also helped in reducing the operating costs. From the chart it is evident that the total distance of movement of the materials in the whole production cycle has been reduced for about 25%. The initial distance has been recorded as 136 m whereas the proposed design records 102 m.

Using formula (2.2), process ratio:

$$PR = \left(\frac{26}{400}\right) \cdot 100 = 6.5\ \%$$

Using formula (2.3), uptime

$$UT = \frac{43200 - 26}{43200} \cdot 100 = 99.90\%$$

4. PRODUCTION IMPROVEMENT POSSIBILITIES FOR THE PLANT

4.1. Evaluating Factors for Implementing Proposed Layout

When the management is considering renovating its existing machinery and production method or creating a new program that requires space, an accurate analysis of space needs should be administered. The assistance of a team of analysts is necessary to review programmatic needs and identify the appropriate amount and type of space required. With a good interpretation of space demands, the relative merits of the factors to be considered should be weighed. An explanation of the factors to consider follows.

Suitability of Space

When considering suitability of space, questions which should be asked include [19]:

- Is the internal layout of the space appropriate for the modification?
- What modifications would be necessary?
- What costs will be incurred to prepare the space for use?

Modifications can result in significant additional costs. If space is being built, or a new facility is to be finished out, it can be designed to suit particular design specifications. However, when existing facilities are used, any additional costs associated with renovations to back fit the space to enhance efficient needs are considered.

Urgency of Need

If the plant is being planned to be renovated, it affects the production for that particular period of time. Various factors are to be considered while carrying out such a plan, like [19]:

- How long does it influence the revenue gaining process?
- What to do with the current workers?
- How to manage the demands or retain the customers?

Location

Proximity to an existing design can have a significant impact on the efficiency of operations. The need to physically interact with other units should be reviewed – including the frequency and type of interaction. Costs associated with staff travel and accessing services should be considered. If the program seeking space would function most efficiently in close proximity to existing departments or programs, identifying or building space in the vicinity should be considered.

Location in an off-campus facility may be desirable in order to serve a specific market. If an existing program is already occupying a facility in a highly desirable location, but the facility is not suitable in its present configuration or finish, renovation should be considered [19].

Cost

Development of a budget and determination of optimal solution requires a thorough understanding of all kinds of cost involved. Costs to be considered basically include: logistic expenses, design fees, construction, and operating expenses for the various other services. In order to determine the relative advantages of renovation or construction, it is necessary for a present value analysis performed on the basis of the overall price involved. Though all other aspects being equal, the present value analysis of possible choices normally will be the determining factor in the preference of a specific option.

Factors that support each option

Renovation:

- Existing space is usable, but not configured for efficient needs.
- Funds for renovation is possible to raise.
- Required to start production as early as possible.

New plant:

- Location near existing program, or in a particular location is essential
- Program duration: need for space is long term
- Need is not immediate
- Availability of own space or possible to acquire one at a reasonable price.
- Finance needed for construction and operation is available.

In addition Table 4.1 shows list of decision factors which provides possible optimal solutions, that the projects fit neatly into this list; it is meant as a guide and special circumstances will require exceptions.

Table 4.1

Decision factors defining possible solutions [19]

Decision factors	Renovate	New plant
Availability of suitable space	Space available but not suitably configured or finished	No suitable facility available
Urgency of need	Within 1-2 months	1 year
Duration of need	Intermediate or long term	Long term
Flexibility	Space needs are expected to be constant for proposed program	Space needs are expected to be constant -- either for proposed program, or future needs
Location	Proximity to existing program or particular location is important	Proximity or particular location is essential
Services	Services to be provided by Business Unit	Services to be provided by Business Unit
Cost	Present Value Analysis supporting lowest cost option	Present Value Analysis supporting lowest cost option
Funding availability	Planning and construction funds available as needed	Planning and construction funds available as needed

4.2. Analysis of Renovation Replacing Certain Machinery

The plan for renovation in the plant requires the replacement of the machinery in the production flow process only in certain parts. It is assumed that the remaining portions of the plant remain the same and continue to operate for the manufacturing cycle in future. In recent years, demand for the new generation of production methods has affected the average lead-time largely. Equipment reliability directly relates to profitability and in the end, overall customer satisfaction – the only true indicator for increasing profitability.

4.2.1. Reasons for replacement of equipment

The reasons for replacement of equipment are mentioned below along with the layout design for stations requiring replacement of machinery.

To improve efficiency

As a result of various significant improvements in the efficiency of modern machinery, there are now sound economic reasons why older machinery should be decommissioned even when they are still functioning properly. However, despite being normally observed as the best practice under many circumstances, machinery are still rarely replaced before failure for production efficiency reasons alone. If it is not related to a substantial change in the productivity level, machinery efficiency will rarely trigger replacement.

Block plans to consider space and project cost scenarios

With respect to the cost tradeoffs of replacement, consideration should be given to space planning and rough cost estimation based on future market needs. Architect and planning firms offer needs assessments, block space planning, and cost estimation services.

It is necessary for the management to understand:

- Requirements of the current building and facility and the essential mechanical, electrical and structural system upgrades to meet standard code.
- Expenses of site improvement, utilities, and land acquisition for any off-campus areas under thought.

Expensive renderings of the facility should be avoided until the cost and benefit tradeoffs of the various replacement scenarios have been addressed. Later in the process, the selection of project scope and cost will become an input into the allocation of depreciation and interest used in estimating cost-based reimbursement for the firm.

Understand financing alternatives and prioritize financing needs

With the setting for undertaking expense situations, firms should understand the accessible financing options in the market, and the impact these factors will have on capital structure, liquidity, and interest costs. Investment banks are the appropriate asset helping to forecast debt cash flows accurately with their access to trading and money streams. The management and the board should prioritize financing needs and associated risks of financing alternatives. When considering financing alternatives, industries should understand the cash availability for comfortable project commitment commit and review the possibilities for raising additional funding sources such as donations or tax levies, if required. The balance sheet effect of the chosen financing action, combining equity contributions and other funding sources, should be evaluated and analyzed.

