Implementation of Automated Material Handling System in Assembly Shop

A Major Project thesis submitted

In partial fulfillment for the requirement of the degree of

Master of Engineering
In
Production & Industrial Engineering

By

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CERTIFICATE

This is to certify that the project entitled **"Implementation of Automated Material Handling System in Assembly Shop"** which is being submitted by **Ankit Agarwal,** is a bonafide record of student's own work carried by him under my guidance and supervision in partial fulfillment of requirement for the award of the Degree of Master of Engineering in Production & Industrial Engineering, Department of Mechanical Engineering, Delhi Technological University.

The matter embodied in this dissertation has not been submitted for the award of any other Degree to the best of my knowledge.

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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled **"Implementation of Automated Material Handling System in Assembly Shop"**, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Production Engineering, submitted in the Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering), New Delhi is an authentic record of my own work carried out under the supervision of Dr. A.K. Madan, Associate Professor of Mechanical Engineering Department, Delhi Technological University, Delhi.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

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List of Abbreviations and Symbols

A : Production station of Piston Rod

B : Production station of Piston.

C : Production station of Cylinder Barrel or Body.

D : Production station of Head End Cap.

E : Production station of Rod End Cap.

W : Welding Unit.

A1 : Assembly Unit

B1 : Inspection Unit.

AGV : Automated guided vehicle.

AHP : Analytical Hierarchy Process

DM : Decision Matrix

OTC Overhead Trolley Conveyor

TLC : In-floor Tow Line Conveyor

List of Figures

List of Tables

TABLE OF CONTENTS

ABSTRACT

In general, the term automation describes the employment of automatic devices as a substitute for human physical and mental labor. In an automated manufacturing process, functions once performed by humans are replaced by automatic devices that replicate those functions. Computers are widely used for process control. Automation arose out of a need for improved efficiency, higher output greater uniformity of product and a solution to worker's fatigue. Thus automation has simplified the work. Initially, robots were used to perform simple tasks too dangerous for humans. But nowadays highly advanced robots can accomplish a wide variety of jobs. They can transfer, manipulate and position any kind of work piece. Though, automation is most widespread in automobile industry due to its rapid growth, widely and fast changing demands, cash richness and frantic competition between the players, its use is rapidly increasing in non manufacturing applications as well. There appears no end to technological innovations in the foreseeable future and to the application of automation to new areas. The new frontiers for automation are no longer production but the service industries. Prominent among them are health care, financial services, retail and transportation.

The present work has been carried out to automate the material transfer system of a Hydraulic Cylinder assembly shop. The hydraulic cylinder assembly line under study is a assembly line in which different parts of hydraulic cylinder being transported to the assembly line. In present situation the manufactured parts are transported to the assembly line manually with the help of manually towed trolleys. This system has following drawbacks:-

- Requirement of considerable manpower.
- Delays in deliveries.
- Interference with other material handling equipments.
- Chances of damage to the products.
- Noise pollution.

To automate the present Material transfer system, following three alternatives are analyzed;

- AGV
- In floor towline conveyor.

- Overhead trolley conveyor.

In first alternative, an AGV is used to tow the loaded trolleys from production stations to the assembly line and taking the empty trolleys back to production stations. The system is cost effective, silent, results in manpower reduction, smooth material flow with very less chances of product damage. But at the same time, may interfere with other material handling equipments on the floor which will result in delays and chances of accidents also cannot be ruled out. It requires more maintenance and some manpower is still required for loading and unloading of parts.

In second alternative, an in floor towline conveyor is considered for material handling. In this system, trolleys are pulled by a motorized chain contained in a trench cut in the floor. Loaded/unloaded trolleys required to be transported, are latched in the chain with the help of a pin. On reaching the destination, they are de-latched and used. The system is simplest with low startup cost, requires less maintenance, reduced manpower, low noise levels, less chances of product damage. But in the absence of any smart safety system (unlike AGV), it has more chances of meeting accidents and traffic on shop floor.

The third alternative is of overhead trolley conveyor which not at all uses floor area. In this system, a power driven chain located overhead forms closed loop. To this chain are attached equally spaced carriers. The parts are loaded on these carriers at the production stations and unloaded at the assembly station. These carriers travel overhead in the assembly line thus ruling out even the minutest chance of its interference with other material handling equipments running on the assembly shop floor. The system gives guaranteed no accidents, timely delivery and smooth material flow, elimination of man power, silent operation low maintenance, and no damage to the product. But the system demands huge initial investments and longer installation time.

These three alternatives are then evaluated by AHP technique. The overall rating of each alternative is then calculated and the one with highest rating is selected. In present case the selected alternative is overhead trolley conveyor.

CHAPTER 1
INTRODUCTION

Manufacturing has changed completely over the time of the last 20 years and these developments are sure to take place continuously. The evolution of new manufacturing methods incite by severe competition, will result in production of new products and processes. New decision-making procedure and labor practices, institution structures, will also evolve as complements to new products and processes. Every person and its teams will know about the new skills due to advanced network-based learning, computer-based conversations beyond extended program, Enhanced conversations between people and machines, and advancement in the transaction and related infrastructure.

Automation means "to act by itself". An Automated Material handling system consists of a driverless vehicle which can perform material handling operations such as loading, transporting and unloading. It includes numerous vehicles operating in a workshop, generally instructed by a computer. An automated process is a self dictated process which is designed to have extended capacity of performing certain tasks previously performed by humans and to manage series of operations without involvement of humans. Automation is a step beyond mechanization. Mechanization reduces the need for physical effort whereas automation reduces need of human sensory and mental requirement. The computer takes the decisions regarding dispatching and the routing of automated material handling system. This technology helps in reducing operating costs of material handling and also the reliability of material handling systems increases. However, the cost associated with purchasing and installation is high, therefore the design of an automated material handling system should be made carefully.

"*A material handling system can be simply defined as an integrated system involving activities such as handling, storing and control of materials*".

The word material has a wide meaning. It includes all types of raw materials, work in process inventory, sub-assemblies and finished assemblies. The main aim of employing an automated material handling system is to assure that the right amount of material is securely delivered at the right time to the required destination and at a minimum cost. Material handling is an important part of any manufacturing institution. The cost of material handling can constitute 30% to 70% of the total manufacturing cost. Also the equipment is prone to accidents. Thus it is important that the material handling system is designed properly from efficiency as well as safety point of view.

The most used part in modern automation is industrial robotics. It has many advantages such as repeatability, higher quality control, higher efficiency, increased productivity and labor reduction. Some drawbacks are large capital requirements, highly decreased flexibility and increment in dependence on maintenance and repair. For example Japan scrapped many of its industrial robots when they found that these are incapable of adaptation to changed production requirements (7).

Presently, for manufacturing institution, the scope of automation has transferred from increasing productivity and reducing costs to wider issues, like increasing quality and flexibility in the manufacturing operations. For example, automobile pistons used to be installed into engines manually. When it was done through automated machine, the rate of error reduced from 1.5% to 0.0001%. Therefore, the manufacturers are increasingly demanding the capability to easily switch from manufacturing product ‘X’ to product ‘Y’ without any need of completely restructuring the production lines.

1.2 Problem Statement

The present work concentrates on automation of material handling in a hydraulic cylinder company. The hydraulic cylinder assembly line under study is a assembly line in which different parts of hydraulic cylinder being transported to the assembly line. In present situation the manufactured parts are transported to the assembly line manually with the help of manually towed trolleys. The parts to be transported to Assembly station are:-

1. Piston
2. Piston Rod
3. Cylinder Barrel or Body

4. Head End Cap
5. Rod End Cap

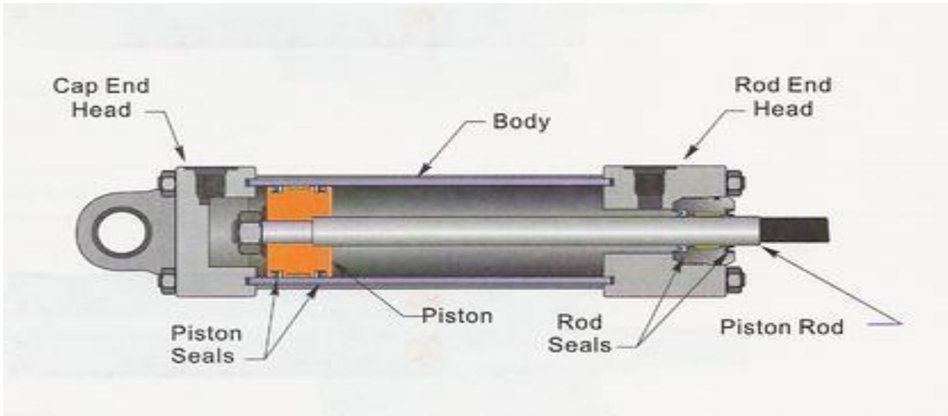

Figure 1.1 Main Parts of Hydraulic Cylinder (5)

This method even though is the most obvious and simplest one but it has many disadvantages:

- It keeps the gangway heavily congested.
- Excessive movement of trolleys creates lot of noise.
- Trolleys require regular maintenance.
- Requires large manpower.
- Chances of damage to the parts are more due to mishandling.

Present work is aimed to automate the transfer of parts to the assembly line and to eliminate the above mentioned disadvantages. Different alternatives will be considered keeping in view the present constraints. These alternatives will then be analyzed by laying down certain criterion which may affect the decision.

1.3 Objective

Aim of the project is to design and analyze the automation of the part transfer system of a hydraulic cylinder assembly shop. The objectives of the project are;

- To study and analyze different alternatives available to automate the transportation of parts to the assembly line.

- To check the feasibility of each alternative in the light of practical constraints present on the line and select the most appropriate one.
- To eliminate the requirement of manpower for transportation of parts.
- To decongest the gangway.
- To reduce the noise pollution caused by the movement of the trolleys.

1.4 Scope of the project

- To fabricate and install an automated parts transfer system in the assembly shop of a hydraulic cylinder manufacturing company.
- To incorporate necessary measures in the system to enable it meet the flexibility of demand.
- To streamline the production of hydraulic cylinder and synchronize its production rate. This will eliminate the chances of chaos and confusion.

1.5 Methodology

- The present system of manual parts transfer was carefully studied and analyzed.
- The need for automation was ascertained.
- Various methods of parts transfer were investigated in the light of constraints like space, technical feasibility and movement of other material handling equipment.
- AHP analysis was performed.
- The method which gave no risk of accidents with other material handling equipments apart from the other benefits was finally selected (highest final ranking in AHP analysis).

CHAPTER 2

LITERATURE REVIEW

One of the ancient examples of automation in industries was introduction of mechanized weaving machines in the 1700s. The output of weavers was increased and they saved many hours of making and often reworking designs. In 1801, Joseph Jacquard evolved a programmable weaving loom completely operated by punched cards. This invention was revolutionary in the area of textile industry. But at the turn of the century, a lot of the proprietary content has been melted away through the rapid and widespread growth of information technology in the global arena. Automation knowledge that produces good quality products at low cost has now become a commodity.

2.1 Automation

Automation is the technology by which an operation or process is carried out without intervention of human assistance. It is achieved using a program of instructions along with a control system that executes the instructions. To automate an operation or process, power is required (to drive the process itself and to operate the program) and a control system **(3).** Automation is suitable where people have to carry out dull, heavy, unpleasant or harmful routine tasks. It also results in improvement in the efficiency, increasing output rate, and less worker fatigue. Therefore automation has simplified the work. Initially robots were used to perform tasks that were too dangerous for humans. However Modern robot can transfer, manipulates and position any kind of work pieces, whether it is red hot iron bar or sharp metal pieces. Examples of automated manufacturing systems **(3):**

- Automated machine tools that process parts.
- Transfer lines that perform a series of machining operations.
- Automated assembly systems.
- Use of industrial robots in manufacturing systems that perform processing or assembly operations.
- Automated material handling systems to integrate manufacturing operations.

Apart from this, automation can also be used to describe non manufacturing systems, in which programmed gadgets can operate without human intervention. For example,

- In the telecommunication industry, an automatic switching exchange is used. Dialing, transmission and billing are done automatically.
- In the field of aviation, an aircraft can be set to ‘autopilot’ mode.
- Another good example is in the military. Ballistic missiles are guided till the very stage when they can be allowed to fall as free projectiles. The most advanced cruise missiles can detect and avoid obstacles in their paths **(13).**

2.2 Levels of Automation

The automation of work processes can be divided into five levels:-

- **Device level:-** This is the lowest level of automation. It includes the actuators, sensors and other hardware components that comprise the machine level. The devices are combined into the individual control loops of the machine.

- **Machine level:-** Hardware at the device level is assembled into individual machines. For example, industrial robots, powered conveyors, automated guided vehicles etc. control functions at this level include performing the sequence of steps in the program of instructions in the correct order and making sure that each step is properly executed.

- **System level:-** Automation at this level operates under instructions from the plant level. A manufacturing system is a group of machines or workstations connected and supported by a material handling system, computer and other appropriate equipment. Production lines are included in this level. Functions included are part dispatching and machine loading, coordination amongst the machines and material handling system.

- **Plant level:-** At this level the system receives the instructions from the corporate information system and translates them into operational plans for production. Functions included are, order processing, process planning, inventory control, purchasing, material requirement planning, shop floor control and quality control.

- **Enterprise level:-** This is the highest level, consisting of the corporate information system. It is concerned with all of the functions necessary to manage the company. Marketing and sales, accounting, design, research, aggregate planning and master production schedule (3).

