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INFLUENCE OF INDUSTRY 4.0 ON MANUFACTURING FACILITY DESIGN PROCESS& OUTCOMES OF THE FACILITY LAYOUT

FACULTY ENGINEERING TECHNOLOGY

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INFLUENCE OF INDUSTRY 4.0 ON MANUFACTURING FACILITY DESIGN PROCESS& OUTCOMES OF THE FACILITY LAYOUT

Master Assignment Report

For

Master's Degree in Mechanical Engineering, with a Specialisation in Production Management

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It was an exciting moment when I chose this project topic "Industry 4.0 and Manufacturing Facility Design". Because Industry 4.0 is the futuristic concept of the industrial revolution, I thought of learning futuristic concepts and it never disappointed me. This made me learn things and new upcoming technologies that are willing to be the future of manufacturing. This gave me better clarity about my futuristic skill sets that I should learn to prepare for the upcoming Industries revolution. Overall, this project made me insightful about next-generation manufacturing and helped me improve my analytical skills.

I am a person who had zero knowledge about research projects, and I had never gone through the process until I chose a Masters' at the University of Twente. For this great opportunity, I am thankful to the University of Twente. As the research process started, there were times I used to get stuck with the process and it was hard to get over it. In those times Dr. Ir. S. Hoekstra, who was my supervisor and my program coordinator was very helpful in providing suggestions and necessary feedback. And wholeheartedly I thank Dr. Ir. S. Hoekstra for his patience and valuable time guiding me through this successful project.

At this moment, I take an opportunity to thank IR. M. J. B. Duyvestijn (Monique)and IR. J. G. De Kiewit (Annet) motivated me throughout the project and made it successful even in this pandemic.

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Summary

Beginning in the 18th century, Industries have been revolutionizing from mechanical production to Intelligent production or also known as Fourth Industrial Revolution or Industry 4.0. The objective of Industry 4.0 is to achieve a higher level of automation, operational effectiveness, and productivity. Industry 4.0 has main characteristics such as digitization, optimization, and personalization of production, automation and adaption, and human-machine interaction. These characteristics of Industry 4.0 are reflected through cyber world technologies such as the Internet, Cloud computation, Data Analytics, Digital twin, etc to the physical manufacturing world through Cyber-physical systems (CPS) [1]. As a result, these characteristics and technologies of Industry 4.0 turn from traditional factories to smart factories. A smart factory is changing the factory environment with manufacturing facilities or resources such as machines, robots, actuators, sensors, etc that are integrated and possess real-time intercommunication between each other [2]. Hence this research project focus on the influence of industry 4.0 on manufacturing facility design. As a result, a modified facility design process is proposed to achieve the outcomes of Industry 4.0 Facility Layout. This might help in distinguishing in the future to know whether to follow traditional facility design process or new facility design process to create a smart factory.

To conduct the project research, analysis was made on the concept Industry 4.0 to gain deeper knowledge about the concept. To implement Industry 4.0 technologies, there were six design principles: interoperability, decentralization, virtualization, capacities in real-time, service orientation, and modularity & reconfigurability. So, the changes with manufacturing facility design are analysed under the influence of Industry 4.0 principles and technologies. After researching the concept of Industry 4.0, traditional facility design was analysed to know the methods and processes involved to design greenfield manufacturing facilities. Muther’s systematic layout planning was considered as a traditional facility layout design process to study the changes influenced by Industry 4.0 technologies and principles in the designing process of the facility layout. Later, analysis was made on the changes that occurred in the manufacturing facility design components by Industry 4.0 technologies and principles. So, those changes help to propose modified facility designing steps to create a smart factory. Concerning Muther’s systematic layout, modified Industry 4.0 facility designing steps were developed., those design steps depict that Industry 4.0 expects modular layout and material handling equipment with intelligent algorithms for adaptive scheduling and flexible moment.

To evaluate the modified Industry 4.0 facility design steps, a case study on the virtual manufacturing company is conducted. In which, two facility layouts are created using traditional facility designing steps and Industry 4.0 facility design steps. As the evaluation process is carried out by comparing the outcomes of both facility designing steps. Outcomes of both facility layouts are compared with the factors such as layout, material handling equipment, production capacity, dynamic shop floor efficiency, autonomous level, and cost. The Facility designing steps of both the facility layouts are evaluated quantitatively and qualitatively. For quantitative analysis investment cost and maintenance cost of the facilities are compared and for qualitative analysis, layout and material handling system designing process is discussed by comparing both the facility designing steps. Outcomes of the facility layout also provide the key technologies required to create smart factories. Analysis of the case study concludes that Industry 4.0 facility layout is economical, dispenses faster response to the product change, and provides higher productive time than traditional facility layout.

1. Chapter 1

This chapter provides an overview of the project work and the content of the report. Section 1.1 introduces the concepts that are discussed in the project. Section 1.2 defines the objective of the project so that it reflects the final goal of the project. Section 1.3 defines research questions that could be answered by this project work. Section 1.4 shows a research framework that reflects the structure of the project report. Section 1.5 – Literature review briefs about the method of getting the resources that are used in this project work. Section 1.6 explains the research methodology on how this project is carried out to reach the goal or accomplish the research objective. Section 1.7 concludes the chapter with what knowledge the reader must continue reading the report.

1.1. Introduction

This is an MSc project based on the topics of the fourth industrial revolution and manufacturing facility design processes and it provides an insight towards the future development of manufacturing facility design processes. In the competitive nature of industries, manufacturers need to implement new methodologies[3]. As industrial production is revolutionized by the digitalizing technologies, the high-tech strategy of the German government introduced Fourth Industrial Revolution (Industry 4.0) for computerization of manufacturing[4]. The incessant innovations of the Internet of Things (IoT), Cyber-physical Systems (CPS), Internet of Services (IoS), Big data, robotics, augmented reality, and cloud and cognitive computing results in important changes in the production system[4]. The academic literature has given more importance to the topic Industry 4.0 and it remains non-consensual. This new Industrial revolution connects physical and digital worlds through Cyber-Physical Systems improved by the Internet of Things and these changes are expected to make major changes in markets and economy, enhancing the production processes and increasing productivity, changing the product lifecycle, creating new business models, changing the work environment and restructuring labour force[2]. However, it is believed that industry 4.0 is still a conceptual phase and there would be a misunderstanding in researching about the mission and vision and what involves in Industry 4.0[2]. There is a fact that 80% of the Industries all over the world know the significance of Industry 4.0 and they consider it as an opportunity for their development. Apart from that 80% rest of the industries does not bother about this industrial revolution as it does not affect their working condition or manufacturing processes[1].