Forecast future Revenues and Expenses with the Project

After investigating business driven construction situations and capital market accessibility, the management should concentrate on understanding the future expense structure and repayment impacts of the project. Management should forecast future revenue in light of included service lines, expected price patterns, and demand and market capture. To the extent that service blend is not expected to affect the task, this investigation is required to be conducted at a high level to save time and expense. Understanding the total revenue forecast and foreseen expense structure associated with project situations is important for the management under consideration.

4.2.2. Peculiarities of replacement of equipment

Considering various factors discussed above and the conditions for the production facility discussed in Chapter 3, a facility with replacement of machinery is determined. This replacement can impact the production of the plant in a positive way, causing productivity increase and helping to earn profit for the company.

Table 4.2

Plant facts before and after replacement

	Current situation	After replacement (~)	Development
Production for a day, units	60 pumps	70 pumps	+10 pumps
Company sales for a week, units	300 pumps	350 pumps	+50 pumps
Production cost, €	360	360	-
Selling cost, €	440	440	-
Profit per pump, €	80	80	-
Profit for a week, €	24 000	28 000	+ 4 000

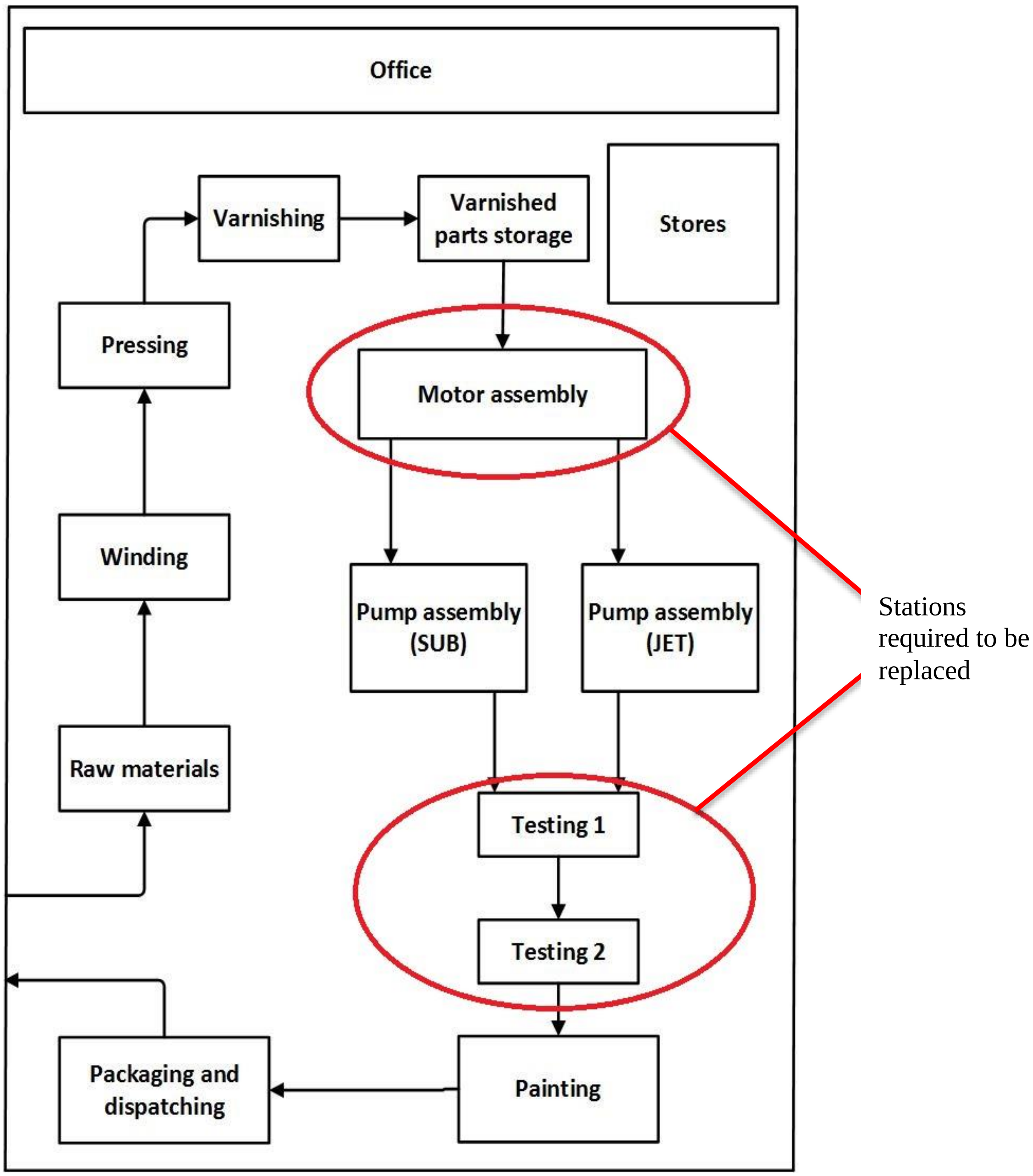


Fig. 4.1 Facility layout design with replacement required

The layout with the machinery required to be replaced is hown in Fig. 4.1. For replacement of machinery for the indicated parts of the layout in Fig. 4.1, includes purchase orders, machinery costs, and transportation to the plant along with installation costs. The total expense is estimated to be 251 250 €, with comparing some real time replacement scenarios. It is also estimated that it requires 4 weeks (assumed estimation) for the management to complete the replacement process.

4.3. Earned Value Management Analysis in Construction Process

The management of the company employs a team to implement the plan for construction and installation of machinery, which provides an estimation with comparison with some real time projects. Since it is a long term plan, the company wanted to make sure that the operations for such a project to be planned and executed perfectly. The basis for project execution are planning, scheduling and budgeting. The team of managers evaluated the situation and came up with a project report with a budget of 837 500 € for the completion of the whole project. Considering certain facts about the activities, the total duration is estimated to be 51 weeks. It has been determined that the establishment of the project requires 10 activities with construction activity being the longest with 32 weeks. Annex 3 shows the list of activities along with their duration and a Gantt chart. The performance of the project is analyzed using one of the tools in project management, called Earned Value Management [20].