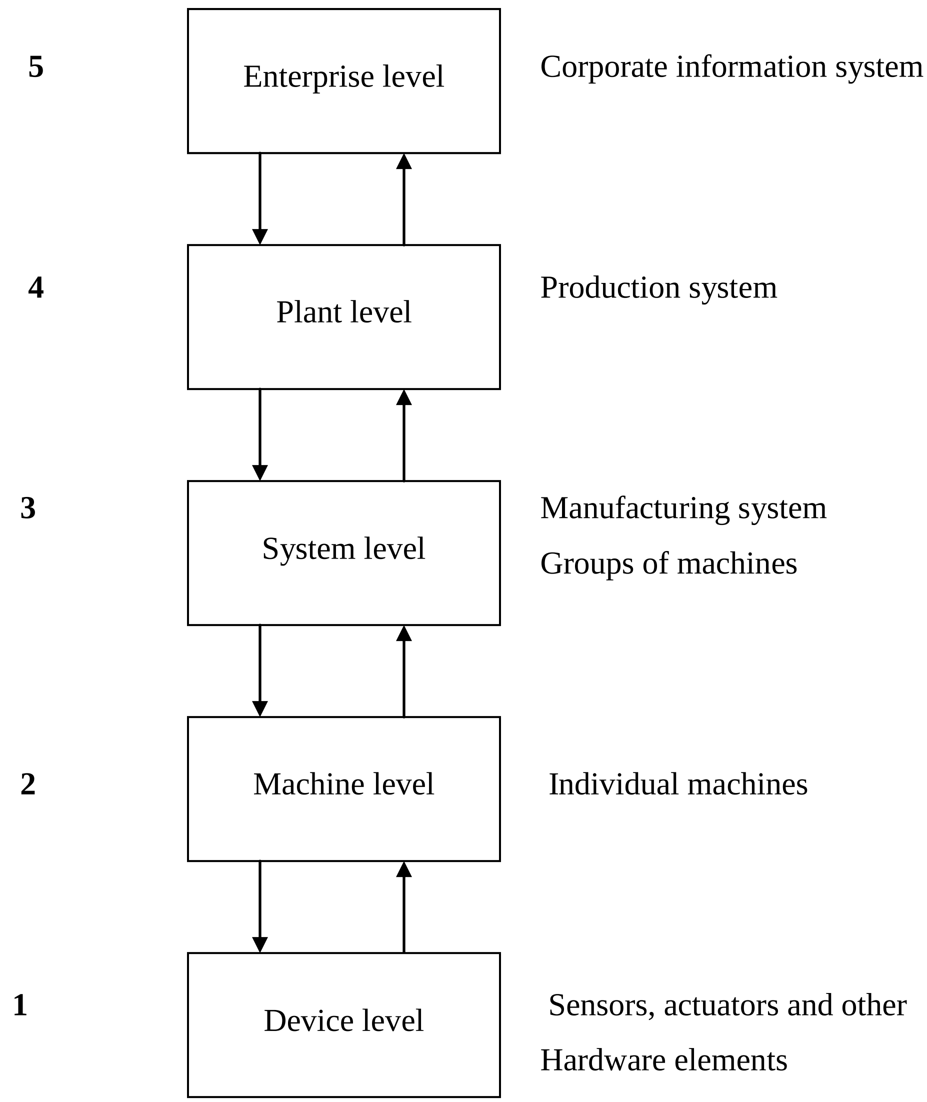

Figure 2.1 Five Levels of Automation and **Control (3).**

2.3 Elements of an Automated System

An automated system typically consists of three basic elements:

- **Power:** an automated system is used to operate some process and power is required to drive the process as well as the controls. The principle source of power in automated systems is electrical energy. Use of alternative power sources is rare in automated systems. Even when they are used, they are used to drive the process only where as electrical energy is used for the controls that automate the operation. For example, in casting or heat treatment, the furnace may be heated by fossil fuels, but the control system to regulate temperature and time cycle is electrical.

- **Program of instruction:** The actions performed by an automated process are defined by a program of instructions. Each part or product style made in the operation involves one or more processing steps that are unique to that style. These processing steps are performed during a work cycle. a new part is completed during each work cycle . The particular processing steps for the work cycle are specified in a work cycle program.

- **Control system:** The control system of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function, which for our purpose is to carry out some manufacturing process.

The controls in an automated system can be either **closed loop** or **open loop.** A closed loop control system also known as feedback control system, is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output in agreement with the input. A closed loop system is shown in fig. 2.2 and is consisting of six basic elements; 1) input parameter, 2) process, 3) output variable, 4) feedback sensor, 5) controller and 6) actuator. The input parameter often referred to as set point, represents the desired value of the output. In a home temperature control system, the set point is the desired thermostat setting. The process is the operation or the function being controlled. Output variable is the one which is being controlled in the loop and usually is some process variable like temperature, force or flow rate etc. a sensor is used to measure the output variable and close the loop between input and output. Sensors perform the feedback function in a closed loop control system. The controller compares the output with the input and makes the required adjustments in the process to reduce the difference between them. The adjustment is accomplished using one or more actuators, which are the hardware devices which physically carry out the control actions such as an electric motor, a flow control valve (3) or pneumatic positioner etc

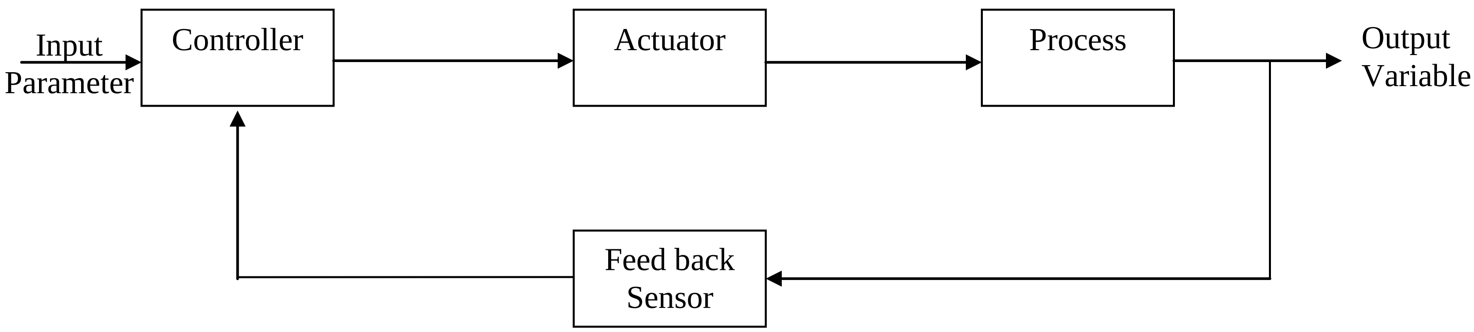

Figure 2.2 Closed Loop System (3)

In contrast to the closed loop control system, an open loop control system operates without a feedback loop as shown in fig. 2.3 in this case; the controls operate without measuring the output variable, so no comparison is made between the actual value of the output and the desired input parameter. The controller relies on the accurate model of the effect of its actuator on the process variable. With an open loop system there is always a risk that the actuator will not have the intended effect on the process. Its advantage is that it is generally simple and less expensive as compared to a closed loop system. Open loop systems are generally used under following conditions;

- The actions performed by the control system are simple.
- The actuating function is very reliable.
- Any reaction forces acting opposite to the actuation are small enough to have no effect on the actuation (3).

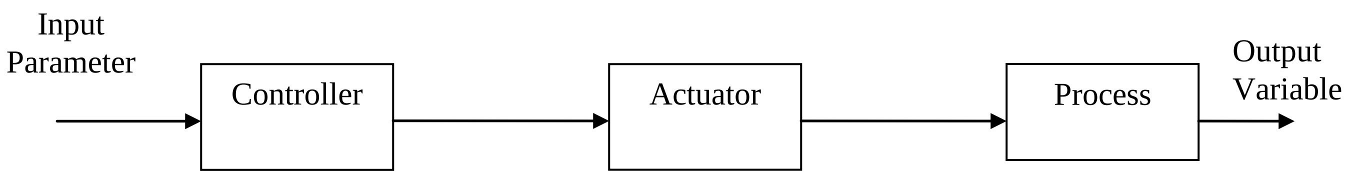

Figure 2.3 Open Loop System (3)

2.4 Reasons of Automation

Some of the reasons used to justify automation are as follows

- To increase labor productivity. Automating a manufacturing system usually increases production rates. This means greater output per hour of labor input
- To reduce labor cost. Ever increasing labor cost has been and continues to be the trend in the industry. This justifies the replacement of human labor by the high capital requiring machines.
- To improve worker safety. Automation of a given manufacturing process has transferred the operator from its active involvement in the process to a supervisory role making the work safer. The safety and well being of the worker has become a matter of concern with the enactment of OSHA (Occupational Safety and Health Act). This has further strengthened the path for widespread application of automation.
- To improve product quality. An automated process performs the operation with greater uniformity and conformity to quality specifications. Reduction of fraction defect rate is one of the chief benefits of automation.
- To reduce the effects of labor shortage. Shortage of labor in many areas has stimulated the development of automated operations as a substitute for labor.
- To eliminate routine tasks. There is a social value in automating operations that are routine, boring and fatiguing. Automating such tasks serves a purpose of improving the general level of working conditions.
- To perform operations that cannot be done manually. There are operations that require precision, complexity and miniaturization which cannot be achieved manually. For example, IC fabrication, Rapid prototyping etc (3).

2.5 Types of Automation

Automation of manufacturing systems can be classified into three types;

1) Fixed automation.
2) Programmable automation
3) Flexible automation

2.5.1 Fixed automation

It is a system in which the sequence of processing operations is fixed by the equipment configuration. Each of the operation in the sequence is usually simple, involving perhaps a plain linear or rotational motion or an uncomplicated combination of the two. Typical features of fixed automation are;

- High initial investment for custom engineered equipment.
- High production rates.
- Relatively inflexible in accommodating product variety.

Therefore this system is suitable for mass production applications where high initial cost of the equipment can be spread over a very large number of units, thus making the unit `cost attractive. Example of this type of system is automated assembly machines (3). Operations manager favor fixed automation when demand volumes are high, product designs are stable and product life cycles are long. These two conditions compensate for the process's two primary drawbacks: large initial investment cost and relative inflexibility. Because fixed automation is designed around a particular product, changing equipment to accommodate new products is difficult and costly. However, fixed automation maximizes efficiency and yields the lowest variable cost per unit (18).

2.5.2 Programmable automation

In this system the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that they can be read and interpreted by the system. New programs can be prepared and entered into the equipment to produce new products. Some features of programmable automation are;

- High investment in general purpose equipment.
- Lower production rates than fixed automation.
- Flexibility to deal with variations and changes in product configuration.
- Most suitable for batch production.

To produce each new batch of products, the system must be reprogrammed with the set of machine instructions that correspond to the new product. The physical setup of the machine must also be changed: tools must be loaded, fixtures must be attached to the machine table and the required machine settings must be entered. This changeover procedure takes time. Consequently the typical cycle for a given product includes a period during which set up and reprogramming takes place followed by a period in which the batch is produced. Examples of programmable automation include numerically controlled machine tools, industrial robots and programmable logic controllers (3).

2.5.3 Flexible automation

It is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to another. There is no lost production time while reprogramming the system and altering the physical setup like tooling, fixtures, machine settings etc. consequently, the system can produce various combinations of parts instead of requiring that they may be produced in batches. What makes flexible automation system possible is that the differences between the parts produced are not significant. It is a case of soft variety, so that the amount of changeover required between different types is minimal. Some of the features of flexible automation are;

- High investment for a custom engineered system.
- Continuous production of variable mixtures of products.
- Medium production rates.
- Flexibility to deal with product design variations (3).

As industry places growing emphasis on agility, the need for systems with flexibility at scales not previously possible is becoming critical. Automakers, for example, traditionally produced only one car on a particular assembly line, and that model usually would be made continuously for at least several years, so an inflexible system did not pose any problem. Nowadays, however, competition is dictating that automakers manufacture several models on one line, so more versatile equipment is needed. Flexible automation is an operational response to this need. “Manufacturing is shifting from attempting to exploit economies of scale to exploiting economies of scope”. Said Michael Higgins, marketing director of ABB Flexible Automation Inc. “As a result, the ability to adapt to changing market requirements, product designs, and technological developments is becoming a key factor in the competitiveness of an organization. Viewed from the shop floor, this translates into dealing efficiently with frequent changeovers of parts and small production batches.”(25).

Traditional automation systems were extremely limited in scope. Each would do a single task very well over and over again but had little or no ability to adapt to any other task. For example, when an automobile manufacturer needed a robot welder on an assembly line to work on a different part, technicians and engineers had to make significant hardware and software changes. Besides being labor intensive, such changeovers typically required extensive downtime (25).

Whereas traditional automation systems could only handle one part, existing technology has made it feasible for them to handle batches of the same part. The systems under development however, will be so versatile that they can work effectively even if every part is different. Genesis Systems Inc. in Davenport, Iowa, is developing a system that identifies parts in real time using a bar code or magnetic tag. As a part moves down the line, vision devices automatically identify the tag. Contained in the system is a database that specifies the proper control program for a part with that tag. By the time this part makes it to the tool, that tool is ready to perform the appropriate operations on it.

A part can not be positioned exactly the same way every time, however, so the vision system may not always be able to identify it. Such part identification systems have improved enormously in recent years, and many can handle position deviations. Furthermore the software can be configured to adjust the program slightly to account for minor deviations in position (25).

Eventually, operator intervention will not be needed in the reprogramming process. Information about a particular part won't even need to be stored in the database, because all the information about a particular part will be taken solely from the vision system. The system will look at the part and will write the control program on the spot. Theoretically, the system can then work on any part, as long as the part's dimensions are within the range that the hardware can handle (25).