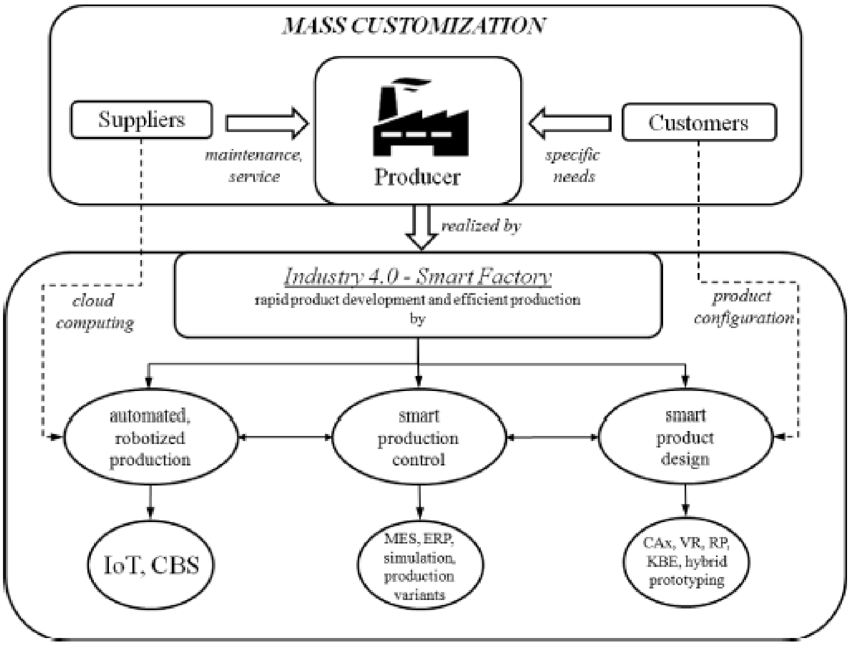

Figure 1 Mass Customization Strategy by an Intelligent Factory[5]

Industry 4.0 is a "Mass Customization" in manufacturing industries, as it focuses on fulfilling individual customer satisfaction by production companies[5].

Facility design is a process of designing an organization using the physical assets of the company to make efficient use of resources such as people, material, equipment, and energy. Facilities design includes things such as plant location, building design, plant layout, and material handling systems. Manufacturing facilities are defined to be the building that puts labour, material, and machines together for manufacturing a product or providing a service. Selection of the location is one of the fundamental aspects of facilities planning. This factor would influence the availability of the resources like raw materials, energy supply, and labour force. The profitability and productivity of the company depend majorly on the manufacturing facility design and material handling systems. A facility design (plant layout) project is one of the challenging jobs for the manufacturing engineer or industrial engineer. [6][7][8]

The manufacturing facility design process is the task of designing plant, layout including, material handling, information and communication, construction, public works, and other important contents. Designing or redesigning complex systems like manufacturing facilities and their processes evolve within the production system and this concerns capital investments and operational costs. So, designing the right production system with available facilities plays an important role in efficient manufacturing. A well-designed facility allows for effective shop floor control and in turn reduces lead time and increases productivity [9][10].

Considering the industrial revolutions from the beginning there is always a major update with the technologies that make manufacturing more and more autonomous, from mechanical working Industries to automated working factories. Now in the Fourth Industrial revolution i.e. Industry 4.0, Industries will be working on intelligent shop floors by creating adaptive shop floors through Industry 4.0 technologies. So, this project would give an insight into the influence of Industry 4.0 on the parts of manufacturing facility design and brief about how it is influencing[12][2].

1.2. Research Objective

The objective of this research project is to discuss the changes that occur in the current facility design and the facility designing process by the influence of Industry 4.0 and show the outcomes of the changes in the facility layout design. After discussing the changes in manufacturing facility design and facility designing process due to the influence of Industry 4.0, a modified facility designing process is proposed to implement on a case study and achieve modified outcomes of the facility layout. Using a case study, the proposed modified facility layout outcome and traditional facility layout outcome are compared. Fourth Industrial Revolution or Industry 4.0 is the upcoming future production and consists of major components like the Internet of Things (IoT), Internet of Services (IoS), Cyber-Physical Systems, and Smart factory[2]. These major components would make mass customization in the present manufacturing. Therefore, with the background information of the upcoming industrial revolution, this research objective would serve the companies in designing the manufacturing processes efficiently and economically with the upcoming technologies.

1.3. Research Methodology

The objective or goal of this research project is to find the changes in the manufacturing facility design process due to Fourth Industrial Revolution (Industry 4.0). To achieve this research objective, Qualitative data was required about the manufacturing facility design process and Industry 4.0. Because the change in the facility design process was not quantifiable. The data that was gathered was secondary data that was already collected by other researchers. Data to achieve the research objective was collected from research papers available in online search engines such as Google

Scholar, Web of Science, Scopus, IEEE explorer, and Science Direct. Within several research papers, necessary research papers were categorized through a year of publication i.e. 2011 and above, the highest number of citations, and with the search strings such as Industry 4.0, manufacturing facility design, Industry 4.0 and implementation, and manufacturing facility design, Industry 4.0, and manufacturing and design, Industry 4.0 technologies, smart manufacturing and Industry 4.0 facility design. After the gathered research papers, analysis was made on the qualitative data from those research papers. Analysis was made on the content of the resources based upon language, terminologies, images, etc. From the analysis of the data, the influence of the Fourth Industrial Revolution on the Manufacturing Facility Design process was found. This methodology is a standard comparison of two concepts, which was easier to follow and was able to implement in the project as quickly as possible. Apart from time and difficulty level, not to waste more time in looking for other methods this methodology was followed. But structuring the research project was difficult by following this research methodology due to its simpler approach.

1.4. Research Questions

Upon achieving the objective of the research project, different concepts are discussed in this report. Research questions provide an idea about the concepts that are going to be covered by the objective of this research. So, those concepts are framed as questions and mentioned below:

- What are the main Influences of Industry 4.0 in Manufacturing Facility Design?

This would be the main research question, on which this research project would be based. As the Industry 4.0 concepts are partially trial running in the countries of Germany, the USA, and China, exact methodology or implementation aren't concluded yet [1]. Therefore, this research project wouldn't reflect any implementation process or practical experimentation. So, from this main research question following some of the sub-questions could also be answered and those sub-questions are mentioned below:

a. What is Industry 4.0?

This gives a brief introduction to the Fourth industrial revolution or Industry4.0. It provides insight towards in what fields developments happen like in logistics, management or marketing, etc.

b. What are the technological developments in the sector of manufacturing from the Industry 4.0 point of view?

In every organization, innovation and technological developments play an important role by standardizing the different elements of manufacturing systems including both hardware and software. For efficient and secure data transfer, devices, input/output communication, and protocols must be standardized. However, there would be new challenges that would arise in the organization while implementing digital transformations as industry 4.0 would bring change in products and manufacturing systems regarding design, processes, operations, and services [13] [14].

c. What is Manufacturing Facility Design? and what are the processes, tools, and methods that are used currently, to design Manufacturing Facilities?