4.3.1. Earned Value Management

Earned Value Management (EVM) is a methodology used since the 1960s, when the USA department of defense proposed a standard method to measure the project's performance [20]. The system relies on a set of often straightforward metrics to measure and evaluate the general health of the project. These metrics serve as early warning signals to timely detection of project problems or to exploit project opportunities. The purpose of an EVM system is to provide answers to project managers on questions such as [21]:

- What is the difference between budgeted and actual costs?
- What is the current project status? Ahead of schedule or schedule delay?
- Given the current project performance, what is the expected remaining time and cost of the project?

Earned Value Management in general involves the standard comparison between budgeted and actual costs. Earned Value Management is used to determine and relate the real progress of the project and to integrate the three critical elements of project management (scope, time and cost management). It takes into account the work completed, the time taken and the costs incurred to complete the project and it helps to evaluate and control project risks by measuring project progress in monetary terms. More traditional approach of forecasting the project's duration using the basic key metrics in earned value, elaborates the time aspect of EVM and compares a newly developed method, called earned schedule [21].

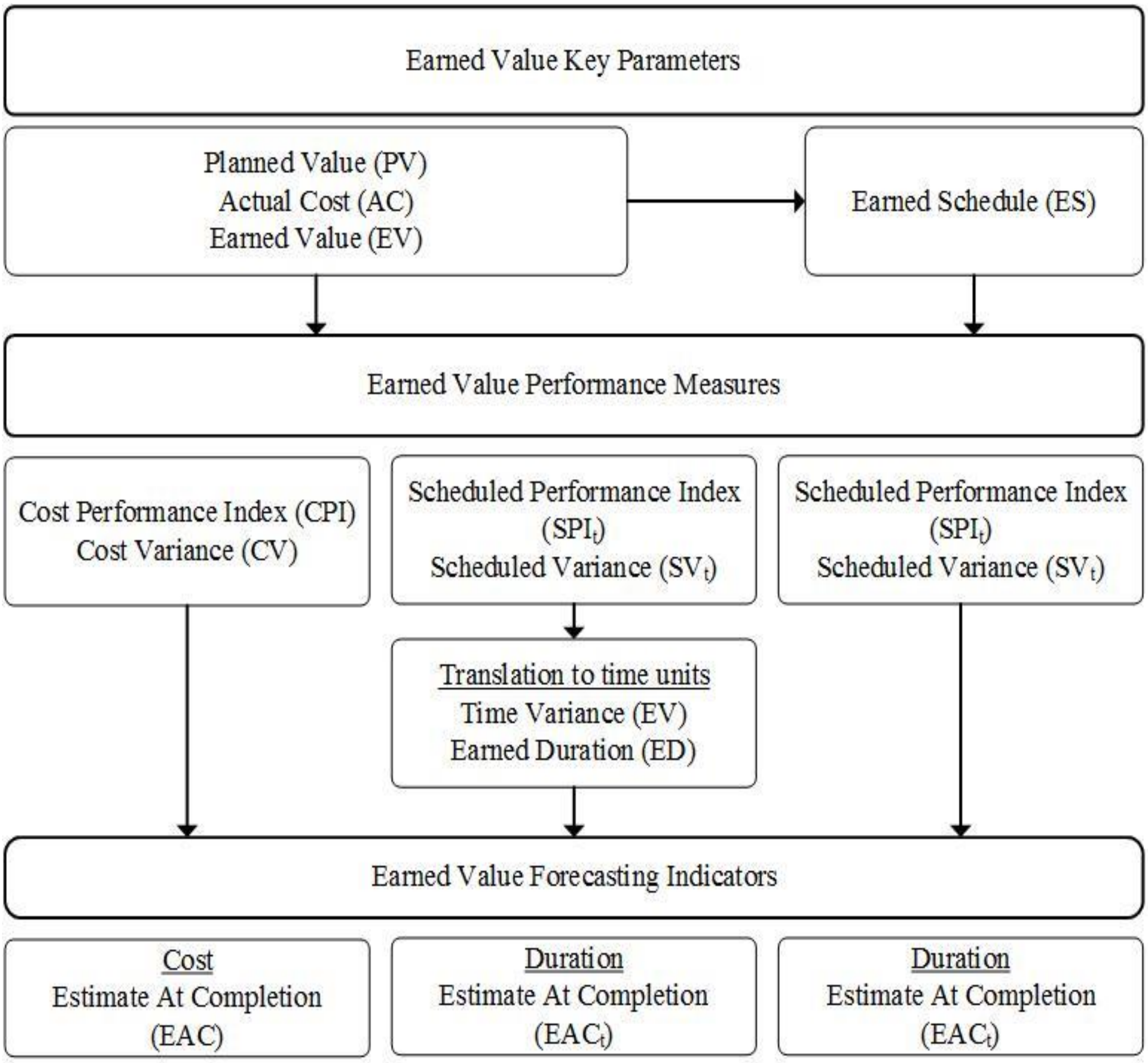


Fig. 4.2 Earned Value Management: key parameters, performance measures and forecasting indicators

4.3.2. EVM Key Parameters

Evaluating the efficiency of the project in development requires a particular point of reference and awareness about the key metrics used in an EVM scheme. The planned duration PD is the total project duration as a result of the activities in the critical path and is referred to as schedule at completion. The actual time AT or actual duration AD specifies the number of time periods, the project is in progress at the current occasion, for example weeks. Subsequently, these parameters are used to calculate the progress of the project along with the number of time increments it is running and are used to define performance measurements from the start to the finish of the project. The real duration RD indicates the real final project duration with respect to the project's finish. The budget at completion BAC is the total of all budgeted costs estimated to be incurred for the individual activities.