The area in which flexible automation is most pervasive is the automotive industry. This industry not only has a great need for automation systems but also has the budget to afford such expensive and elaborate systems. However, as the system prices decrease steadily, flexible automation is beginning to penetrate virtually every sector of manufacturing. Eventually anyone on a factory floor will be able to use a flexible automation system just like using any other tool. A significant benefit of this is that the companies will no longer need to worry about a key employee retiring or changing jobs. The knowledge will be retained in the software and accessible to any authorized user (25). Figure 2.4 shows the applicability of different types of automation system with respect to the production volume and product variability.

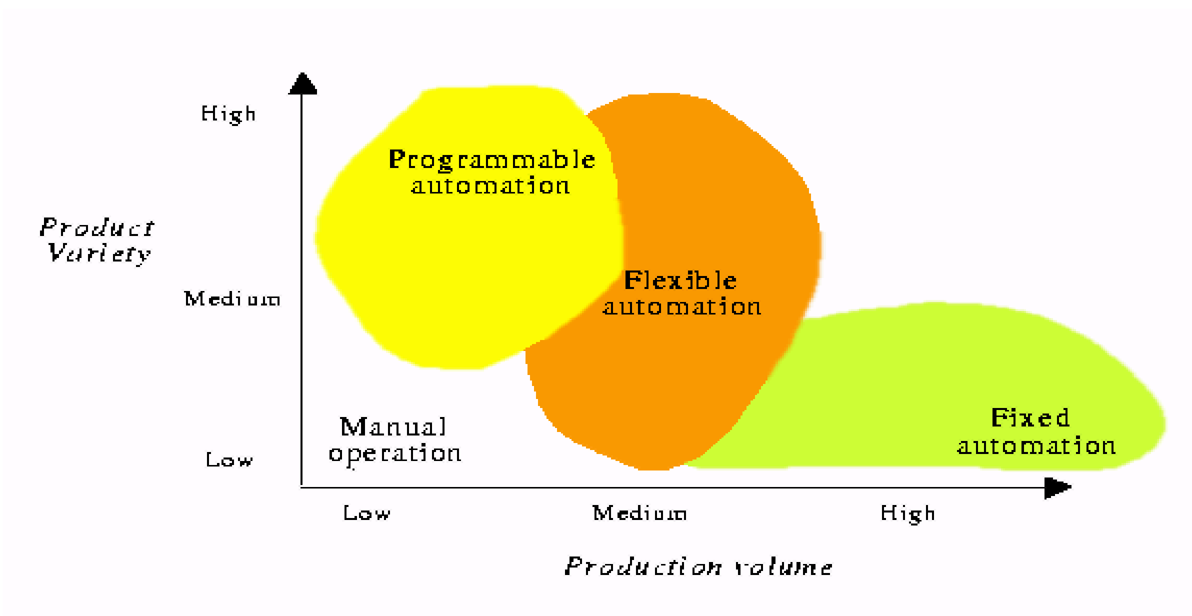

Figure2.4 Product Volume and Product Variety (28).

A relationship is shown between fixed and flexible automation in fig. 2.5. Capital intensity is the amount of investment on automation equipment. Resource flexibility is the ease with which the equipment and the employees can handle a wide variety of resources.

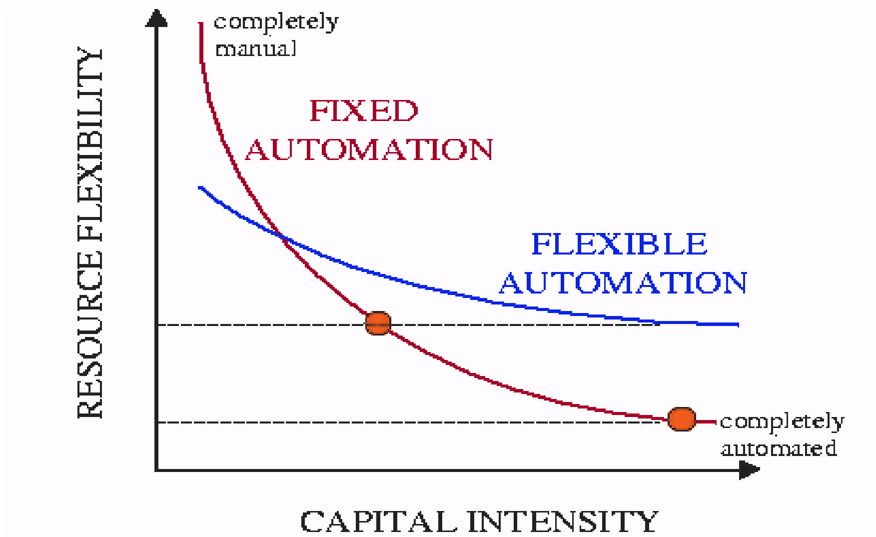

Figure 2.5 Flexible V/s Fixed Automation (28).

2.6 Special Automation Functions

In addition to provide its intended benefits. Automated systems should be capable of providing certain special functions which are not application specific. These are;

1). Safety monitoring

2). Maintenance and repair diagnostics.

3). Error detection and recovery.

2.6.1 Safety monitoring

One of the significant reasons for automating a manufacturing process is to remove operator from a hazardous working environment. It is often installed to perform a potentially dangerous operation that would otherwise be accomplished by a human operator. There are two reasons for providing an automated system with a safety monitoring facility: (1) To protect human workers in the vicinity of the system and (2) To protect the equipment associated with the system. Safety monitoring in an automated system involves the use of sensors to track the system's operations and identify conditions and events that are unsafe. The system is programmed to respond to unsafe conditions in one or more of the following ways.

- Complete stoppage of the automated system.
- Sounding an alarm.
- Reducing the operating speed of the system.

Following are some of the sensors used for the purpose of safety monitoring.

- Limit switches to detect the proper positioning of the part.
- Photoelectric sensors to check the presence or absence of the part.
- Temperature sensors to detect the temperature of the coolant in an engine that gives an indication of the amount of engine heating.
- Smoke sensors to detect fire hazards.
- Pressure sensitive floor pads to detect the presence of human intruder inside the work cell.

2.6.2 Maintenance and repair diagnostics

It refers to the capabilities of an automated system to assist in the identification of the stage where system requires maintenance. Following are the three modes of maintenance and repair diagnostics.

- **Status monitoring.** Here the diagnostic subsystem monitors and records the status of key sensors and parameters of the system during normal operation. When desired, the system can display any of these values and provide an interpretation of current system status. Status monitoring serves two important functions (1) providing information for diagnosing a current failure and (2) providing data to predict a future failure. First, when failure of the equipment has occurred, it is usually difficult for the repair team to determine the reason for failure and what steps should be taken for repairs. It is often helpful to reconstruct the events leading up to the failure. The computer is programmed to monitor and record the variables and to draw logical inferences from their values about the reason for the malfunction or failure. This diagnosis helps the repair team to make the necessary repairs and replace the appropriate components. This is especially helpful in electronic repairs where it is often difficult to determine on the basis of visual inspection which components have failed.

The second function of status monitoring is to identify signs of an impending failure, so that the affected components can be replaced before failure actually causes the system to go down. These parts replacement can be done during the night shift or other time when the process is not operating, with the result that the system experiences no loss of regular operation.

- **Failure diagnostics.** It invokes when a malfunction or a failure takes place**.** Its purpose is to interpret the current values of the monitored variables and to analyze the recorded values preceding the failure so that the cause of the failure can be identified.
- **Recommendation of repair procedure.** Here the subsystem provides a recommended procedure to the repair team as to the steps that should be taken to effect repairs.

2.6.3 Error detection and recovery

The error detection step uses the automated system's available sensor systems to determine when a deviation or malfunction has occurred, correctly interpret the sensor signals and classify the error. Design of the error detection subsystem must begin with a classification of the possible errors that can occur during the system's operation. The errors in a manufacturing process tend to be very application specific and must be anticipated correctly in advance in order to select the sensors that will enable their detection.

The two main design problems in error detection are, (1) to anticipate all of the possible errors that can occur in a given process and (2) to specify the appropriate sensor systems and associated interpretive software so that the system is capable of recognizing each error. Solving the first problem requires a systematic evaluation of the possibilities of error occurrence. If the error has not been anticipated, then the error detection subsystem can not correctly detect and identify it.

Error Recovery. It is concerned with applying the necessary corrective action to overcome the error and bring the system back to normal operation. The problem of designing an error recovery system focuses on devising appropriate strategies and procedures that will either correct or compensate for the variety of errors that can occur in the process. Generally, a specific recovery strategy and procedure must be designed for each different error. Following are the different strategies adopted for the purpose;

- **Make adjustments at the end of the current work cycle.** When the current work cycle is completed, the part program branches to a corrective action subroutine specifically designed for the error detected, executes the subroutine, and then returns to the work cycle program. This action reflects a low level of urgency and is most commonly associated with random errors in the process.
- **Make adjustments during the current cycle.** In this case the action to correct or compensate for the detected error is initiated as soon as the error is detected. However, it must be capable to accomplish the designated corrective action while the work cycle is still being executed. This kind of action reflects a higher level of urgency.
- **Stop the process to invoke the corrective action.** In this case the deviation or malfunction requires that the execution of the work cycle be suspended during corrective action. It is assumed that the system is capable of automatically recovering from the error without human assistance. At the end of the corrective action, the regular work cycle is resumed.
- **Stop the process and call for help.** In this case the error requiring stoppage of the process cannot be resolved through automated recovery procedures. This situation arises when the error cannot be classified into the predefined lists of errors. Here human assistance is required to correct the problem.

Error detection and recovery requires an interrupt system. When an error in the process is detected and identified, an interrupt in the current program execution is invoked to branch to the appropriate recovery subroutine. This is done either at the end of the current working cycle or immediately. At the completion of the recovery procedure, program execution reverts back to the normal operation (3).

2.7 Mechatronics

Mechatronics is the synergistic integration of mechanical engineering, with electronics and intelligent computer control in the design and manufacture of products and processes. from this definition it is clear that mechatronics is not itself a separate discipline within the overall spectrum of engineering but rather it represents an integration across a number of different fields within engineering as shown in fig.2.6. It is the application of latest techniques in precision mechanical engineering, control theory, computer science and electronics to design and development of products and systems. The word mechatronics was first coined by a senior engineer of a Japanese company Yaskawa in 1969, as a combination of “mecha” of mechanisms and “tronics” of electronics and the company was granted the trademark rights on this word in 1971, though it was given up later (6).

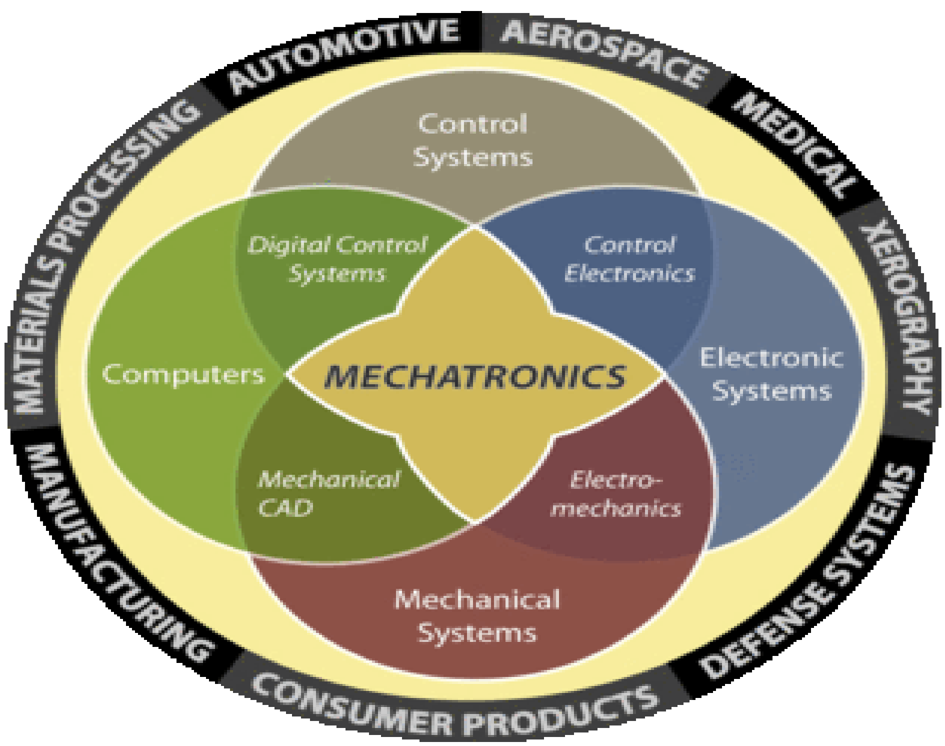

Figure.2.6 Integration of Various Disciplines (27).

In the first stage in 1970’s the technologies used in mechatronic systems developed rather independently of each other and individually. During the second stage, in eighties, a synergistic integration of different technologies started taking place, the notable example being in optoelectronics (integration of optics and electronics). The concept of hardware/software co-design also started in these years. The third stage starts with the early nineties with increased use of computational intelligence in mechatronic products and systems, possibility of miniaturization of components in the form of micro actuators and micro sensors and systems, possibility of miniaturization of components in the form of micro actuators and micro sensors (6).