This question is all about briefing the concept of Manufacturing Facility Design and mentioning the process, tools, and methods used to create Manufacturing Facility Design.

d. What is the influence of Industry 4.0 on manufacturing facility design?

This question discusses the influence of Industry 4.0 on manufacturing facility design and discusses how it influences.

e. What are the outcomes of the Manufacturing Facility Design after considering the influence of Industry 4.0? and what are the modified processing design steps to be followed to achieve the Industry 4.0 Manufacturing Facility design outcomes?

This question discuss the changes that occur in the Manufacturing Facility Design outcomes and designing steps due to the influence of Industry 4.0.

f. How does the Industry 4.0 Manufacturing Facility Design outcomes and modified design process is analysed and evaluated?

In this question, changes in the outcome and the designing process of manufacturing facilities are analysed and evaluated, to validate this research project's findings.

1.5. Research Framework

The research framework gives the outline of the report and indicates the chapters included in the report. Figure 2 represents a schematic representation of the project flow in this report:

Figure 2 Research Framework

This project has been split into 7 chapters. The respective chapter contents and the answers provided by the chapters to respective research questions are discussed below:

Chapter 1 is the introduction to the report which reflects the objectives, introduction, framework, literature work of the research project. So, from this chapter, the reader could have an idea about the content of the report and indeed save time in reading the whole report if it's irrelevant to the reader.

Chapter 2gives the introduction about the concept of Industry 4.0 and briefs about the Industry 4.0 components, which include Internet of Things, Internet of Services, Cyber-Physical system, and smart factory and thus provides an answer for the research question 'a 'and 'b'. Those questions are said to be:

- *What is Industry 4.0?*
- *What are the technological developments in the sector of manufacturing from the Industry 4.0 point of view?*

Chapter 3 explains the Manufacturing Facility Design concept and the facility designing process. Next, briefs about the influence of Industry 4.0 on manufacturing facility components such as facility layout and material handling system. As a result, the main research objective and research question 'c' and 'd' are answered, and they are mentioned below:

- *What is Manufacturing Facility Design? and what are the processes, tools, and methods that are used currently, to design manufacturing facilities?*
- *What is the influence of Industry 4.0 on Manufacturing Facility Design?*

Chapter 4 is from the conclusion of chapter 3 and it explains Industry 4.0 influence on the manufacturing process, providing a deeper knowledge about the facility layout expected in Industry 4.0 shop floor. Chapter 4 adds additional information for the research question 'd'. i.e.:

- *What is the influence of Industry 4.0 on Manufacturing Facility Design?*

Chapter 5 describes the outcomes of the Industry 4.0 facility layout and material handling system. So, a modified facility designing process is proposed to achieve the Industry 4.0 outcomes of the layout and material handling system. Then concludes the chapter with Industry 4.0 facility design processing steps. Chapter 5 proposes a modified facility design process to achieve Industry 4.0 Facility Layout outcome, from the analysis of Chapter 4 and Chapter 3 content and conclusions. Thus, research question e gets the answer from this chapter. Research question 'e' is mentioned below:

- *What are the outcomes of the Manufacturing Facility Design after considering the influence of Industry 4.0? and what are the modified processing design steps to be followed to achieve the Industry 4.0 Manufacturing Facility design outcomes?*

Chapter 6 is the case study to implement the changes that are influenced by Industry 4.0 on the Manufacturing facility design process and discuss the outcomes of the Facility Layout. Proposed Industry 4.0 Facility Design process from chapter 5 and traditional Facility Design process Chapter 3 is implemented in the case study. Chapter 6 is concluded with the evaluation of Traditional Facility Layout and Industry 4.0 Facility Layout and discusses the key technologies of the Industry 4.0 shop floor. Answers to research question 'f' can be found in Chapter 6. The research question is mentioned below:

- *How does the Industry 4.0 Manufacturing Facility Design outcomes and modified design process is analysed and evaluated?*

Chapter 7 concludes and recommends by explaining the process of the project and the outcomes of the project and suggests some recommendations to improvise this project or help other projects. This chapter also discusses the limitations of this research project work.

1.6. Literature review

The term Industry 4.0 and Manufacturing facility design is the basic keywords to start the literature work. Initially, to find research papers on Industry 4.0, the highest number of citations, the year limited to 2011, and section manufacturing was limited. Assuming that, the highest cited would have reliable information and the concept Industry 4.0 was began in 2011. The manufacturing section was chosen because of the research objective. Almost all the research papers related to Industry 4.0 search string mentioned in Table 1 are selected on these factors. For Manufacturing facility design factors such as recent year, highest cited, and research papers with Muther's systematic layout planning as a keyword is used to filter the research papers. Apart from filtering in the websites, some of the research of the papers were filtered through keywords and the conclusion of the research paper. For Industry 4.0, keywords such as Industry 4.0, smart factory, intelligent material handling system, cyber-physical system, etc were used to filter out the papers. Google Scholar, Scopus, IEEE Explorer, Web of Science, and science direct were some of the popular well-known search engines. If there weren't enough research papers available on the database, alternatively other databases were used. Even to check the quality of the content of the research paper, multiple databases were useful. As the research project is based on Industry 4.0 and Manufacturing facility design, only those terms with different combinations were used as search strings. In the below, table number of papers selected from the search engine has been mentioned.

Industry 4.0 is called with various terminologies like smart manufacturing, intelligent manufacturing in the different parts of the world like the United States, Germany, and Japan [1]. Below Table 1 represents the number of resources that are picked up from the respective research database:

Search strings	Google Scholar	Scopus	IEEE Explorer	Web of Science	Science Direct
Industry 4.0	14	3	0	0	2
Manufacturing Facility Design	2	0	0	0	6
Industry 4.0 and Implementation and Manufacturing Facility Design	0	2	2	0	0
Industry 4.0 and Manufacturing and Design	4		2	2	0
Industry 4.0 Technologies	0	1	0	1	0
Smart Manufacturing	1	2	0	0	0
Industry 4.0 Facility Design	0	0	2	0	0

Table 1 Literature Review Classification

1.7. Conclusion

This chapter gives an overview of the research project and the purpose of this research project is mentioned in the research objective. The working flow of the research project is known from the research framework. The literature review provides an idea about the resources that are filtered and used for the project. Finally, research methodology provides the process of developing this project and the method followed for validation of the project. By the end of this chapter, anyone could have an idea about the content of the report.