These variables can be summarized as follows [21]:

PD	Planned Duration (often known as Schedule At Completion (SAC)) →expected total duration known from the schedule
RD	Real Duration →real project duration only known when the project is finished
BAC	Budget At Completion →expected total cost as a result of the baseline schedule
RAC	Real At Completion →real project cost only known when the project is finished
AD	Actual Duration (or Actual Time AT) at the current time →number of time periods the project is in progress

EVM requires three key parameters to measure the project performance such as [21]:

1. Planned Value (*PV*)
2. Actual Cost (*AC*)
3. Earned Value (*EV*).

Planned Value

Planned Value *(PV)* is the amount or resource estimated to be spent according to the budget and the plan throughout the time period of the project. It simply means the value based on the translation of cost into time based activities execution. It is an aggregate increase in the total cost of activities which are budgeted at the start and finish times indicated in the plan.

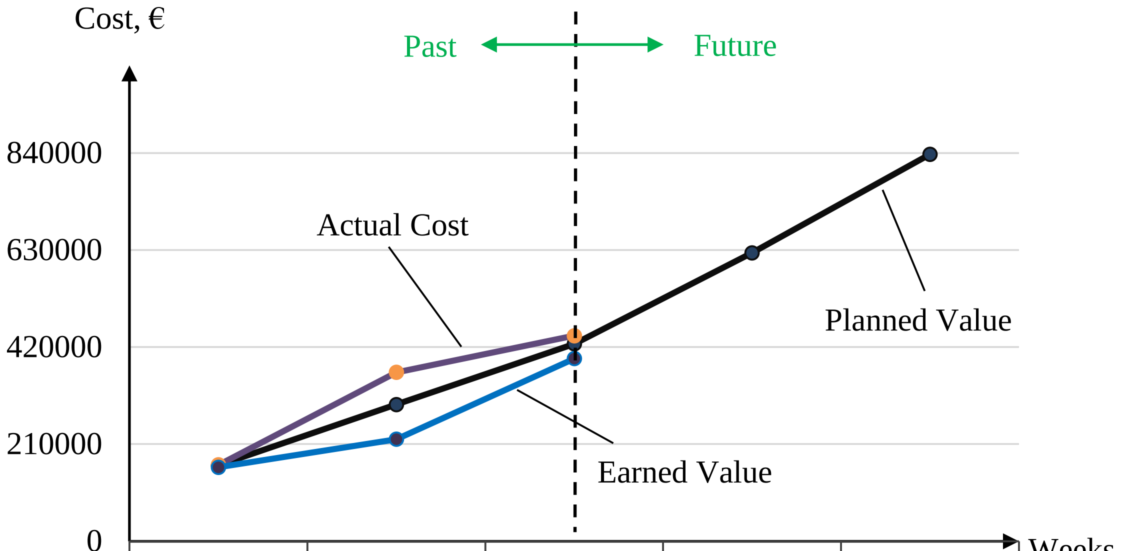
Actual Cost

Actual Cost *(AC)* basically refers to the actual expenses incurred for activities performed and is the increasing actual cost spent at a given point of time *(AD).*

Earned Value

Earned Value *(EV),* often called the Budgeted Cost of Work Performed (BCWP) represents the amount budgeted for performing the work that was accomplished at a given point AT in time. It equals the mutiplied product of the total activity (or project) budget at completion and the percentage activity (or project) completion (PC) at the particular point in time ($PC \times BAC$). It is determined that 47% of the work has been finished by the end of 26th week and the total is

$$EV = 0.47 \cdot BAC = 395\ 000\ €$$



	10	18	26	38	51
PV	164215	295590	426950	623998	837500
AC	165000	365200	444720		
EV	160000	220500	395000		

Fig. 4.3 Planned Value, Actual Cost and Earned Value (in €)

Earned Schedule

Both the Planned Value (PV) and the Earned Value (EV) measures show a planned and an earned increase of the project in monetary terms, while EVM helps to monitor both time and cost of the project. The Earned Schedule (ES) is an extended format of the EV and PV metrics and can be calculated as follows:

‘t’ is determined such that $EV \geq PV_t$ and $EV < PV_{t+1},$

$$ES = t + \frac{EV - PV_t}{PV_{t+1} + PV_t} \qquad (4.1)$$

where

ES – Earned Schedule;

EV – Earned Value at the actual time;

PV_t – Planned Value at time instance t;

The ES metric for the 51 weeks project by the end of 26th week, using (4.1) is equal to

$$\mathrm{ES} = 25 + \frac{395\,000 - 410\,540}{429\,960 - 410\,540} = 24.05 \text{ weeks}$$

Performance Measurement

The key parameters of the previous section can be used to measure the current and past performance of the project in progress. The values for the three key parameters are as follows:

1. The EV curve measures how much value has been earned at the current time (26th week) given the work that has been done up to now, which is equal to 395 000 €.
2. The PV curve measures how much value should have been earned according to the baseline schedule at 26, and is equal to 426 960 €.
3. The AC curve measures the actual cost incurred up to the current time (26th week) given the work that has been done and equals 444 720 €.

Consequently, the following conclusions can be made:

- Since PV stipulates that there should have been earned 31 960 € more than actually earned (EV) at week 26, the project is clearly late.
- Since the value of the work done up to 26th week (AC) exceeds the value that should have been earned with that current work done as stipulated in the baseline schedule (EV), the project is clearly over budget.

Variances

The time and cost deviations (underruns and overruns) can be expressed by variances or unitless indicators and are determined from the project‘s situation. Project performance, both in terms of time and costs, by comparing the three fundamental parameters like *PV*, *AC* and *EV* results in establishing two performance variances such as Schedule Variance (*SV*) and Cost Variance (*CV*).

$$SV = EV - PV \tag{4.2}$$

SV
- = 0: project on schedule
- < 0: project delay
- > 0: project ahead of schedule

$$CV = EV - AC \tag{4.3}$$

	= 0: project on budget
CV	< 0: budget overrun
	> 0: budget underrun

Using (4.2) and (4.3),

$$SV = 395\,000 - 426\,950 = -\,31\,960\ €$$

$$PV = 395\,000 - 444\,720 = -\,49\,720\ €$$

Since time variances SV are expressed in monetary units, the ES metric can be used to translate this variance to time units, using the Schedule Variance with earned schedule *(SV_t):*

$$SV_t = ES - AT \tag{4.4}$$

	= 0: project on schedule
SV_t	< 0: project delay
	> 0: project ahead of schedule

where t is used to make a distinction with the traditional SV time indicator.