2.7.1 Mechatronics in manufacturing

Manufacturing is a vital part of any industrialized economy. It is the main element of development resulting in stiff global competition. More recently, manufacturing has come to be understood as a system, with all parts of the system interacting with each other. Computers and other electronic devices have been used extensively for the control of the production processes and equipment with the aid of CNC/DNC. A better understanding of processes and the development of appropriate transducers allow control in adaptive mode, responding to changes in process conditions. These interfaced systems termed as **mechatronics**, provide the solution to present day manufacturing situations of small/medium batch production of variety of components subject to frequent changes in design often needing shorter lead-time to meet fluctuating market demands (10).

2.8 Automation in Industry

Industries use automation in various amounts depending upon the type of application and financial standing. Many industries are highly automated whereas others use automation only in some part of their operation. In telephone industry, dialing, transmission and billing are all done automatically. Railroads too are controlled by automatic signaling devices, which have sensors that detect cars passing a particular point. In this way the movement and location of the trains can be monitored.

Not all the industries require same amount of automation. Agriculture, sales, and some service industries difficult to automate. The agriculture industry may become more mechanized, especially in processing and packaging the food. However, in many service industries such supermarkets, for example, a checkout counter may be automated but the shelves or supply bins must still be stocked by hands. Similarly, doctors may consult a computer to assist in diagnosis, but they must make the final decision and prescribe accordingly (21).

The oil and chemical industries have developed the continuous flow method of production, owing to the nature of raw material used and the final product. In a refinery, crude oil enters at a point and flows continuously through pipes in cracking, distillation and reaction devices as it is being processed into gasoline and fuel oil etc. an array of automatically controlled devices governed by microprocessor and coordinated by a central computer is used to control valves, heaters and other devices, thereby regulating both the flow and reaction rates (21).

In steel, beverage and canned food industry where production takes place in batches a different set up of automation is used. For example, a steel furnace is charged with the ingredients brought up to heat and a batch of steel ingots is produced. In this phase very little automation is evident. These ingots, however then be processed automatically into sheets or other structural forms by being squeezed through a series of rollers until the desired shape is achieved (21).

The automobile and other consumer product industries use the mass production techniques of step by step manufacture and assembly. This technique approximates the continuous flow process but involves transfer machines; thus from the viewpoint of the auto industry, transfer machines are essential to the definition of automation. Each of these industries uses automated machines in all or part of its manufacturing process. As a result each industry has a concept of automation that fits its particular production needs. More examples can be found in almost every phase of commerce. The widespread use of automation and its influence on daily life provides the basis for the concern expressed by many about the influence of automation on society and the individual (21).

2.8.1 Social effects of automation

Automation has made a major contribution towards increase in both free time and real wages enjoyed by most workers in industrialized nations. It has greatly increased production and lowered costs, thereby making automobiles, refrigerators, televisions telephones and other goods available to more people. Not all the results of automation have been positive. Some argue that automation has caused overproduction and waste, and that it has created alienation among the workers and that it generates unemployment. Of these issues, the relationship between automation and unemployment has received the most attention. Some economists argue that automation has little if any effect on unemployment-that workers are displaced rather than dismissed and are usually employed in another position in the same company or in the same position at another company that has not automated (21).

Some claim that automation generates more jobs than it displaces. They point out that although some laborers may become unemployed; the industry producing the automated machinery generates more jobs than were eliminated. The computer industry is often cited to illustrate this claim. Business executives would agree that although the computer has replaced many workers, the industry itself has generated more jobs in the manufacturing, sales and maintenance of computers than the device has eliminated (21).

These social issues that are derived from automation will continue to confront society. There appears to be no end to the technological innovations in the foreseeable future and to the application of automation in new areas. The demands of future will require manufacturing systems, which could need to be engineered to provide for flexibility without intervention of human element. While elements of the system could be readily obtained, the systems will have to be designed with appropriate sensors and other interfacing devices, reprogrammable systems with common database so that real time control can provide the required quality of specific varieties in quantities in specific time frame in the most competitive manner. The new frontier for automation is no longer production only, but the service industries. Prominent among them are health care financial services, telecommunication, retail and transportation (10, 15).

CHAPTER 3

ALTERNATIVES TO IMPROVE MATERIAL FLOW IN WORK SHOP

Alternative - 1

3.1 Automated guided vehicle (AGV)

An automated guided vehicle is essentially a driverless industrial truck. It is steerable, driven by electric motors using storage batteries, and it follows a predefined path along an aisle (fig 3.1). AGV may be designed to operate as a tractor, pulling one or more carts, or may be unit load carrier (22). AGV's are programmed to drive to specific points and perform designated functions. Since their introduction in1955, AGV's have found they are becoming increasingly popular worldwide in applications that require repetitive actions over a distance. They are able to navigate a guide path network which is flexible and easy to program. AGV can be an integral part of a conventional warehouse characterized by long distances and "same path" movement. It offers an alternative to fixed-path conveyors and overhead materials handling equipment for this type of facility (23). A distinguishing feature of an AGV, compared to rail guided vehicle systems and most conveyor systems, is that the pathways are unobtrusive. An AGV is appropriate where different materials are moved from various load points to various unload points (3).

Figure 3.1 Automated guided vehicle.

3.1.1 AGVs as a part of FMS

AGV usage is growing. One reason is that as manufacturers strive to become more competitive, they are adopting FMS. These systems integrate automatic material handling systems, robots, NC machine tools and automated inspection stations. FMS are more responsive to changes in production requirements. These systems yield high product quality and increased productivity. FMS can benefit from the linkage with AGVs. While robots are often highlighted as saving billions in production costs, at some plants- automated material handling systems have made the biggest inroads (12).

3.1.2 Steering control

To help an AGV navigate, differential speed control system is most commonly used. In this method, there are two sets of wheels being driven by different drives (motors). These drives are driven at different speeds in order to turn and at same speed in order to move straight. The AGV turns in a similar fashion to a tank. This method of steering is good in the sense that it is easy to maneuver in small spaces. More often than not, this system is seen on AGV that is used to transport and turn in tight spaces or when the AGV is working near machines (12).

3.1.3 Navigation

It refers to following a predefined path and stopping or slowing down as per the requirements. One of the methods of navigation is ***magnetic tape mode*** where a magnetic tape is laid on the surface of the floor. Not only does it provide the path for the AGV to follow but also select desired path. A magnetic tape is a thin plastic film containing small magnetic particles whose pole orientations can be used to encode bits of data into the tape. The different combinations of these poles tell the AGV to change lane and also speed up slow down and stop (3, 12).

3.1.4 Safety features of AGV:

- The safety of humans located along the pathway is an important objective in AGV design. An inherent safety feature of AGV is that its traveling speed is slower than the normal walking pace of a human. This minimizes the risk of overtaking a human walking along the guide path in front of the vehicle.

- AGVs are usually provided with automatic stopping of the vehicle if it strays more than 50-150mm from the guide path. This distance is referred to as vehicle's acquisition distance.

- An obstacle detection sensor is located on each vehicle. The vehicles are programmed to stop or slow down when an obstacle is sensed ahead of the vehicle. The reason for slowing down is that the sensed obstacle may be located off to the side of the vehicle path or directly ahead but beyond a turn in the guide path or the obstacle may be a person who will move out of the way as the AGV approaches. In any of these cases the vehicle is permitted to proceed at a slower (safer) speed until it has passed the obstacle. The disadvantage of programming a vehicle to stop when it encounters an obstacle is that this delays the delivery and degrades system's performance.

- A safety device included on virtually all the commercial AGVs is a safety bumper. It surrounds the front of the vehicle and protrudes by a distance of 300mm or more. When the bumper makes contact with an object, the vehicle is programmed to brake immediately.

- Other safety devices are warning lights (blinking or rotating) and or warning bells which alert humans that the vehicle is present (3).

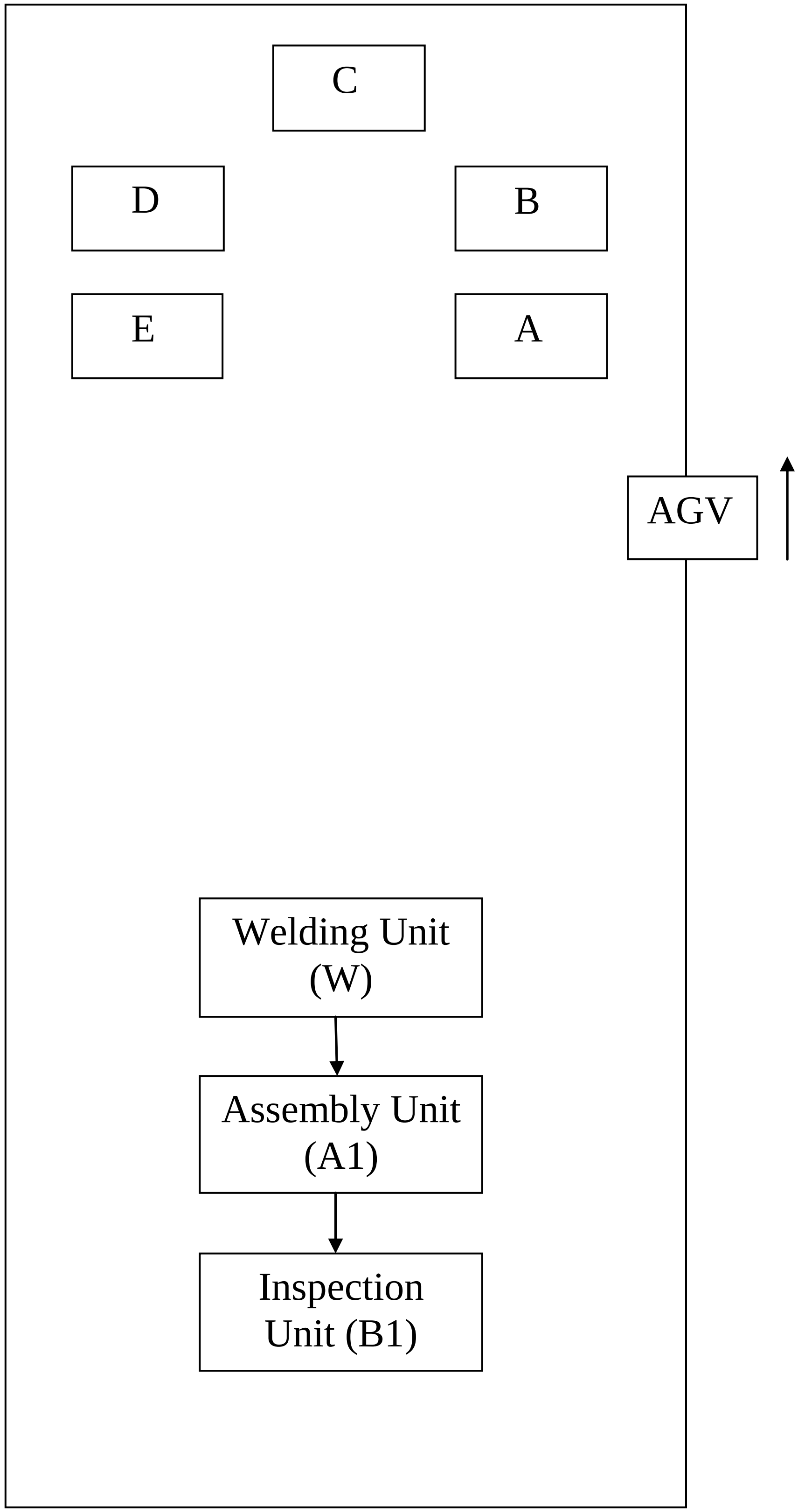

Figure 3.2 Track of AGV in the Present Layout

3.1.5 Application of AGV in present work:

In present work different parts of a hydraulic cylinder are to be transported to the assembly station. Piston rod, Piston, Cylinder Barrel or Body, Head end cap and Rod end cap are produced at station A, B, C, D and E respectively.

However these parts are transported on manually towed trolleys. Five workers are deputed only for performing these movements of loaded and unloaded trolleys. This system seems to be the simplest and most obvious has many disadvantages like uncontrollable traffic of trolleys on aisles, confusion, noise and chances of accidents.

In an attempt to automate this parts transfer system, possibility of using AGV is explored and analyzed. The figure 3.2 shows the present layout of the assembly line. The solid boundary line in the figure shows the path of AGV.

3.1.6 Working

Working of the system can be explained by the following steps –

- AGV moves only when operator presses start button mounted on its panel.
- AGV stops at the desired destination automatically if an address mark is located there. Address mark actually is an 8-bit magnetic code which when sensed and decoded by the AGV, it stops.
- AGV otherwise stops either by pressing emergency button mounted on its panel or if the obstruction sensor senses an obstacle in the path of AGV.
- At station A, Piston rod is loaded to the AGV. Operator presses the start button; AGV starts moving and reaches at B, stops here by decoding the address mark and gives out sound signals to make its presence felt to the operator at B.
- At B, Piston is loaded to AGV. Operator presses start button and AGV reaches at C, stops and here it is loaded with the Cylinder Barrel. Similarly it takes place for Head end cap at station D and for End cap at station E.

- At E when the operator presses start button, AGV moves to Welding Station ‘W’ and stops there. Unloads Cylinder Barrel and End Cap.
- At welding station AGV is loaded with the welded parts and Operator presses start button and AGV moves to Assembly Station ‘A1’.
- At A1, Piston, Piston rod, Head End Cap and welded parts are unloaded. Here AGV is loaded the assembled hydraulic cylinder and Operator presses start button and AGV moves to Inspection Unit ‘B1’.
- At Inspection Unit the hydraulic cylinder is checked for any leakage of pressurized fluid.
- Operator presses start button and now AGV with empty trolley moves to station A.