2. Chapter 2 - Industry 4.0

This chapter explains the fourth industrial revolution, which is the current advancement in Industries. Initially, section 2.1 Introduction elaborates on the meaning, history, impacts, and integration of Industry 4.0, which is necessary to know how it started and how it is getting integrated with the current Manufacturing Industries. Then section 2.2 principles of the Industry 4.0 are mentioned, briefing the direction of this industrial revolution. Later section 2.3 describes technologies of industry 4.0 and it gives an idea about technological advancements that come across in factories. Finally, Industry 4.0 in manufacturing has been explained and the purpose is to educate about how manufacturing is going to be shaped under Industry 4.0 apart from a business and management perspective. The chapter is concluded with outcomes of reading about this chapter.

2.1. Introduction

The current issues among the major competitors in the Global Industry are labelled as Industry 4.0. Industry 4.0 is the fourth industrial revolution that has been named for the next generation manufacturing methods and it’s the term that explains industry automation, robotization, and digitization. As there is a decrease in Industrial value share in western European countries by 25% from 36%, these problems drive the Industries towards technological development for reducing the labour force, shortening the developing time of the product, and using resources efficiently [12]. Industry 4.0 is based on improving computer and communication systems with the use of cyber-physical systems. It’s mainly focused on the direction of innovation. These new technological advancements and concepts started to emerge in the year 2011 Fair event at Hanover, Germany, and have a lot of unsolved research questions and in only a few countries we could find the partial implementation of industry 4.0. It is also known as “Smart Manufacturing”, by which it is a new paradigm with new technologies supporting accurate engineering and decision making by converging through the existing manufacturing systems. Industry 4.0 will benefit manufacturers by making sensors, machines, products, supply chain, and necessary objects to exchange information and control actions with each other independently and autonomously. Figure 3 represents the framework for a product. The main aim of Industry 4.0 is to unite all the smart machines, storage systems, and manufacturing facilities through CPS. So, this leads to smart products that could be identified and located after manufacturing. So that product maintenance is done regularly and autonomously. This new revolution will make a trend of connectivity, service orientation, advanced materials and processing technology, and collaborative advanced manufacturing networks; networks of advanced manufacturing devices controlled by computers combining them into a physical-digital environment. This trend includes the whole value chain from raw materials to end-use to recovery, impacting business and support functions like sales and supply chain. To differentiate from the traditional production system, Industry 4.0 possess four key points: vertical integration of production system, horizontal integration with the new generation of global value chain networks, flow production through the entire value chain, and acceleration using Smart Technology. As a result, Industry 4.0 will create opportunities for new business models, the latest solution offerings, and new products. This leads to greater challenges in many forms, likely in the incorporation of new IT capabilities, the impact of exponentially increasing amounts of data from sensors and connected devices in the operating environment, suppliers, and distribution networks. Industry 4.0 also leads to the emergence of self-regulating and adapting supply systems. This also includes the risk in data security as there will be an increase in the connectivity of the systems. [13][14][15][16][17][18][2][12], these references are mentioned to indicate the above paragraph is based upon the analysis of the information mentioned in those references.

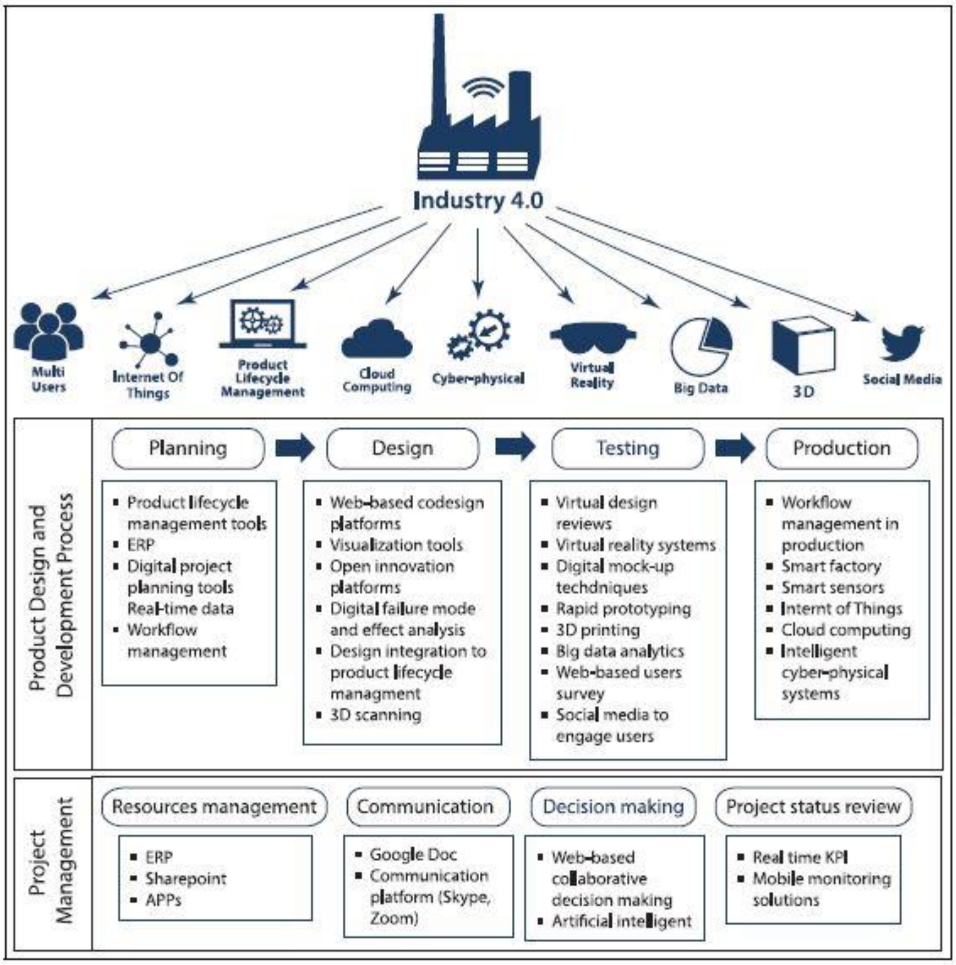

Figure 3 Framework of Industry4.0 for a Product

To begin with the history of the industrial revolution, Figure 4 represents the revolution of industries from the First industrial revolution to the present Fourth industrial revolution. The first industrial revolution was started in mid of 18th century and ended in the 19th century with the beginning of mechanical production facilities. Electrification of the production facilities and assigning works for the labours was started in the second industrial revolution during the 1870s. In 1970, the third industrial revolution started with the digital revolution using advanced electronics and information technology, which developed further the automation of the production process. Then in 2011, an initiative for self-behaviour machines with some automation called “Industry 4.0”, the Fourth Industrial Revolution was started. In the last few years, there are drastic changes in the industrial landscape resulting in successive innovations and disruptive developments, especially in the field of digital technology and manufacturing. Comparing Industry 4.0 to the previous three industrial revolutions would make a huge technological development. Using steam power first industrial revolution increased productivity and efficiency, the second industrial revolution started mass production using electricity, and the third industrial revolution started automation using electricity and Information Technology. The emerging fourth industrial revolution involves rapid growth in computer and automation technologies, network communication, digital manufacturing, and many other related areas. From the first industrial revolution till today manufacturing facilities are gaining self-behaving capabilities from each industrial revolution. So, the main idea of Industry 4.0 is to develop intelligent, integrated, and fully autonomous factories. [2][19]