The 10-activity project the project is late and over budget, according to the calculated SV = −31 960 € and CV = −49 720 € (Fig. 4.3). The SV_t metric of the 51 weeks project is equal to 24.05 − 26 = −1.95 weeks, clearly denotes that the project is currently behind schedule.

Indicators

When performance is measured by a unitless metric, the time and cost metrics can be replaced by schedule and cost performance indices, which express the project's progress as a percentage of the baseline performance. Those performance measures are Cost Performance Index (CPI) and Schedule Performance Index (SPI) which are determined below:

$$CPI = \frac{EV}{AC} \tag{4.5}$$

	= 0: project on budget
CPI	< 0: budget overrun
	> 0: budget underrun

$$SPI = \frac{EV}{PV} \tag{4.6}$$

	= 0: project on schedule
SPI	< 0: project delay
	> 0: project ahead of schedule

Using the *ES* concept, an alternative to the traditional SPI indicator can be defined also as Schedule Performance Index with earned schedule (SPI_t):

$$SPI_t = \frac{ES}{AT} \tag{4.7}$$

	= 0: project on schedule
SPIt	< 0: project delay
	> 0: project ahead of schedule

Using equations (4.5), (4.6) and (4.7),

$$CPI = 395\,000/444\,720 = 0.888$$

$$SPI = SPI_t = 395\,000/444\,720 = 0.925$$

Table 4.3

Comparison of possible SPI and SPI_t values at the project finish

Performance index	End of project	Index value at project finish
SPI = EV/PV	EV = PV	SPI = 1 (always) SPI_t > 1 (early project, i.e. ES = PD > AD)
$SPI_t = ES/AD$	ES = PD	SPI_t = 1 (on time project, i.e. ES = PD = AD) SPI_t < 1 (late project, i.e. ES = PD < AD)

Forecasting

Forecasting the total project cost and the time to completion is crucial to take corrective actions when problems or opportunities arise and hence, the performance measures will be mainly used as early warning signals to detect these project problems and/or opportunities.

The general formula for predicting the project's total duration is given by the *Estimated duration at Completion* (EAC_t) as follows:

$$EAC_t = AD + PDWR \tag{4.8}$$

where

EACt	Estimated duration at Completion
AD	Actual Duration (or Actual Time AT)
PDWR	Planned Duration of Work Remaining

The general and similar formula for predicting the project's final cost is given by the Estimated cost At Completion (EAC), as follows:

$$EAC = AC + PCWR \tag{4.9}$$

where

EAC	Estimated cost at Completion
AC	Actual Cost
PCWR	Planned Cost of Work Remaining

Time Forecasting

The overall performance of the project beyond the evaluating point is assumed to be on schedule according to the plans. Annex 4 shows how forecasting helps in determining the final cost and total time of the whole project with respect to estimated final cost and time overrun. Earned Duration (ED) method helps in determining the forecast results, which is the product of the actual duration AD and the schedule performance index SPI, i.e. ED = AD × SPI, and hence the generic earned duration forecasting formula is:

$$EAC_t = AD + \frac{PD - ED}{PF} \tag{4.10}$$

The performance factor PF is used to adapt the future performance to the past performance (depending on the project characteristics) and reflects the two situations, the two forecasting methods to predict total project duration are:

- PF = 1: Duration of remaining work as planned

$$EAC_{tED1} = AD + (PD - ED) = PD + AD \,.\, (1 - SPI) \tag{4.11}$$

- PF = SPI: Duration of remaining work with SPI trend

$$EAC_{t\,ED2} = AD + \frac{PD - ED}{SPI} = \frac{PD}{SPI} \tag{4.12}$$

From equations (4.11) and (4.12),

$EAC_{t\ ED1}$ = 51+ (26 – 24.05) = 52.95 weeks

$EAC_{t\ ED2}$ = 51/0.925 = 55.135 weeks

Table 4.4 summarizes the forecasting metrics used by EVM time forecasting. The PDWR metric is the component that has to be estimated, and heavily depends on the specific characteristics and the current status of the project. The project situation assumes that the remaining work PDWR will be done according to the baseline schedule.

Table 4.4

Time forecasting methods (EAC_t)

Expected future performance	Earned duration forecasting method, weeks
According to plan	$EAC_{t\ ED1}$ = 52.95
Follows current SPI	$EAC_{t\ ED2}$ = 55.135

Cost Forecasting

Predicting the final cost of the project during its progress can be done using a similar approach than the time prediction methods. Table 4.5 displays three main predefined methods, although many extensions are possible [21]:

$$EAC = AC + \frac{BAC - EV}{PF} \tag{4.13}$$

- PF = 1: Future performance is expected to follow the baseline schedule (version 1).
- PF = CPI: Future performance is expected to follow the current cost performance (version 2).
- PF = SPI or SPIt : Future performance is expected to follow the current time performance (version 3).

Using (4.13),

For version 1, EAC = 444 720 + (837 500 – 395 000) = 888 720 €

For version 2, EAC = 444 720 + (837 500 – 395 000) / 0.888 = 943 030 €

For version 3, EAC = 444 720 + (837 500 – 395 000) / 0.925 = 923 098 €

Similar to the time prediction methods, each method relies on another performance factor (PF) which refers to the assumption about the expected performance of the future work and are tabulated in Table 4.5 as follows:

Table 4.5

Cost forecasting methods (EAC)

		SPI	EAC (€)
Version 1	According to plan	PF = 1	887 220
Version 2	According to current cost performance	PF = CPI	943 030
Version 3	According to current time performance	PF = SPI	923 098

4.3.2. Project Crashing

When the project is performing behind schedule, project 'crashing' is the manager's option. The factors which influence the management to speed-up project execution in the middle [22]:

- While doing project planning, the initial project duration recommended, used to be too optimistic but the ground realities are pessimistic. This usually happens when numerous predictable/unpredictable risks which may highly affect the total duration of project, are not taken into account.
- The product is in demand in the market, which is being developed, earlier than expected. This demand forces the management to speed-up the project in order to fulfil the necessity of the market.
- Due to late execution of project high penalties will be attracted, which requires to consider the loss in goodwill.