3.1.7 Advantages of using AGV:

- Reduced manpower.
- Increased productivity.
- Elimination of unnecessary fork-lift trucks.
- Reduced product damage.
- Better control of material management.
- Vehicles are always available, alleviating problems associated with scheduling employees on nights, weekends and holidays.
- They are flexible and can be adapted to many different needs.

3.1.8 Limitations

- The floor surface used by the system is shared by other material handling equipments also. So the chances of interferences con not be ruled out which may affect the performance of the system.
- The system still involves the operator for loading and unloading of material.
- The magnetic tape laid for guiding the vehicle may get prematurely damaged due to fork lift movement.

Alternative - 2

3.2 In-floor Towline Conveyor (TLC)

It's a variant of a chain conveyor. In this conveyor system, four wheel trolleys are used which are powered by a moving chain or cable located in trenches in the floor as shown in fig 3.3. The chain or cable is called the tow-line; hence, the name of the conveyor.

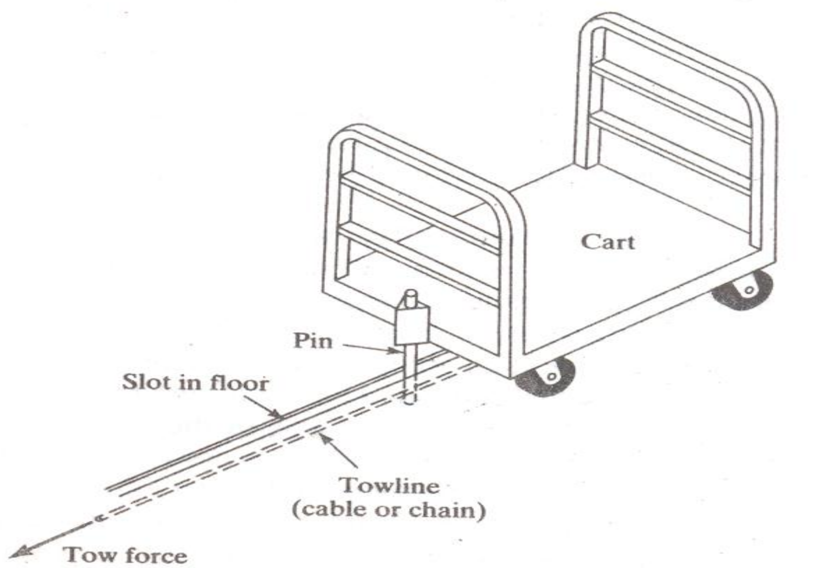

Figure 3.3 In-floor Tow Line Conveyor (3).

Pathways for the conveyor system are defined by the trench and the chain. The chain is driven by the electric motor. Switching between powered pathways is possible in a towline system to achieve flexibility in routing. The trolleys use steel pins that project below the floor level into the trench to engage the chain for towing. This pin can be pulled out of the chain to disengage the trolley for loading, unloading, accumulation of the parts and manually pushing a trolley off the main pathway. Towline conveyors are used in the manufacturing plants and warehouses (3).

3.2.1 The system

The layout of the system is shown in figure 3.4. The boundary line shows the trench cut in the floor. This trench is 80mm wide and 150mm deep. An endless chain is positioned in this trench.

At four corners and two intersection points of the trench is fitted one sprocket each a, b, c, d, e and f with sprocket 'a' mounted on the electric drive. The electric drive is a motor positioned below the floor level, coupled with a gear box for speed reduction. There is no need to fabricate new trolleys as the existing ones can be utilized for the purpose of material handling system with slight modifications. Each trolley will now have-

- A bracket fixed at its front edge to accommodate a latching pin.
- A protrusion at a specific orientation so that it hits the limit switch of a desired station only.
- Its identification code (this code actually is the name of the component) written boldly on all sides of it for clear visibility. The purpose is to load batches of different components on the trolleys dedicated to them only. For example, a trolley with P/R written on it should be loaded with Piston Rods only and same is applicable for other components as well.
- Each trolley is fitted with a battery source that raises an alarm when the obstruction sensor mounted on it senses an obstruction. The warning lights provided on the trolleys also keep on glowing continuously.
- Each trolley is painted with bright fluorescent color for better visibility.

At loading stations A, B, C, D and E conveyor start and stop buttons are provided in addition to limit switches. When a code C/B comes for Cylinder Barrel, it will hit only the limit switch at station C. This will stop the conveyor and sound a buzzer so as to make its presence felt to the operator at station C. It is now loaded with the batch of Cylinder Barrel and start push button is pressed, making the conveyor to start. At unloading stations W, A1 and B1 only resettable limit switches are provided. When any of these limit switches is hit by a corresponding trolley, the conveyor stops and the buzzer goes on. The conveyor will start again and the buzzer will go off only when the operator resets the limit switch. The stop signals are given preference over the start signals. This means that if a trolley has been stopped at a given station, it will start only if the start signal is given by the same station. One another path EF is made for movement of trolley of Welding unit and Assembly Unit.

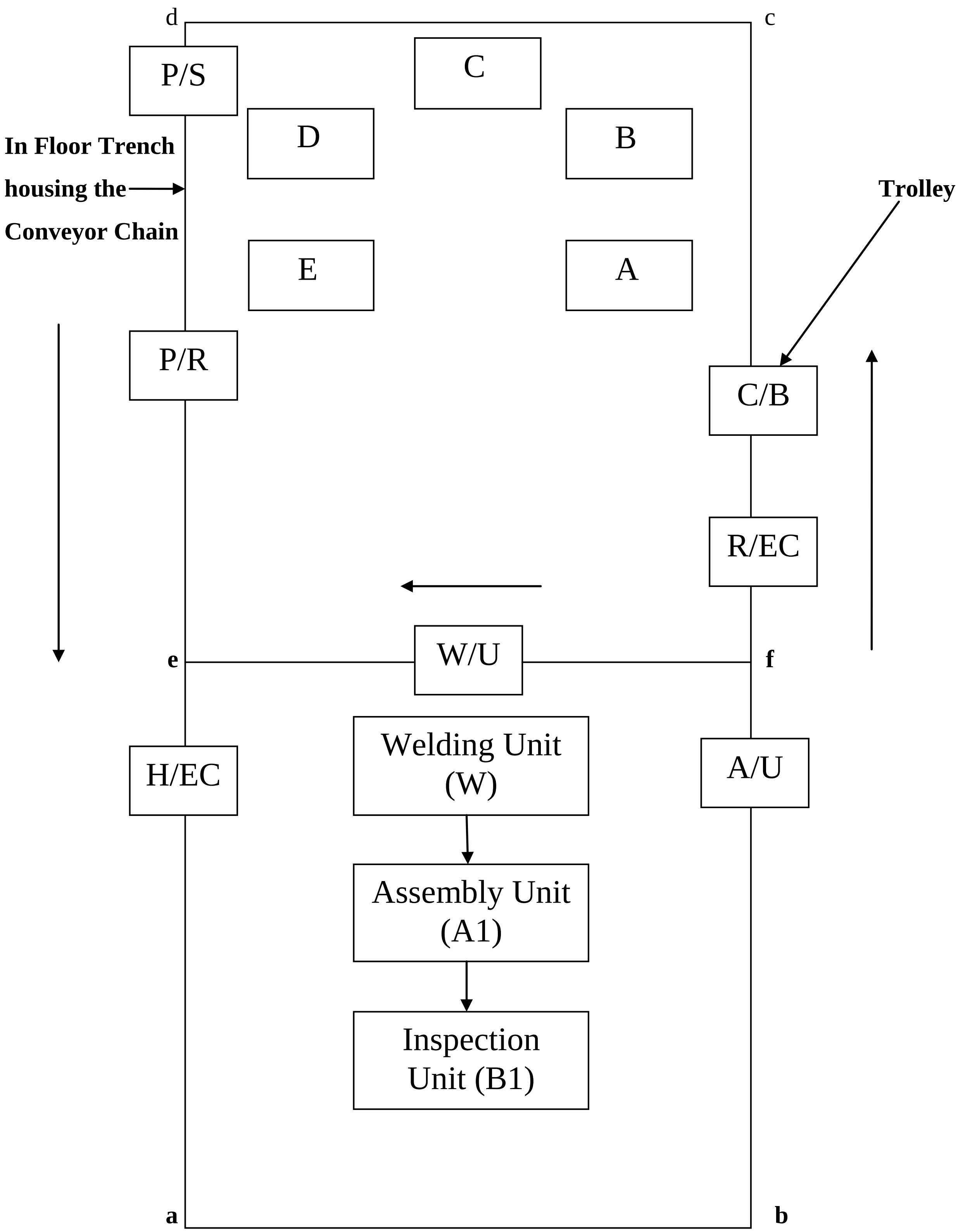

Figure 3.4 In- floor Tow Trolleys in Present System.

3.2.2 Working

- Let us start with the instance where an empty trolley marked C/B approaches station A. it will neither stop at A nor at B due to the specific orientation of its protrusion. The protrusion will hit the limit switch of station C only.
- The conveyor stops and the buzzer go on. The operator pulls out the latching pin and manually pulls the trolley away from the tow line. If at this station no other trolley is ready for dispatch, the operator simply presses the start push button and lets the conveyor move.
- At the same station if another trolley of Cylinder Barrel is loaded and ready to dispatch, then the operator will push this one to the tow line, engage the latching pin and then press the start push button.
- This trolley now moves towards the welding stations. It will hit the limit switch of station ‘W’ only. The conveyor stops and the buzzer go on. The operator de-latches the pin, pulls the loaded trolley and if there is an empty trolley (C/B), latches it with the conveyor and resets the limit switch.
- In the similar manner, loaded and unloaded trolleys are transported between the stations.
- The presence of specifically oriented protrusions on these trolleys ensure that the trolley belonging to a specific station stops there only as it cannot hit limit switches of other stations due to the specific orientation of the protrusion.

3.2.3 Safety measures

- The trolleys are painted with bright fluorescent colors for clear visibility.
- The speed of trolleys is fixed to a maximum of 500mm/sec which is less than the normal walking speed of humans. This feature ensures that the trolley will not chase and hit a person even if he is walking ahead of it.
- Emergency switches are provided at convenient locations in the line which when pressed, stops the conveyor.
- An obstruction sensor is provided on each trolley along with a battery operated warning light and a horn. When this sensor senses any obstruction in front of the trolley, warning

lights start glowing and the horn makes sound to attract the attention of people around. If the obstruction is a human, then he will clear the passage, but if the obstruction is an object then this horn may attract someone’s attention who will press the emergency switch to stop the conveyor.

3.2.4 Advantages

- Low cost solution.
- Man power reduction.
- No need to make new trolleys. Cost of making new trolleys is saved.
- Simple in construction.
- Robust with very long life.
- Very less maintenance is required. The wear and tear of trolleys is also less as they now move smoothly at a slow speed
- Chances of damage to the product due to mishandling are also eliminated.
- Latching pins can be spring loaded for easy and positive engagement of pins with the chain.

3.2.5 Limitations

- The major limitation of this system is that it does not stop on its own after sensing an obstruction on its way
- The system still involves the operator for loading and unloading operations.
- The system may interfere with the movement of other material handling equipment like fork lift trucks. Chances of accidents cannot be ruled out.

Alternative – 3

3.3 Overhead Trolley Conveyor (OTC)

The two systems explained so far in the form of alternative -1 and 2, operate at floor level. This on one hand makes the system simple, easy to operate, easy to maintain and easy to inspect, but at the same time, they consume one of the most valuable asset of any manufacturing unit- floor space. To avoid the occupation of floor space, chain driven conveyors can be designed to operate overhead, suspended from the ceiling of the facility so as not to consume floor space. The most common types are overhead trolley conveyors (3). A trolley in a material handling system is wheeled carriage running on an overhead rail from which loads can be suspended (3). An overhead trolley conveyor is shown in figure 3.5.

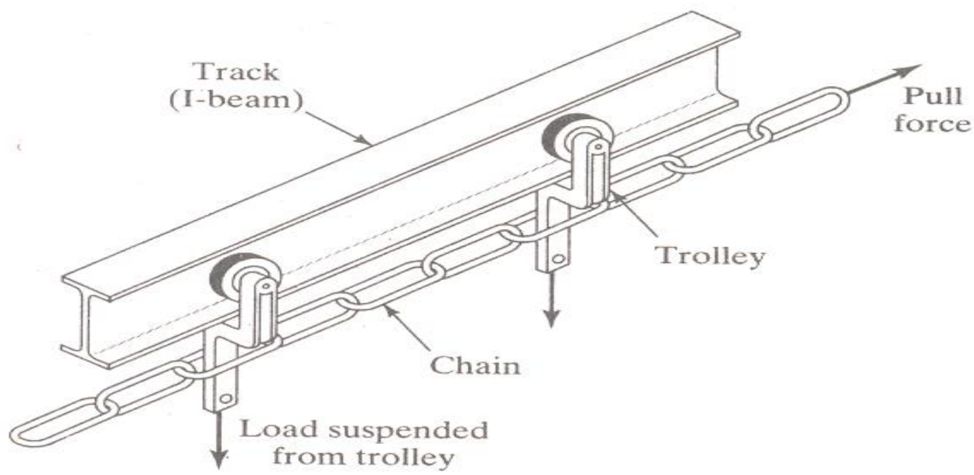

Figure 3.5 Overhead Trolley Conveyor (3).

It consists of multiple trolleys, usually equally spaced along a fixed track. The trolleys are connected together and moved along the track by means of a chain or cable that forms a complete loop. Suspended from the trolleys are hooks, carriers, baskets or other receptacles to carry loads. The chain is attached to a drive wheel that supplies power to move the chain at a constant velocity. The conveyor path is determined by the configuration of the track system, which has turns and possible changes in elevation. These types of conveyors are used in the factories to move parts and assemblies between different stations (3). These conveyors prove to be ideal choice at places where there is shortage of floor space and/or there if considerable traffic of other material handling equipment.