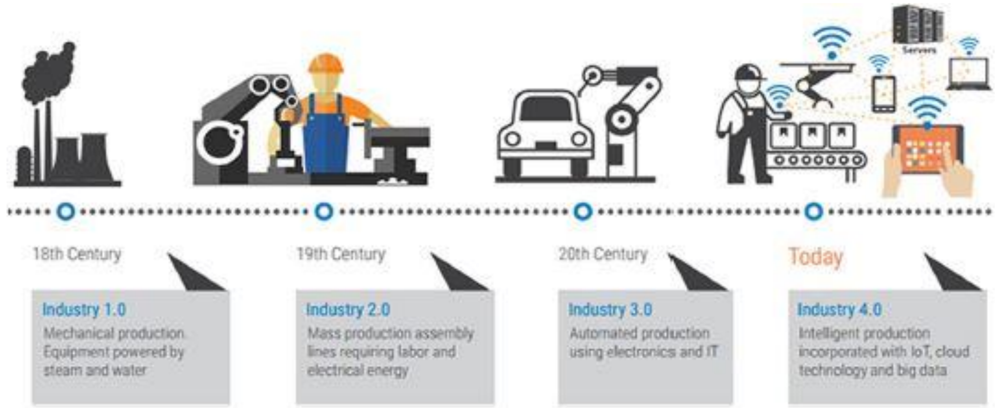

Figure 4 Industrial Revolution[19]

This industrial revolution impacts several domains that go beyond the industrial sectors. Its impact has been categorized into six main areas: (1) Industry, (2) Products and services, (3) Business models and market, (4) Economy, (5) Work environment, and (6) Skills development.[2]

1. Industry – It is the major sector that suffers from the impact of industry 4.0. This makes manufacturing decentralized and digital production, where production is carried out autonomously by controlling themselves, responding to the environment, and triggering actions. The new model of production proposes mass customization instead of mass production; therefore, the complexity of the processes increases gradually. This new industrial revolution changes the current industrial landscape through three main points: (1) Digitization of Production, (2) Automation, and (3) Linking the Manufacturing site in a comprehensive supply chain. Every Industrial revolution aims to increase productivity, but the fourth industrial revolution goes beyond increasing productivity by affecting the supply chain from product development and engineering processes to outbound logistics.
2. Products and Services – In the last few years, the economic landscape and dynamic market requirements have resulted in an increased demand for the development of more smart and complex products. This promotes mass customization and leads to products that are more configurable and modular by satisfying customer requirements. Therefore Industry 4.0 promotes innovation and introduces products and services with embedded systems for tracking them in real-time and optimizing the whole value chain by providing information about their status during their lifecycle.
3. Business Models and Market – It has been rapidly changed with innovative business models. The emergence of industry 4.0 technology led to change in the selling of products and services, impacting traditional businesses and bringing new business models and opportunities. Since industry 4.0 brings a close connection towards customers and manufacturers, allowing a closer interaction with customers and adaption of business models to market requirements. An increase in the digitalization of industries makes the system more complex and competitive by eliminating barriers between information and physical structures.
4. Economy – As digitalization converge the physical and virtual world and have a wide range of impact on all economic sector. This plays a major role in productivity and competitiveness and thereby driving the system towards innovation.
5. Work Environment – It has been changed quickly due to the reason of technical advancements and transformation of jobs and skills. The most remarkable change would be the human-machine interface. Which holds a new set of collaborative works. There would be an increase in smart machines with sensors and CPS systems, and fully automated robots enhancing the digitalization of the current manufacturing environment. The ergonomics of the workplace is

taken care, of by focusing more on workers and their importance. There would be change job profiles with the jobs of higher management and it's a challenging task to redefine the current jobs.

6. Skills Development – This is one of the most important key factors for the adoption and implementation of the industry 4.0 framework. High-quality training is required for learning the new technologies that have been implemented in modernizing the current manufacturing. There would be a massive impact on the labour market and professional roles because of the new industrial paradigm and it would be crucial to ensure that new jobs created would compensate for the number of jobs that disappeared. For the new technological trend, workers must be ready to perform new tasks, engineers should be trained like professionals of the future and the managers must learn new business strategies required for the new market. Moreover, highly qualified staff are required in the technological field to understand the concepts and implementation processes adapted in industry 4.0.

This is a methodology followed to integrate Industry 4.0 to the industries, so one must have an idea of how to connect different systems or sectors of the industry. There are three types of Industry 4.0 integrations, Horizontal Integration, Vertical integration, and End-to-End integration. Figure 5 represents Industry 4.0 integration below:

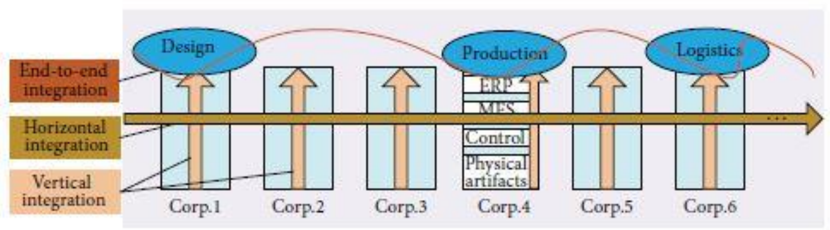

Figure 5 Industry 4.0 Integration Aspects [20]

a. Horizontal Integration: It is the value network that collaborates inter-corporation of the system and creates an efficient eco-system. Finance, information, and materials flow among the corporations smoothly if there is good collaboration and from these new business models will be emerged.
b. Vertical Integration: It is the process of integrating information or signals of different levels of the factory such as control, actuator and sensor, production management, manufacturing, and corporate planning. Vertical integration is an important process in building a flexible and reconfigurable manufacturing system through its information flow from all the levels to the Enterprise Resource Planning (ERP) level of the factory. This integration makes the manufacturing transparent and supports the implementation of self-organizing smart machines, that can dynamically reconfigure to adapt to different product types.
c. End-To-End Integration: In a product-based manufacturing company, there are certain activities such as customer requirement expression, product design and development, production planning, production engineering, production, services, maintenance, and recycling is involved. Integration of these activities would create a continuous and consistent product model, which can be reused by every stage and its effects can be foreseen through a powerful software tool chain to check whether the product customization is enabled.