It is the process by which duration of project is shortened by increasing the amount of resources assigned. It is important to consider that crashing is done only to activities which affect the project's duration in mainstream and can be attained by the following approaches:

- Addressing productivity issues of the current resources and making them more efficient. This can be done by taking better care of resources available and cutting cost and time wherever possible.
- Fetching new additional resources to speed up the operations.
- By evaluating alternatives available and analyzing them in order to find which one will help in compressing the duration with lowest cost.

While allocating resources to mainstream activities, it is essential to take into consideration the slack available in non-critical activities. This will help to assure that project crashing is not affecting the other activities of the entire project nor the project's scope.

Prospects of Project Crashing

1) Various external and internal factors may lead the management to go for crashing but it usually affects the quality of work as the time taken (besides cost) is the major issue.

2) Using additional resources does not always guarantee better results. For example if the organization decides to hire more employees, it is not sure that those additional employees are trained enough to deliver as per expected standards [22].

The information from EVM analysis, shows that the project is behind schedule and over budget. So it is necessary to find a solution to overcome such a crisis. So the project team, it considering crashing of activities. Though construction activity is the longest one with a duration of 32 weeks, it is assumed that this activity requires its own course of time to complete. The project is being evaluated at the end of 26th week and at that scenario construction activity has only few more weeks to get completed. Considering the features of this activity, it is determined that crashing it may affect the overall quality of the building in long term. So the project team decides to select the activity ‘Machinery Installation’ for crashing, according to the list of activities and its vitality for the project. ‘Machinery Installation’ requires 14 weeks of time and its cost is 230 000 €. Crash cost is the summation of penalty cost and the normal cost of the activity. The crash penalty is assumed to be 25% of the actual cost with respect to the duration of the activity. The crashing of this activity has various options to be considered and Table 4.6 shows them.

Table. 4.6

Crashing durations and their expenses

Crash duration, weeks	Penalty cost, €	Crash cost, €
5	41 050	271 050
6	49 275	279 275
7	57 475	287 475

The information below shows the profit scenario of the plant according to the predicted production.

Facts	Estimated values (~)
Production for a day, units	75 pumps
Company sales for a week, units	375 pumps
Production cost, €	360 €
Selling cost, €	440 €
Profit per pump, €	80 €
Profit for a week, €	30 000 €

Annex 5 shows the list of activities after crashing. It is found that there are other options for crashing activities upto 7 weeks, which are even profitable. According to the initial plan, it is scheduled to start production in the plant by the end of 51st week. But due to some uncertainities in the execution of activities, the project went out of control and it has to be rectified in terms of monetary terms and capable to face customer demands. It also shows that if the project is let to be completed with its own course of performance, leads to revenue loss to the company along with increasing overall value of the project and the comparison is shown in Fig. 4.4 and Table 4.7.

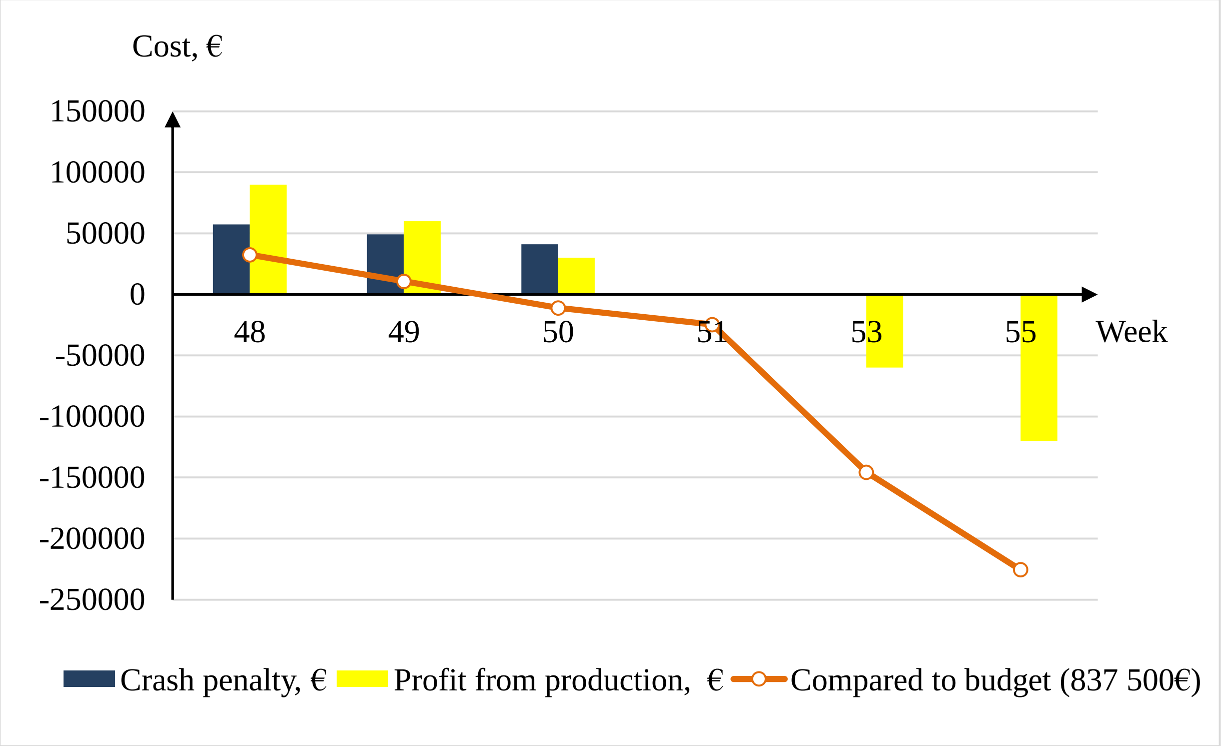


Fig. 4.4 Progress of the project by comparing cost factors

Table 4.7

Various scenarios for project completion

Duration, weeks	Penalty cost, €	Total expenses, €	Present value of project, €	Compared to budget (837 500 €)	Profit from production, €
48	57 475	894 975	804 975	32 525	90 000
49	49 275	886 775	826 775	10 725	60 000
50	41 050	878 550	848 550	-11 050	30 000
51	-	862 132	862 132	-24 632	0
53	-	923 100	983 100	-145 600	-60 000
55	-	943 030	1 063 030	-225 530	-120 000