3.3.1 The system

The layout of the system is shown in figure 3.6**.** The boundary line shows the pathway of the overhead trolley conveyor. The conveyor remains overhead during ‘d-e’ and ‘f-g-h-a’. It comes down to ground working level during ‘a-b-c-d’ and ‘e-f’. The conveyor is having one more attractive feature that the carriers swivel in the horizontal plane. This feature makes the component trolley move very near to the ceiling, resulting in virtually no interference with the traffic of other material handling equipment moving on the shop floor making the system almost invisible.

This system is identical to the **In-floor Towline Conveyor system. The only difference is that the floor towline conveyor system** operates at floor level whereas this system is suspended from the ceiling of the facility so as not to consume floor space. It makes the system simple, easy to operate, easy to maintain and easy to inspect, but at the same time, they do not consume one of the most valuable asset of any manufacturing unit- floor space.

3.3.2 Working:

- Let us start with the instance where an empty trolley marked C/B approaches station A. it will neither stop at A nor at B due to the specific orientation. It will stop at Station C only.
- The conveyor stops and the buzzer go on. The operator pulls the trolley away from the conveyor line. If at this station no other trolley is ready for dispatch, the operator simply presses the start push button and lets the conveyor move.
- At the same station if another trolley of Cylinder Barrel is loaded and ready to dispatch, then the operator will attach this one to the Conveyor line, and then press the start push button.
- This trolley now moves towards the welding stations. It will stop at station ‘W’ only. The conveyor stops and the buzzer go on. The operator Pulls the loaded trolley and if there is an empty trolley (C/B), attaches it with the conveyor and press the start button.

- In the similar manner, loaded and unloaded trolleys are transported between the stations.

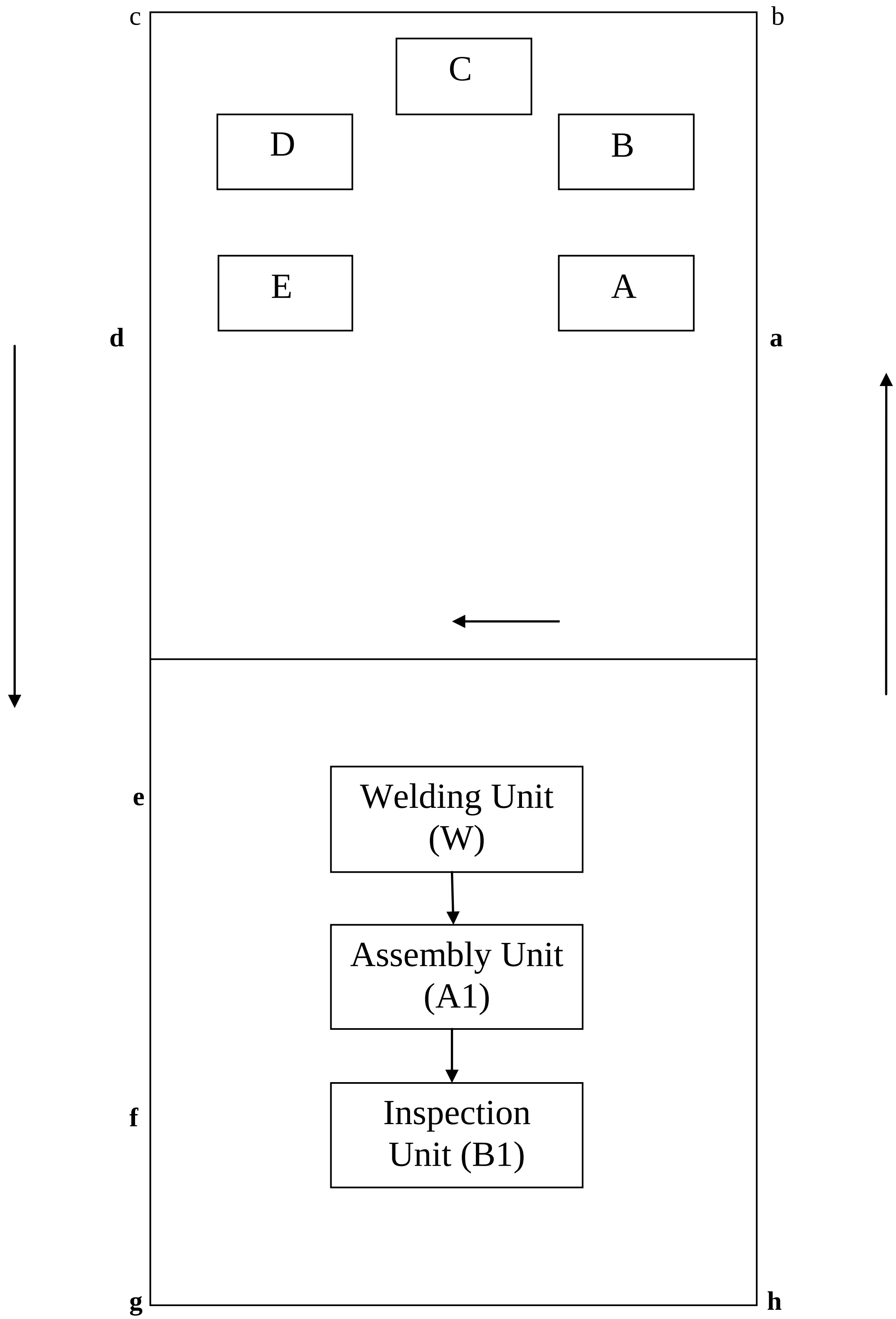

Figure 3.6 Overhead Trolley Conveyor in the Present System

3.3.4 Advantages

1. No accidents guaranteed.
2. No interference with other material handling equipments.
3. Smooth material flow.
4. Manpower earlier required for doors handling is virtually eliminated.
5. Highly reliable.
6. No noise pollution.

3.3.5 Limitations

1. Very high initial investment.
2. Longer installation times.

CHAPTER 4
EVALUATION OF ALTERNATIVES

4.1 Introduction

We have discussed and analyzed three different alternatives so far, for material handling problem at hand. Each one has got its own advantages and disadvantages. We have to now make the decision as to which one is the right alternative for the final selection. The decision has to be based on some logical considerations because once implemented, it will have long lasting effects both good as well as bad. Secondly, the money and reputation at stake is also huge. In the process of alternate selection, the alternatives are evaluated by a method which includes appraisals of qualitative factors. The method is explained as below-

- We first identify the factors important for selecting among alternatives. When selecting factors, there is constant trade-off between simplicity and completeness. We do not want to omit factors that may be important, yet we do not want to include the factors that have a very small effect on our decision. In addition, the only factors important for selection among alternatives are those on which the alternatives differ. Even if a factor such as cost is important, it can be dropped from the analysis if all the alternatives are equally good with respect to it.(4)

4.2 criteria (factor) selection

There could be numerous criteria (factors) available which may affect the selection among alternatives. A careful study of the line helped to list following criterions;

Criteria (factor)	**Expectation**
• Installation cost	Low
• Maintenance cost	Low
• Life expectancy of the alternative	Long

• Housekeeping	Good
• Safety	High
• Simplicity	Reasonable
• Material flow	Smooth
• Noise level	Low
• Congestion of aisles	Less
• Product damage	Nil
• Synchronization between the fabrication and assembly stations	Excellent
• Scope of further improvement	Good
• Flexibility	Reasonable
• User friendly	Yes
• Manpower reduction	Yes
• Reliability	Good
• Labor cost	Low
• Ease of maintenance	Yes
• Standardization	Yes
• Floor space requirements	Less

Out of the above mentioned criterions (factors) we have to consider the selected ones that have considerable impact on the selection decision. In present case, based on survey conducted on the assembly line with the people who are very near to the process, following three criterions with twelve sub criterions were short listed

- **Cost**
  1. Installation cost: This includes the actual cost of the system and commissioning cost.
  2. Maintenance cost: This includes the preventive maintenance cost and breakdown costs
  3. Manpower cost: This includes the salaries and perks paid to the manpower required (if any) after installation of this automation system at assembly line

- **Operational**
  1. Safety: Safety against interference with other material handling equipments and human operators which may result in accidents.
  2. Floor space requirements: Presently the floor space is shared by many other material handling equipments so the proposed alternative should be conservative as far as this requirement is concerned
  3. Reliability: The proposed system should be reliable in performance with minimum breakdowns.
  4. Synchronization: The system must ensure synchronization of material delivery between fabrication and assembly stations.
  5. Standardization: Parts used in the proposed system should be of standard nature to have cheap and less spare parts inventories.
  6. Ease of maintenance: Maintenance of the system should be easy and less time consuming.

- **Flexibility**
  1. Flexibility of design: the system must be capable to accommodate any change in the present design of the product without major changes.
  2. Flexibility of layout: The system must be capable to accommodate any future change in layout without incurring much cost, labor and time.
  3. Flexibility of volume: the system must be capable of handling any fluctuation in the demand of the product without affecting the synchronization of delivery.

4.3 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process as propounded by Saaty (1980) is used to priorities multiple criteria of the decision making and indicate the overall preference for each of the decision alternatives. AHP is designed to handle tangible as well as intangible factors and thus the subjective judgment of individuals is fully represented. This enables decision makers to represent the interactions of multi criteria in complex and unstructured situations by developing a hierarchy of the problem. Then judgment is provided about the relative importance of each of the criteria and then to specify a preference for each decision alternative with respect to each criterion. The key benefits of AHP are as follows:

- The AHP model is transparent. The hierarchical structure is easy to understand and communicate.
- AHP is easy to apply iteratively. The hierarchy can be expanded; for example, the criteria can further be decomposed to encompass still lower level attributes.
- AHP permits managers to quantify their subjective judgments. This is especially useful when one is evaluating to incorporate the multiple viewpoints of different user departments in an organization.
- The approach is useful to solve unstructured problems.
- Both tangible and intangible factors can be considered.
- Flexible technique capable of analyzing many complex problems.
- The hierarchical structure of AHP makes it possible to disaggregate many intangible factors into more meaningful and quantifiable factors.

4.3.1 AHP Procedure

The general approach of AHP is to decompose the total problem into smaller sub problems such that each sub problem can be analyzed and handled appropriately with practical perspectives in terms of data and information. The general structure of the AHP approach that provides decision support can be under stood with the help of the following sequential procedure as given by Mohanty and Deshmukh (1996).

1. List the set of equipment alternatives that are shortlisted.
2. Identify the factors that may intrinsic as well as extrinsic, tangible as well as intangible, which may have an impact on the choice of alternatives.
3. Develop a graphical representation of the problem in terms of the overall goal, the factors, the criteria and the decision alternatives. Such a graph depicts the hierarchy for the problem.

4. Perform pairwise comparison of elements in one level relative to a single element in level immediately above it to derive local priorities of these elements that reflect their relative contribution to the subject of comparison.
5. Assign weights to each alternative on the basis of the relative importance of its contribution to each decision criterion. Table 4.1 shows a typical scale for pairwise comparison, which may be used foe preparing the pairwise matrix for each criterion. The format of comparison matrix is given in table 4.2. the entries of the matrix are the responses to the questions asked during pairwise comparison. These are supplied by the decision maker rather than the analyst. Only the upper triangular part of this matrix is shown since it is a reciprocal matrix.
6. Consistency Ratio: For an n dimensional matrix of the AHP, it can be shown that the largest Eigenvalue of the matrix, $\lambda_{max} - n \geq n$, (Arbel and Siedmann 1984), where equality holds for a perfectly consistent case. A consistency index (CI) is defined as:

$$CI = (\lambda_{max} - n)/ (n-1)$$

Consistency ratio (CR) is defined by Saaty (1980) as:

$$CR = CI/RI$$

Where, random index (RI) has been recommended by Saaty (1980) as:

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Consistency Ratio (CR) is required to be less than 0.10 for acceptable results.

Table 4.1: Scale of Relative Importance (7)

Scale	Definition
1	Equally Preferred
2	Equally to Moderately Preferred
3	Moderately Preferred
4	Moderately to Strongly Preferred
5	Strongly Preferred
6	Strongly to Very Strongly Preferred

7	Very Strongly Preferred
8	Very Strongly to Extremely Preferred
9	Extremely Preferred

Table 4.2: Format of Pairwise Comparison Matrix

Evaluation criteria	C_1	C_2	C_3	C_m
C_1	1	Degree of preference of C_1 over C_2	Degree of preference of C_1 over C_3	Degree of preference of C_1 over C_m
C_2		1	Degree of preference of C_2 over C_3	Degree of preference of C_2 over C_m
C_3			1	Degree of preference of C_3 over C_m
C_m				1

Places below the diagonal to be filled by reciprocal of entries

7. Using the priority of the single element in the level immediately above it, the global priorities of the elements are derived. The process is repeated for all the levels and global priorities of all elements are determined.
8. Once the global priority of each element is established by pairwise comparison, the normalized priority of each alternative is synthesized. This is done as follows:
   - Compare the alternatives with respect to each of the elements of the lowest level in the hierarchy structure and local priorities of the alternatives are derived.
   - Using the priorities for the elements, the local priorities for each alternative are converted into global priorities.
   - The sum of the global priorities of the alternatives yields the normalized priority of the alternatives.