2.2. The Design Principles of the Concept Industry 4.0

Design Principles of Industry 4.0 are developed to identify the technologies that help implement Industry 4.0 and Industry 4.0 technologies are mentioned in section 2.3 of Chapter 2 - Industry 4.0. These principles are useful at the time of the planning stage to construct an Industry after deciding the product and product design. Using these principles as supporting pillars for creating a manufacturing system, a checklist can be made and check whether the upcoming Industry meets all the design principles. And it is not mandatory to use all the principles but some of them are interdependent and some of them use similar technologies as others. Those design principles are discussed below:[21]

d. Interoperability – It is an important means that would connect CPS (Cyber-Physical Systems) and people through IoT (Internet of Things) and IoS (Internet of Services). Its main aim is to bring cooperation among all the elements of the company. It also focuses on human resources in connecting, communicating, and operating together through the Internet of Things (IoT), Internet of Services (IoS), and Internet of People (Internet of people). This is purely concerned with data communication of the systems.

e. Virtualization – Virtualization enables the "Digital Twin" of the smart warehouse, smart factory, all the equipment and machinery, and even smart products by merging the sensor data from the physical world into virtual or simulation-based models. Through CPS, virtualization can monitor physical processes. So that process engineers and designers could enhance the existing process or optimize the functionality of production lines in complete isolation without disrupting the physical processes they have virtualized. Digital twin creates a digital footprint of the new or existing products, enabling manufacturers to have the whole lifecycle of the product from design and development to the end of the product. Virtualization is not only about getting real-time collecting data but also involves real-time data analysis, real-time decision making, and even real-time cyber-security attack detection.

f. Decentralization –It is the process of making every different component of the smart factory work independently and make autonomous decisions to succeed in organisational goals. Cyber-physical systems (CPS) are one of the key enablers of making the system self-regulating and creating an intelligent-control mechanism. CPS enabled embedded computers to make decisions on their own and in case of failure tasks, are delegated to higher-level decisions. For smart factories, decentralisation means RFID tags that tell the machines which working steps are necessary. From decentralisation, central planning and controlling might be no longer needed[22].

g. Capacities in real-time – Control systems are essential to collect and analyse data in real-time to indicate a malfunction or to shift the production line. It is more towards creating smart products that are embedded with sensors to communicate with the environment and collect, store and transfer data, during their life cycle. It means during manufacturing, smart products in production lines can communicate valuable information regarding the place of manufacturing, current state, and future steps they are going through to become the desired product.

h. Service orientation – In creates customer-oriented production. Through the Internet of service, customers from their smart gadgets can order or customize the products. And this customisation directly goes to the factory and factory responses by making necessary changes with the manufacturing process. So, smart factories with a service-orientation strategy are not just selling the products but they are also selling the services that allow the customers to customize their products. Service orientation focuses on customer-oriented production in smart factories. For this service, they use a real-time data monitoring system and analytics method to identify the process, equipment, or market changes.

i. Modularity and reconfigurability – Modularity and reconfigurability is the design principle that refers to creating modules either in business models or in a manufacturing system so that those modules can be reconfigured for the changing requirements and needs of Industry. Modules are creating individual components from the larger product. Modularity makes a change of process or equipment easier and more flexible. For example, the Display screen, monitor frame, monitor stand, etc are the different modules of a Monitor. In manufacturing, it is focused on designing production for flexible material flow systems, modular decision-making procedures, and flexible processes. Modularity creates product personalisation manufacturing which is more customer-oriented production. Modular systems easily get adapted to the changing requirements to change or extend the module for fluctuating product characteristics. Technologies such as CPS, IoT, automation, and additive manufacturing have enabled product reconfiguration based on continuous changing of customer preferences. From IoP (Internet of people), simulation and data analytics demands of the product are forecasted and manufacturing is reconfigured according to the product preferences.

2.3. Technologies of the Industry 4.0

A new generation of technologies is arriving to support the Industry 4.0 principles for implementation in the current and future industries. It is assumed that Industry 4.0 technologies tend to dominate the production process through implanted technologies, cooperating and coordinating machines, self-decision-making systems, autonomous problem solving, learning machines, etc[19]. Factories equipped with sensors, actors, and autonomous systems are known to be smart factories and this technological development makes the manufacturing process more intelligent, flexible, and dynamic. This up-gradation of the technology is called to be Industry 4.0. As this technological development has a major impact on fulfilling the capacity requirement, complexity, and standard quality of the products, it is the major goal of industry 4.0. Interconnection between IoT, IoS, and CPS enables smart factories, to encourage the idea of the decentralised production system. In decentralised production system humans, resources and machines communicate with each other like they used to do in the social network. Tracing products in smart factories is way easier, as they are independently gone through the production processes.[17]. Industry 4.0 makes some of the technological advancements for the present generation of manufacturing. These technologies are already present in current factories, but with the implementation of industry 4.0 they transform production: isolated, optimized cells will come together as a fully integrated, automated, and optimized production flow. This led to higher efficiency and changing traditional production relationships among suppliers, producers, and customers. Below are the following technological advancements other than basic components of industry 4.0 [16]. Following are the basic components of the concept Industry4.0.[23][2]

1. Internet of Things (IoT) –It is the technology used for networking machines and transferring data from the physical world to computer-based systems. With the help of this technology data collected by the sensors of the machines can be exchanged for improvement of productivity. Sensing, networking, service, and interface are the architectural steps of IoT. As the internet is the globally connecting network it is used to connect the manufacturing systems by transferring the data for economic production. IoT is generally organized in a vertical automation pyramid in which sensors and field devices with limited intelligence and automation controllers into a widespread control system of manufacturing processes. Due to the facility of interaction between the machines, even the unfinished products can be

upgraded with the standard technologies.[23][20][15], data from these references were analysed to discuss the Internet of Things.

Internet of Services (IoS) – It is a technology that uses the internet to provide all the services regarding the product. By connecting the network of the manufacturers and customers, it helps to deliver the products all over the world and brings the recognition of the products. Figure 6 represents the architectural structure of IoT and IoS, showing the purpose that serves in the Industry. The intention behind this technology is to provide services through web technology, so private consumers and companies could combine and create new value-added services.[23]

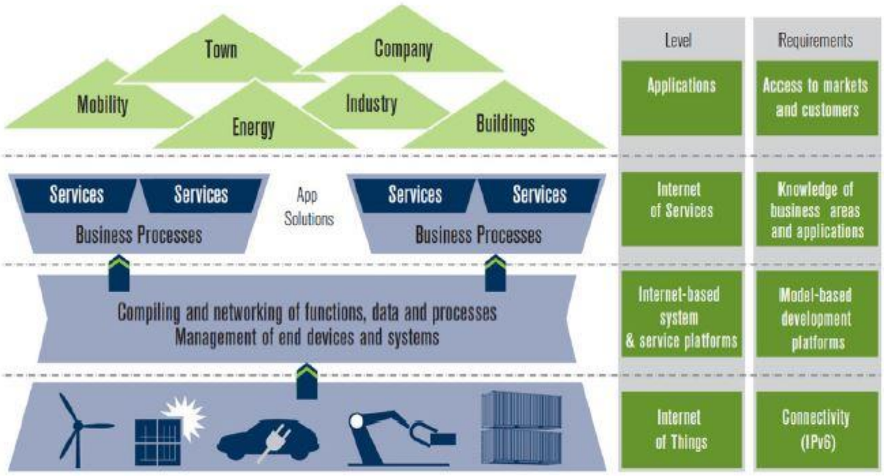

Figure 6 Architectural structure of IoT and IoS[15]