4.4. Suggestions and Recommendations

The analysis about the possibilities for production improvement in the plant of company X provides information about different options to be considered. Replacement of machinery can be performed in 4 week time and the production can be started after that. It improves the revenue and also helps to face the customer demand, but not in a long run. It is important to carry out this implementation with minimum disruption of the production system. According to the management team, it is planned to start production in the plant by the end of 51st week. But due to some uncertain issues in the execution of activities, the project went out of control and it has to be rectified in terms of monetary terms and customer demands. Whereas the company has the sufficient funds for construction of new plant and it can be initiated, without affecting the current production. In the case of new plant construction, the uncertain issues leading to extension of the project duration is rectified using project crashing. The crashing of 'Machinery Installation' activity from 14 weeks to 7 weeks helps the company to start production 3 weeks earlier than the planned schedule. It not only helps the company to gain profit, but also assisist in increasing the overall value of the project. From Table 4.2 and Table 4.7, the costs involved in replacement of machinery in existing system and construction of new plant.

Table 4.8

Scenarios involved in the project and their reviews.

Scenarios	Duration, weeks	Profit, €	Remarks
Replacement	4	28 000	Revenue for a week increases from 24 000 after replacement
New Plant	48	90 000	Crashing for 7 weeks, helps in reducing the expenses incurred for project completion.
	49	60 000	Increases overall profit from production, also reduces the project cost.
	50	30 000	Increases profit, but overruns budget of the project.
	51	-	Expected completion of project.

CONCLUSIONS

From the investigation about lean aspects and implementing those in the layout designing along with the analysis using project management tools serve as important elements in facility arrangement. These factors assist in deriving the following conclusions:

1. The study with respect to recent advancements about facility layout design decisions shows that backtracking and benchmarking time are prominent factors affecting the analyzed plant’s prodcution cycle.
2. Analysis of the plant‘s layout according to lean manufacturing principles shows that reduction of distance travelled and smooth flow of materials are the important aspects affecting the production. Development and designing of a facility layout by rectifying these issues enhance the efficiency of production methods with 25% increased rate determined from flow process chart.
3. It is found out that by the replacememnt of machinery in certain parts of the plant and their criticality helps in increasing the productivity at a elevated rate of 14.3%.
4. Progress of the new plant project when evaluated using Earned Value Management, in terms of cost and time for the activities assists in right planning of activities and their execution. It is determined that reducing duration of the critical activities affects revenue gaining process, which enable the appropriate development of the project and leading to an increased profit of 32 525 € by increasing the overall value of the project.

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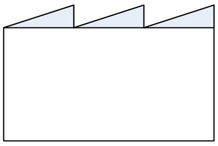
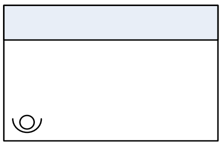
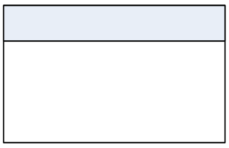
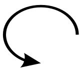
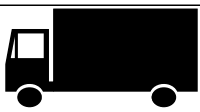
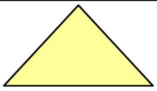
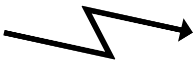
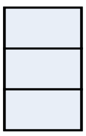
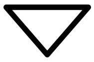
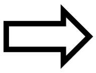
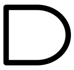
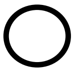
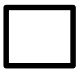
ANNEXURES

Annex 1. - Process symbols used in Value Stream Mapping [1]

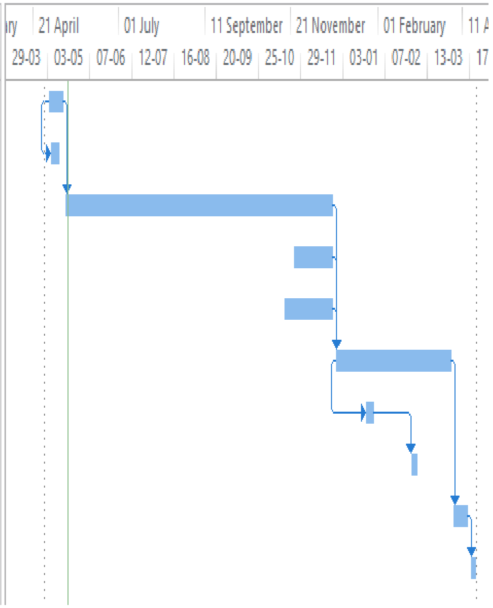
Icon	Name	Description
	Customer/ Supplier	Outside sources represents the supplier when placed in the upper-left, and the customer when placed in the upper-right.
	Process	Process box with operator in the top bar, and the department or function name in the center area.
	Production control	Process box; an area where value can be added to a product. The process or activity name is listed in the top bar, and the department or function name in the center area.
	Physical pull	Withdrawal of materials from a supermarket.
	Shipment truck	Shipments using external transport from a supplier. It may be labeled with the frequency of shipment.
	Inventory	Material queue of products that are not being processed. It represents storage of raw materials as well as finished goods.
	Push Arrow	A push of information or material from one process to another. A process produces something regardless of the downstream needs.
	Manual Information	Manual flow of information.
	Electronic Information	Electronic flow of information.
	Safety/Buffer Stock	Inventory stock reserved for specific circumstances.