4.4 Analyses of the present system by AHP

In present system, we start by laying out the overall hierarchy of the decision. This hierarchy reveals the factors to be considered as well as the various alternatives in the decision. Then, a number of pair wise comparisons are done, which result in the determination of factor weights and factor evaluations. The decision hierarchy for present case has four different levels. The top level describes the overall decision. In our case it's the selection of the best alternative. The second level in the hierarchy describes the three factors- cost, operational and flexibility which will contribute to the achievement of the overall goal. The third level of the hierarchy reveals the sub factors which will play a vital role in the contribution of each factor and finally at fourth level we have three alternatives to automate the material handling system. The decision hierarchy for the present case is shown in figure 4.1.

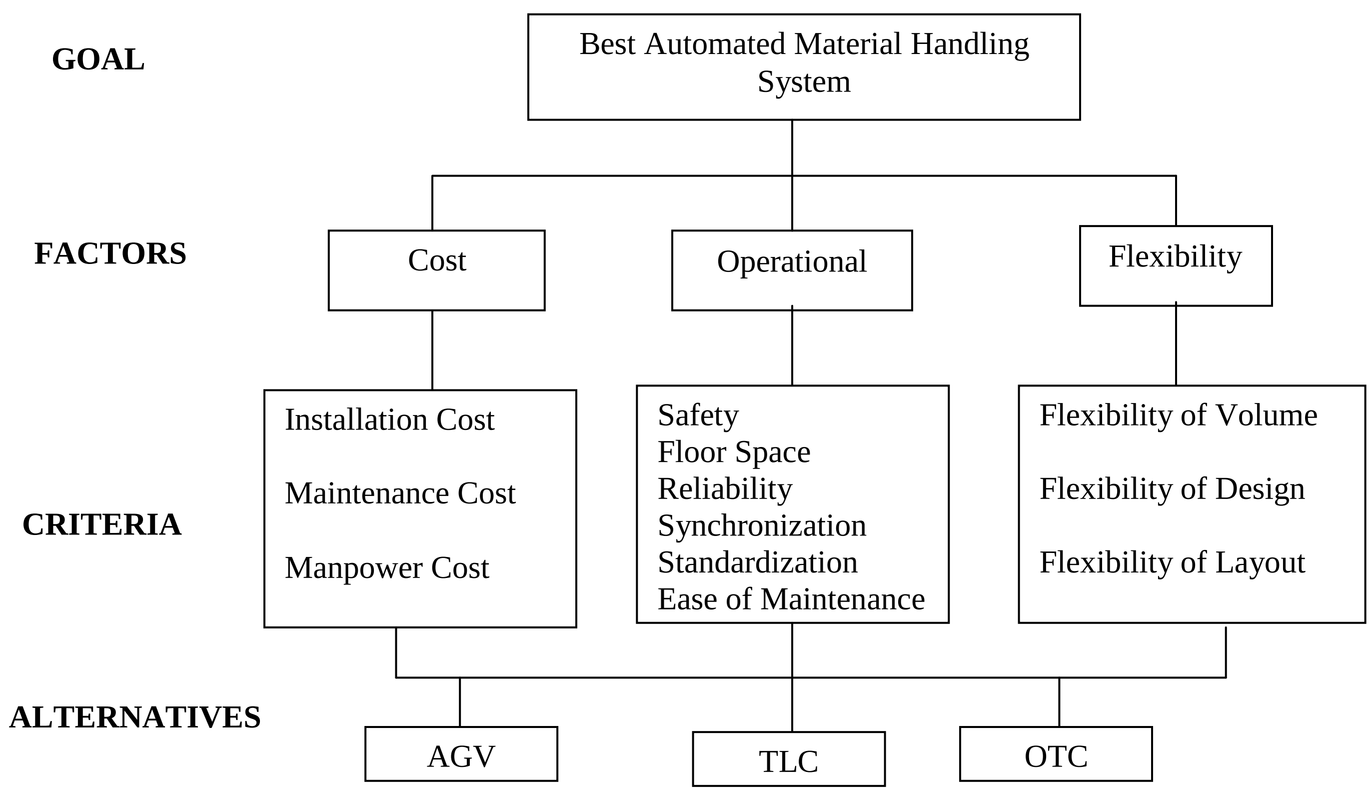

Figure 4.1: Hierarchy of the Decision Making Process

4.4.1 Evaluation of factors

Operational factor is moderately to strongly preferred over cost (use scale value 4). Operational factor is strongly to very strongly preferred over flexibility, (use scale value 6). Finally, cost is moderately to strongly preferred over flexibility, (Use scale value 4).

Factor	**Cost**	**Operational**	**Flexibility**
Cost	1	1/4	4
Operational	4	1	6
Flexibility	1/4	1/6	1
Column total	5.25	1.416	11

All the diagonally vacant places will be occupied by 1 as at these places an alternative is being compared to itself, means equally preferred (scale value 1).

The numbers in the table above are divided by their respective column totals to get Normalized matrix (below)

Factor	**Cost**	**Operational**	**Flexibility**
Cost	0.190	0.176	0.363
Operational	0.761	0.706	0.545
Flexibility	0.047	0.117	0.090

Table 4.3 Row averages of normalized matrix gives the priority weights for factors

Factor	**Weights**
Cost	**0.243**
Operational	**0.670**
Flexibility	**0.084**

Weighted sum vector

It is determined by multiplying the factor evaluation number for the first alternative times the first column of the original pair wise comparison table. We multiply the second factor evaluation times the second column, and the third factor times the third column of the original matrix of pair wise comparisons. Then we sum these values over the rows.

Weighted sum vector =

$$\begin{pmatrix} 0.243X1 & 0.67X1/4 & 0.084X4 \\ 0.243X4 & 0.67X1 & 0.084X6 \\ 0.243X1/4 & 0.67X1/6 & 0.084X1 \end{pmatrix} = \begin{pmatrix} 0.746 \\ 2.146 \\ 0.255 \end{pmatrix}$$

The next step is to determine the consistency vector. This is done by dividing the weighted sum vector by the factor evaluation values determined previously (table 5.3).

Consistency vector =

$$\begin{pmatrix} 0.746/0.243 \\ 2.146/0.670 \\ 0.255/0.084 \end{pmatrix} = \begin{pmatrix} 3.069 \\ -3.202 \\ 3.035 \end{pmatrix}$$

Now that the consistency vector has been found out, two more terms are required to be computed, lambda (λ) and the consistency index (CI), before the final consistency ratio can be computed. The value for lambda is simply the average of the consistency vector. The formula for CI is, CI= $\frac{\lambda - n}{n-1}$, where n is the no. of alternatives/factors being compared. In the present case, n=3 for three different alternatives being compared.

λ = (3.069+3.202+3.035)/3

λ =3.102

CI= $\frac{\lambda - n}{n-1} = \frac{3.102-3}{3-1} = 0.051$

Finally, we are in a position to compute the consistency ratio (CR), which is equal to the consistency index (CI) divided by random index (RI). The random index is a direct function of the no. of alternatives being considered.

CR= $\frac{CI}{RI}$, for n=3, RI= 0.58

Therefore, CR= $\frac{CI}{RI} = \frac{0.051}{0.58} = 0.087$

Since CR is less than 0.10, our pairwise comparison of factors in this case is consistent.

4.4.2 Evaluation of sub factors (criterions)

- **Cost :**

Installation cost is moderately preferred over maintenance cost (use scale value 3). Installation cost is strongly preferred over labor cost, (use scale value 5). Finally, maintenance cost is moderately preferred over labor cost, (Use scale value 3).

Factor	**Installation cost**	**Maintenance cost**	**Manpower cost**
Installation cost	1	3	5
Maintenance cost	1/3	1	3
Manpower cost	1/5	1/3	1
Column total	1.533	4.333	9

The numbers in the table above are divided by their respective column totals to get Normalized matrix (below)

Factor	**Installation cost**	**Maintenance cost**	**Manpower cost**
Installation cost	0.652	0.692	0.555
Maintenance cost	0.217	0.230	0.333
Manpower cost	0.130	0.076	0.111

Table 4.4 Row averages of normalized matrix gives the priority weights for cost

Factor	**Weights**
Installation cost	**0.633**
Maintenance cost	**0.260**
Labor cost	**0.105**

$$\underline{\text{Weighted sum vector}} = \begin{pmatrix} 0.633X1 & 0.26X3 & 0.105X5 \\ 0.633X1/3 & 0.26X1 & 0.105X3 \\ 0.633X1/5 & 0.26X1/3 & 0.105X1 \end{pmatrix} = \begin{pmatrix} 1.938 \\ 0.785 \\ 0.317 \end{pmatrix}$$

$$\textbf{Consistency vector} = \begin{bmatrix} 1.938/0.633 \\ 0.785/0.260 \\ 0.317/0.105 \end{bmatrix} = \begin{bmatrix} 3.061 \\ 3.019 \\ 3.019 \end{bmatrix}$$

λ = (3.061+3.019+3.019)/3

λ =3.033

Consistency Index, CI= $\frac{\lambda - n}{n-1} = \frac{3.033-3}{3-1}$ = 0.016

Consistency Ratio, CR= $\frac{CI}{RI}$, for n=3, RI= 0.58

Therefore, CR= $\frac{CI}{RI} = \frac{0.016}{0.58}$ = 0.028

Since CR is less than 0.10, our pairwise comparison of criterions in this case is consistent.

- **Operational:**

Paired comparison matrix

Criteria	Safety	Floor space	Reliability	Synchronization	Standardization	Ease of maintenance
Safety	1	3	4	4	6	4
Floor space	1/3	1	2	4	5	2
Reliability	1/4	1/2	1	3	4	2
Synchronization	1/4	1/4	1/3	1	4	3
Standardization	1/6	1/5	1/4	1/4	1	1/3
Ease of Maintenance	1/4	1/2	1/2	1/3	3	1
Column total	2.249	5.45	8.083	12.583	23	12.333

Normalized matrix

Criteria	Safety	Floor space	Reliability	Synchronization	Standardization	Ease of maintenance
Safety	0.444	0.550	0.494	0.317	0.260	0.324
Floor space	0.148	0.183	0.247	0.317	0.217	0.162
Reliability	0.111	0.091	0.123	0.238	0.173	0.162
Synchronization	0.111	0.045	0.041	0.079	0.173	0.243
Standardization	0.073	0.036	0.030	0.019	0.043	0.027
Ease of Maintenance	0.111	0.091	0.061	0.026	0.130	0.081

Table 4.5 Priority weights for operational

Criteria	**Weights**
Safety	**0.398**
Floor space	**0.212**
Reliability	**0.149**
Synchronization	**0.115**
Standardization	**0.038**
Ease of Maintenance	**0.083**

Weighted sum vector is given below,

0.398X1	0.212X3	0.149X4	0.115X4	0.038X6	0.083X4
0.398X1/3	0.212X1	0.149X2	0.115X4	0.038X5	0.083X2
0.398X1/4	0.212X1/2	0.149X1	0.115X3	0.038X4	0.083X2
0.398X1/4	0.212X1/4	0.149X1/3	0.115X1	0.038X4	0.083X3
0.398X1/6	0.212X1/5	0.149X1/4	0.115X1/4	0.038X1	0.083X1/3

0.398X1/4 0.212X1/2 0.149X1/2 0.115X1/3 0.038X3 0.083X1

$$\text{Weighted Sum Vector} = \begin{pmatrix} 2.650 \\ 1.458 \\ 1.017 \\ 0.717 \\ 0.238 \\ 0.514 \end{pmatrix}, \textbf{ Consistency vector} = \begin{pmatrix} 2.650/0.398 \\ 1.458/0.212 \\ 1.017/0.149 \\ 0.717/0.115 \\ 0.238/0.038 \\ 0.514/0.083 \end{pmatrix} = \begin{pmatrix} 6.658 \\ 6.877 \\ 6.825 \\ 6.234 \\ 6.263 \\ 6.192 \end{pmatrix}$$

λ = (6.658+6.877+6.825+6.234+6.263+6.192)/6

λ =6.506

Consistency Index, CI= $\frac{\lambda - n}{n-1} = \frac{6.506-6}{6-1}$ = 0.1012

Consistency Ratio, CR= $\frac{CI}{RI}$, for n=6, RI= 1.24

Therefore, CR= $\frac{CI}{RI} = \frac{0.1012}{1.24}$ = 0.081

Since CR is less than 0.10, our pairwise comparison of criterions in this case is consistent.

- **Flexibility:**

Paired comparison matrix

Factor	**Flexibility of volume**	**Flexibility of design**	**Flexibility of layout**
Flexibility of volume	1	4	6
Flexibility of design	1/4	1	3
Flexibility of layout	1/6	1/3	1
Column total	1.416	5.333	10

Normalized matrix

Factor	Flexibility of volume	Flexibility of design	Flexibility of layout
Flexibility of volume	0.706	0.750	0.6
Flexibility of design	0.176	0.187	0.3
Flexibility of layout	0.117	0.062	0.1

Table 4.6 Priority weights for flexibility

Criterion	Weights
Flexibility of volume	**0.685**
Flexibility of design	**0.221**
Flexibility of layout	**0.093**

Weighted sum vector = $\begin{pmatrix} 0.685X1 & 0.22X34 & 0.093X6 \\ 0.685X1/3 & 0.22X1 & 0.093X3 \\ 0.685X1/6 & 0.22X1/3 & 0.093X1 \end{pmatrix} = \begin{pmatrix} 2.127 \\ 0.671 \\ 0.229 \end{pmatrix}$

Consistency vector = $\begin{pmatrix} 2.127/0.685 \\ 0.671/0.221 \\ 0.229/0.093 \end{pmatrix} = \begin{pmatrix} 3.105 \\ 3.030 \\ 3.000 \end{pmatrix}$

λ = (3.105+3.030+3.000)/3

λ =3.045

Consistency Index, CI= $\frac{\lambda - n}{n-1} = \frac{3.045-3}{3-1}$ = 0.022

Consistency Ratio, CR= $\frac{CI}{RI} = \frac{0.022}{0.58}$ = 0.038

Since CR is less than 0.10, our pairwise comparison of criterions in this case is consistent.