2. Cyber-Physical Systems (CPS) –It is also known as Embedded systems. This technological system connects physical assets and computational capabilities. To turn today's factories into industry 4.0 factories, implementation of CPS with logistics, services, and production departments is mandatory. Because they are the systems integrated with large information about any physical asset and run the system autonomously. All autonomous systems are based on CPS, in which physical assets are controlled by the information present in the embedded systems. From the manufacturing point of view, CPS helps in synchronizing the information related to the physical shop floor and the virtual computational space. It facilitates efficiency, transparency, surveillance, and a whole new degree of control in the production process. [24][23]

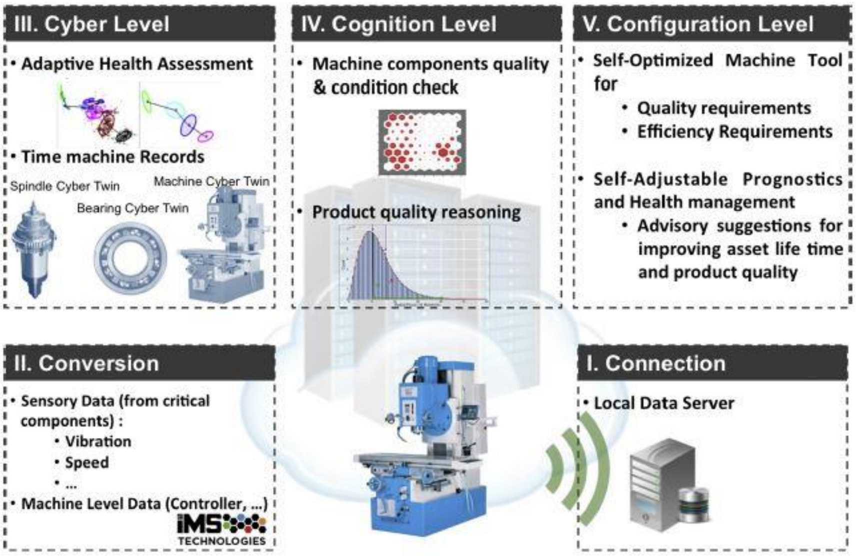

Figure 7 Framework of CPS[24]

In particular, Cyber-Physical System (CPS) is the core technology for the development of the industrial revolution from industry 3.0 to industry 4.0 and is transforming global advanced manufacturing[3]. Figure 7 shows the framework of CPS oh how cyber and physical systems are connected and work together. CPS takes the responsibility to make the changes to the current environment by recognizing the physical world, processing those perceptions as data in computers, making calculations, and indicating systems to take necessary actions. For implementing new technology to the existing systems, a CPS architecture is proposed. The proposed architecture is the Five-layer configuration shown in below Figure 8.

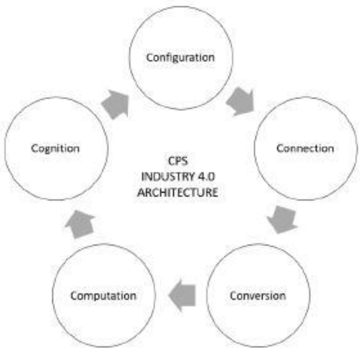

Figure 8 5C CPS-Architecture[3]

Connection is the bottom-most layer and it's the initial step in integrating the elements like sensors, protocols, and actuators. This connection gains more importance when it is applied to the systems like Enterprise Resource Planning (ERP), Customer Relation Management (CRM), and Supply chain Management (SCM). The next step is conversion, where many types of interferences happen from the information received from sources like cloud computing and big data analytics. Calculating the lifespan of multiple items or machines is made easier with an analytical model from an industrial point of view. Computation is the stage where software, algorithms, and computer-based infrastructures are used to analyse present work and predict the future behaviour of logical software constructs like architectures, algorithms, and security. Cognition represents the information gathered in the previous steps and thus helps in decision making. Configuration is the final step where the transformation of intelligence to action happens and helps machines to translate decisions to real-world actions.[3]

CPS plays an important role in designing and developing future engineering systems by providing the capability to increase the levels of autonomy, functionality, usability, reliability, and cyber-security. Other key technologies like IoT, IoS, Cloud computing, etc are integral to CPS.[3]

3. Autonomous Equipment - This autonomous equipment is flexible and interactive with each other through artificial intelligence. Autonomous equipment includes robotic arms and Automated Guided Vehicle (AGV). As robots are interconnected, they work together adjusting their actions automatically and completing production smoothly. These robots are also known to be collaborative robots or Cobots, which work in collaboration with humans. Initially work is learned from humans and starts to work side by side safely without causing any harm. AGVs with new generation algorithms can choose between the multiple tasks with their artificial intelligence and get adapted to the change in production processes. Autonomous production is economical because of the low cost of robots and the high range of capabilities than the ones which are used today.
4. Simulation – These simulations reflect real-time data to virtual model that includes machines, humans, and products. This helps the operator to run the process and test whether the process is at an optimal level to start the production in real-time.
5. Big Data and Analytics – It's a recent technology in the manufacturing world, which improves production quality, saves energy, and improves equipment service. This technology helps in collecting the data from various sources or production equipment and as well as from enterprise and customer management systems, then evaluates for efficient production.
6. Horizontal and vertical system Integration – Its main intention is to connect companies, suppliers, and customers and then within the departments such as engineering, production, and service.
7. Cybersecurity – It's the protection given to the Industrial systems and manufacturing lines. As a result, reliable communications and secure access of the machine information are carried out.
8. The Cloud – As of now companies are using this software for some enterprise and analytics applications, but with industry 4.0, more production-related information is shared across company boundaries. As a result, machine data and functionality will increasingly be deployed to the cloud, enabling more data-driven services for production systems.
9. Additive manufacturing – Currently, additive manufacturing like 3D printing is used to make prototypes and individual components. But with industry 4.0, this will be used widely in manufacturing products that have complex designs.
10. Augmented reality – This technology provides a variety of services in which all the operations are carried out on mobile devices. For industry purposes, it helps in selecting products in the warehouse and indicates repair instructions.

2.4. Industry 4.0 in Manufacturing

The fourth industrial revolution represents new technologies in the automation of manufacturing processes, data processing, and data exchange. It develops communication between the machines leading to efficient and faster manufacturing. At present most of the industries are advanced machines with standard software's but Industry 4.0 focuses on using advanced software in typical machines so that advancement in technology and processes could be continuous.