Annex 2 - Flow process chart symbols

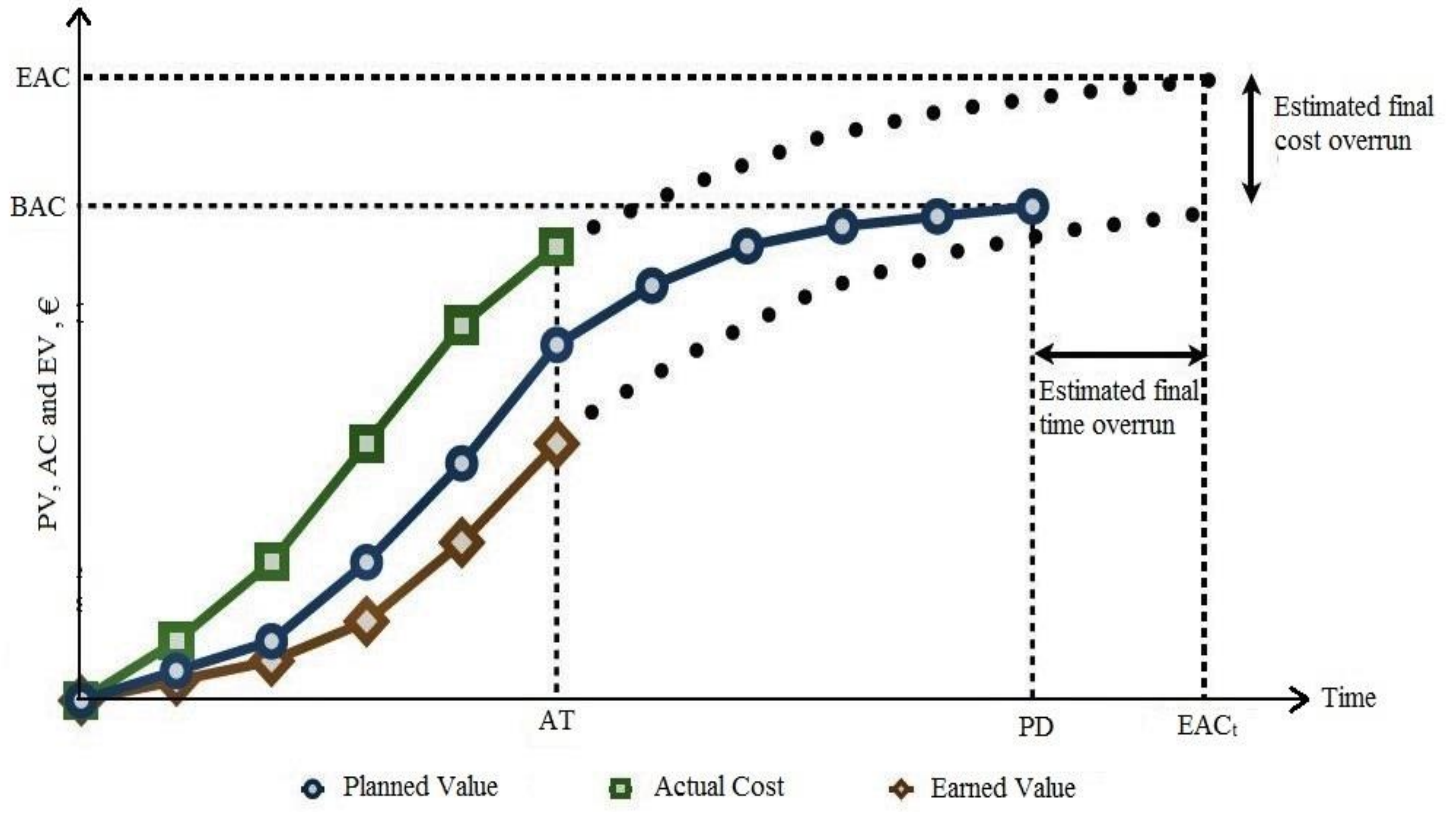
Symbols	Name	Description
	Preparation	Process preparation steps
	Transportation	Movement of people, materials, information and documents
	Delay	Organizational delay
	Operation	Main process steps
	Inspection	Inspection of quality and quantity
	Storage	Awaiting further action at a later date

Annex 3 - List of activities with their duration represented in Gantt chart

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Permits	2 wks	Mon 04-05-15	Fri 15-05-15	
2		3rd party approval	1 wk	Wed 06-05-15	Tue 12-05-1:	1SS+2 days
3		Construction	32 wks	Mon 18-05-15	Fri 25-12-15	1
4		Utilities	5 wks	Mon 23-11-15	Fri 25-12-15	
5		Machinery purchase	6 wks	Mon 16-11-15	Fri 25-12-15	
6		Machinery installatio	14 wks	Mon 28-12-15	Fri 01-04-16	3,4,5
7		Preliminary testing 1	1 wk	Fri 22-01-16	Fri 29-01-16	6SS+2 days
8		Preliminary testing 2	1 wk	Mon 29-02-16	Fri 04-03-16	7FS+3 wks
9		Final testing	2 wks	Mon 04-04-16	Fri 15-04-16	6
10		Production setup	1 wk	Mon 18-04-16	Fri 22-04-16	9



Annex 3 - List of activities with their duration represented in Gantt chart



Annex 5 - List of activities with crashing represented in Gantt chart

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Permits	2 wks	Mon 04-05-15	Fri 15-05-15	
2		3rd party approval	1 wk	Wed 06-05-15	Tue 12-05-15	1SS+2
3		Construction	32 wks	Mon 18-05-15	Fri 25-12-15	1
4		Utilities	5 wks	Mon 23-11-15	Fri 25-12-15	
5		Machinery purchase	6 wks	Mon 16-11-15	Fri 25-12-15	
6		Machinery installation	7 wks	Mon 28-12-15	Fri 12-02-16	3,4,5
7		Preliminary testing 1	1 wk	Wed 06-01-16	Wed 13-01-16	6SS+2
8		Preliminary testing 2	1 wk	Wed 27-01-16	Wed 03-02-16	7FS+3
9		Final testing	2 wks	Mon 15-02-16	Fri 26-02-16	6
10		Production setup	1 wk	Mon 29-02-16	Fri 04-03-16	9