4.4.3 Evaluation of alternatives with respect to different criterions

- **Comparing criteria: Installation cost**

Paired comparison matrix

Installation cost	**AGV**	**TLC**	**OTC**
AGV	1	1/4	6
TLC	4	1	8
OTC	1/6	1/8	1
Column Total	5.16	1.37	15

Normalized matrix

Installation cost	**AGV**	**TLC**	**OTC**
AGV	0.19	0.18	0.40
TLC	0.77	0.72	0.53
OTC	0.03	0.08	0.06

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Installation cost	**0.25**	**0.67**	**0.05**

λ = (2.84+3.08+3.40)/3

λ =3.10

Consistency index CI= $\frac{\lambda - n}{n-1} = \frac{3.10-3}{3-1}$ = 0.05

Consistency ratio CR= $\frac{CI}{RI} = \frac{0.05}{0.58}$ = 0.08

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent

- **Maintenance cost:**

Paired comparison matrix

Maintenance cost	**AGV**	**TLC**	**OTC**
AGV	1	1/5	1/4
TLC	5	1	3
OTC	4	1/3	1
Column Total	10	1.53	4.25

Normalized matrix

Maintenance cost	**AGV**	**TLC**	**OTC**
AGV	0.10	0.13	0.05
TLC	0.50	0.65	0.70
OTC	0.40	0.21	0.23

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Maintenance cost	**0.09**	**0.61**	**0.28**

λ = (3.11+3.11+3.00)/3

λ =3.07

Consistency index CI= $\frac{\lambda - n}{n-1} = \frac{3.07-3}{3-1}$ = 0.035

Consistency ratio CR= $\frac{CI}{RI} = \frac{0.035}{0.58}$ = 0.06

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Manpower cost:**

Paired comparison matrix

Manpower cost	**AGV**	**TLC**	**OTC**
AGV	1	1	1/5
TLC	1	1	1/5
OTC	5	5	1
Column Total	7	7	1.4

Normalized matrix

Manpower cost	**AGV**	**TLC**	**OTC**
AGV	0.14	0.14	0.14
TLC	0.14	0.14	0.14
OTC	0.71	0.71	0.71

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Manpower cost	**0.14**	**0.14**	**0.71**

λ = (3.00+3.00+2.97)/3

λ =2.99

Consistency index CI= $\frac{\lambda - n}{n-1} = \frac{2.99-3}{3-1}$ = 0.005 (ignoring –ve sign)

Consistency ratio CR= $\frac{CI}{RI} = \frac{0.005}{0.58}$ = 0.008

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Safety**

Paired comparison matrix

Safety	**AGV**	**TLC**	**OTC**
AGV	1	5	1/6
TLC	1/5	1	1/9
OTC	6	9	1
Column Total	7.20	15	1.27

Normalized matrix

Safety	**AGV**	**TLC**	**OTC**
AGV	0.13	0.33	0.12
TLC	0.02	0.06	0.08
OTC	0.83	0.60	0.78

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Safety	**0.19**	**0.05**	**0.73**

λ = (2.89+3.2+3.15)/3

λ =3.08

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.08-3}{3-1}$ = 0.04

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.04}{0.58}$ = 0.068

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Floor space**

Paired comparison matrix

Floor space	**AGV**	**TLC**	**OTC**
AGV	1	1	1/7
TLC	1	1	1/7
OTC	7	7	1
Column Total	9	9	1.28

Normalized matrix

Floor space	**AGV**	**TLC**	**OTC**
AGV	0.111	0.111	0.109
TLC	0.111	0.111	0.109
OTC	0.777	0.777	0.781

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Floor space	**0.110**	**0.110**	**0.778**

λ = (2.981+2.981+3.010)/3

λ =2.99

Consistency index, CI= $\frac{\lambda - n}{n-1}$ = $\frac{2.99-3}{3-1}$ = 0.005

Consistency ratio, CR= $\frac{CI}{RI}$ = $\frac{0.005}{0.58}$ = 0.008

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Reliability**

Paired comparison matrix

Reliability	**AGV**	**TLC**	**OTC**
AGV	1	1/4	1/6
TLC	4	1	1/3
OTC	6	3	1
Column Total	11	4.25	1.499

Normalized matrix

Reliability	**AGV**	**TLC**	**OTC**
AGV	0.090	0.058	0.110
TLC	0.363	0.235	0.222
OTC	0.545	0.705	0.667

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Reliability	**0.086**	**0.273**	**0.639**

λ = (3.023+3.036+3.089)/3

λ =3.049

Consistency index, CI= $\frac{\lambda - n}{n-1}$ = $\frac{3.049-3}{3-2}$ = 0.024

Consistency ratio, CR= $\frac{CI}{RI}$ = $\frac{0.024}{0.58}$ = 0.042

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Synchronization**

Paired comparison matrix

Synchronization	**AGV**	**TLC**	**OTC**
AGV	1	2	1/4
TLC	1/2	1	1/5
OTC	4	5	1
Column Total	5.5	8	1.45

Normalized matrix

Synchronization	**AGV**	**TLC**	**OTC**
AGV	0.181	0.250	0.172
TLC	0.090	0.125	0.137
OTC	0.727	0.625	0.689

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Synchronization	**0.201**	**0.117**	**0.680**

λ = (3.009+3.017+3.042)/3

λ =3.022

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.022-3}{3-2}$ = 0.011

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.011}{0.58}$ = 0.018

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Standardization**

Paired comparison matrix

Standardization	**AGV**	**TLC**	**OTC**
AGV	1	1/3	4
TLC	3	1	5
OTC	1/4	1/5	1
Column Total	4.25	1.533	10

Normalized matrix

Standardization	**AGV**	**TLC**	**OTC**
AGV	0.235	0.217	0.400
TLC	0.705	0.652	0.500
OTC	0.058	0.130	0.100

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Standardization	**0.284**	**0.619**	**0.096**

λ = (3.07+3.15+3.02)/3

λ =3.08

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.08-3}{3-2}$ = 0.04

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.04}{0.58}$ = 0.068

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Ease of maintenance**

Paired comparison matrix

Ease of maintenance	**AGV**	**TLC**	**OTC**
AGV	1	1/3	3
TLC	3	1	5
OTC	1/3	1/5	1
Column Total	4.333	1.533	9

Normalized matrix

Ease of maintenance	**AGV**	**TLC**	**OTC**
AGV	0.230	0.217	0.333
TLC	0.692	0.652	0.555
OTC	0.076	0.130	0.111

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Ease of maintenance	**0.260**	**0.633**	**0.105**

λ = (3.019+3.061+3.019)/3

λ =3.033

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.033-3}{3-2}$ = 0.016

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.016}{0.58}$ = 0.028

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Flexibility of volume change**

Paired comparison matrix

Flexibility of volume change	**AGV**	**TLC**	**OTC**
AGV	1	2	1/5
TLC	1/2	1	1/6
OTC	5	6	1
Column Total	6.5	9	1.366

Normalized matrix

Flexibility of volume change	**AGV**	**TLC**	**OTC**
AGV	0.153	0.222	0.146
TLC	0.076	0.111	0.121
OTC	0.769	0.666	0.732

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Flexibility of volume change	**0.173**	**0.102**	**0.722**

λ = (3.005+3.009+3.045)/3

λ =3.019

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.019-3}{3-1}$ = 0.009

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.009}{0.58}$ = 0.016

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent.

- **Flexibility of design change**

Paired comparison matrix

Flexibility of design change	**AGV**	**TLC**	**OTC**
AGV	1	2	4
TLC	1/2	1	3
OTC	1/4	1/3	1
Column Total	1.75	3.333	8

Normalized matrix

Flexibility of design change	**AGV**	**TLC**	**OTC**
AGV	0.571	0.600	0.500
TLC	0.285	0.300	0.375
OTC	0.142	0.099	0.125

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Flexibility of design change	**0.557**	**0.320**	**0.122**

λ = (3.025+3.012+3.008)/3

λ =3.015

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.015-3}{3-1}$ = 0.007

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.007}{0.58}$ = 0.012

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent

- **Flexibility of layout change**

Paired comparison matrix

Flexibility of layout change	**AGV**	**TLC**	**OTC**
AGV	1	4	6
TLC	1/4	1	3
OTC	1/6	1/3	1
Column Total	1.416	5.333	10

Normalized matrix

Flexibility of layout change	**AGV**	**TLC**	**OTC**
AGV	0.706	0.750	0.600
TLC	0.176	0.187	0.300
OTC	0.117	0.062	0.100

Priority weights

Factor	**AGV**	**TLC**	**OTC**
Flexibility of layout change	**0.685**	**0.221**	**0.093**

λ = (3.105+3.036+3.000)/3

λ =3.047

Consistency index, CI= $\frac{\lambda - n}{n-1} = \frac{3.047-3}{3-1}$ = 0.023

Consistency ratio, CR= $\frac{CI}{RI} = \frac{0.023}{0.58}$ = 0.04

Since CR is less than 0.10, therefore our pairwise comparison of factors in this case is consistent

Table 4.7: Total Weighted Evaluations of the Alternatives

Criteria	Local priorities	Global priorities A	AGV score B	AGV Weighted Score (AXB)	TLC Score C	TLC Weighted Score (AXC)	OTC Score D	OTC Weighted Score (AXD)
Cost	**0.243**							
Installation	0.633	0.153	0.250	0.048	0.670	0.102	0.050	0.007
Maintenance	0.260	0.063	0.090	0.005	0.610	0.038	0.280	0.017
Manpower	0.105	0.025	0.140	0.003	0.140	0.003	0.710	0.017
Operational	**0.670**							
Safety	0.398	0.266	0.190	0.050	0.050	0.013	0.730	0.194
Floor space	0.212	0.142	0.110	0.025	0.110	0.015	0.778	0.120
Reliability	0.149	0.099	0.086	0.008	0.273	0.027	0.639	0.063
Synchronization	0.115	0.077	0.201	0.015	0.117	0.009	0.680	0.065
Standardization	0.038	0.025	0.284	0.007	0.619	0.015	0.096	0.002
Ease of maintenance	0.083	0.055	0.260	0.014	0.633	0.034	0.105	0.005
Flexibility	**0.084**							
Of volume change	0.685	0.057	0.173	0.009	0.102	0.005	0.722	0.041
Of design change	0.221	0.018	0.557	0.010	0.320	0.005	0.122	0.002
Of layout change	0.093	0.007	0.685	0.004	0.221	0.001	0.093	0.000
Total weighted score				**0.198**		**0.267**		**0.535**

Table 4.8: AHP Ranking of the Alternatives

Alternatives	**Score**	**Ranking**
AGV	**0.198**	**III**
TLC	**0.267**	**II**
OTC	**0.535**	**I**

4.5 Discussion of the Result

From the diagnosis and analysis of the present case, implementation of OTC is finalized due to its highest final ranking. The ranking score of the other alternatives are low indicating their low contribution towards safety, floor space saving and manpower reduction.

In fact, if we look at the ranking score total of the three alternatives in case of factors like, flexibility of layout change, ease of maintenance and installation cost, we find that AGV and TLC definitely having an upper edge over OTC. But it's due to company's policy of "Safety First", commitment towards complete automation (manpower reduction) and good house keeping (floor space saving) that lead OTC to first choice.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE OF WORK

5.1 Conclusion

In the present work, an attempt has been made to analyze the automation of material handling system between the manufacturing and assembly stations. Three alternative solutions were suggested keeping in view the layout, production rate and other constraints of the line. For the analysis part, various criterions that could affect the final selection of an alternative were listed. A careful survey of the line and the people very closely associated with it helped to narrow down a few most important factors which are Cost, Operational performance and Flexibility. These factors are then further divided into twelve sub factors for proper analysis. The analysis was done by AHP approach, where different factors were compared pairwise by using an appropriate scale to evaluate factor weights. The alternatives were also evaluated pairwise for each factor separately. In each case, the consistency of pairwise comparisons was also checked. Finally, the overall ranking of the alternatives was evaluated with alternative OTC receiving the highest ranking.

Factors like safety, floor space saving, and manpower cost received the highest weightage and clearly outweighed the other two alternatives leaving behind the one that does not consumes the floor space at all- Overhead Trolley Conveyor. This solution has a very high installation cost and least flexibility of layout change, but once installed, gives noiseless operation, synchronization between fabrication and assembly stations, no accidents, excellent housekeeping and no product damage. Adaptation of this alternative will prove to be a step further in the direction of continuous improvement and will strengthen company's commitment towards quality products at low cost with total customer satisfaction.

5.2 Future scope of work

The present work has been carried out by considering twelve criterions analyzed by AHP. While recommending the automation process of similar kind in future, more numbers of criterions can be considered, survey base for the selection of criterions can be broadened with more rigorous brainstorming. Other analysis techniques like ANP (Analytical Network Process) can also be applied along with sensitivity analysis to make the selection of alternatives more consistent. Financial aspects can be included in more details with the calculation of 'return on investments'. The selected alternative can be implemented with more technical up gradations like

- Automatic tension control by pneumatic or hydraulic means.

- Automatic speed adjustments in accordance with the speed of the main conveyor.

- Automatically putting the carriers on other conveyors moving at different speeds to have different amounts of buffer stock to meet different demand rates.

- Smart safety features automatically stopping the conveyor in the event of chain breakage, failure of tension control system, overloading etc.

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