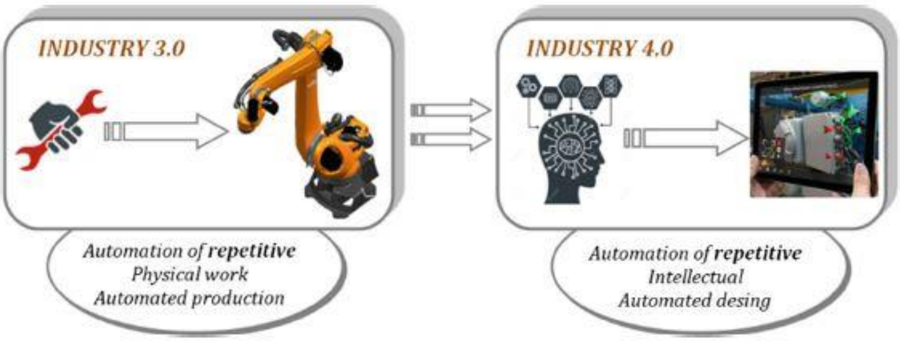

Figure 9 Updating Manufacturing Process from Industry 3.0 to Industry 4.0 [25]

Figure 9, shows how the manufacturing process is being updated. In Industry 3.0, automation of repetition requires physical work and automated production. But Industry 4.0 utilizes intellectual work and automatic design for the automation of repetition. The necessity for the implementation of industry 4.0 to the manufacturing requires the ability to communicate and develop a connection between Cyber-Physical Systems (CPS), people, and production processes, as well as successful linking of CPSs of various manufacturers. CPS in powerful computers creates a virtual copy of the physical manufacturing processes through intelligent sensors with virtual and simulation production models so that it makes decisions within the "smart factory" manufacturing process. In other words, intelligent sensors continuously monitor the process by collecting and processing the data which helps to direct the production process to another machine if the current process fails. Thus, monitoring the process and internet involves all the participants inside and outside of the manufacturing process.

According to the new industrial revolution, manufacturing needs to be more flexible adapting to the larger variety of products. In this sense, production systems should fine-tune their production process to the customised orders from the customer. At present highly customized products are manufactured in smaller quantities, but to achieve the larger size new trend has to be indulged to quickly modify and design the factory layouts and processing flow[26]

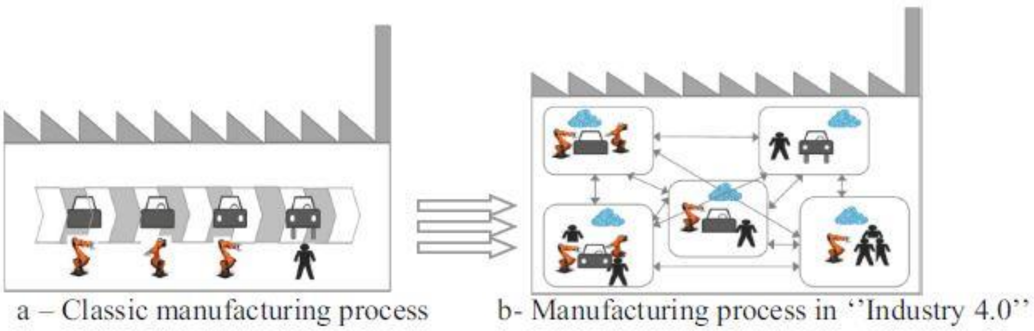

Figure 10 Difference between Classic Manufacturing and Industry 4.0 Manufacturing[25]

From Figure 10 we can see the difference between classic manufacturing and Manufacturing in Industry4.0. Classic manufacturing used line production and in automation, first-generation industrial robots were used by separating them from workers to prevent injuries. Due to this kind of rigid automation, it was very difficult to change the production line which consumed a lot of time to reorganize and reprogram. Industry 4.0 made closed connecting working cells for the production process and create a flexible movement of products. This closed-loop production process is equipped with the technologies like cloud computing, robotics & automation, intelligent sensors, 3D printers, and radio frequency identification- RFID to increase productivity, quality, introduce innovations, increase creativity, and better design to compete in the global market. Apart from this production cell, Industry 4.0 tracks the product path and provides the live location of the product. With all the new technologies like Cyber-physical system, Industry 4.0 focus on supplying the products right-time, right-quality, and right-place. The cyber-physical system not only creates efficient product delivery on the shop floor but also to the other enterprises outside the factory. [23] explains the implication of Industry 4.0 in the context of Just-in-Time (JIT) and Cross-company Kanban systems precisely. To show the Industry 4.0 initiatives concerning logistics management. Equipment connectivity, flexible movement of the materials or products, and adaptive scheduling concepts of Industry 4.0

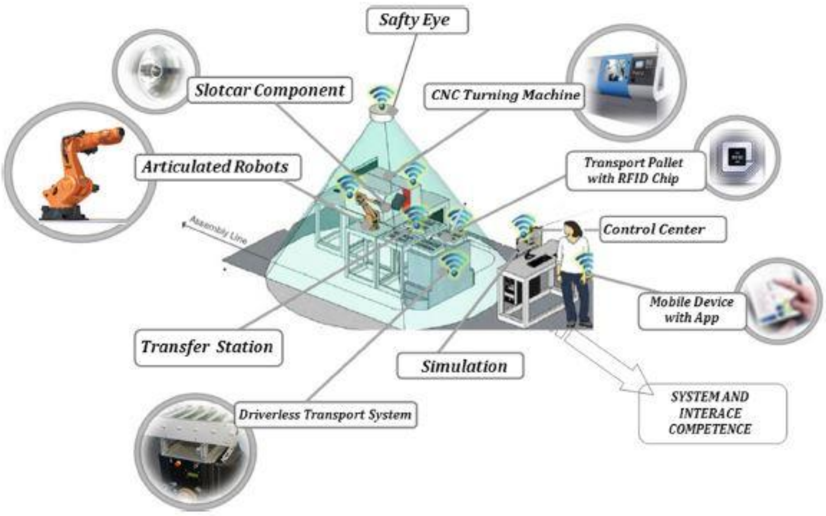

Figure 11 Physical automated and digital production cell[25]

Figure 11 is an example of an automated and digital/virtual production cell for a car rim. CNC lathe, industrial robot, transport station, transport robot, RFID chip conveyor, safety, the control center for simulation, and mobile device with the application to enter parameters are required for the machining of the car rim. All these devices are connected and communicate with each other exchanging data through cyber-physical systems. The equipment starts the work autonomous once they receive product-based commands externally or by the internet through the control technology. The manufacturing process becomes smarter when these production cells are connected through networks or this is also known as a smart factory.

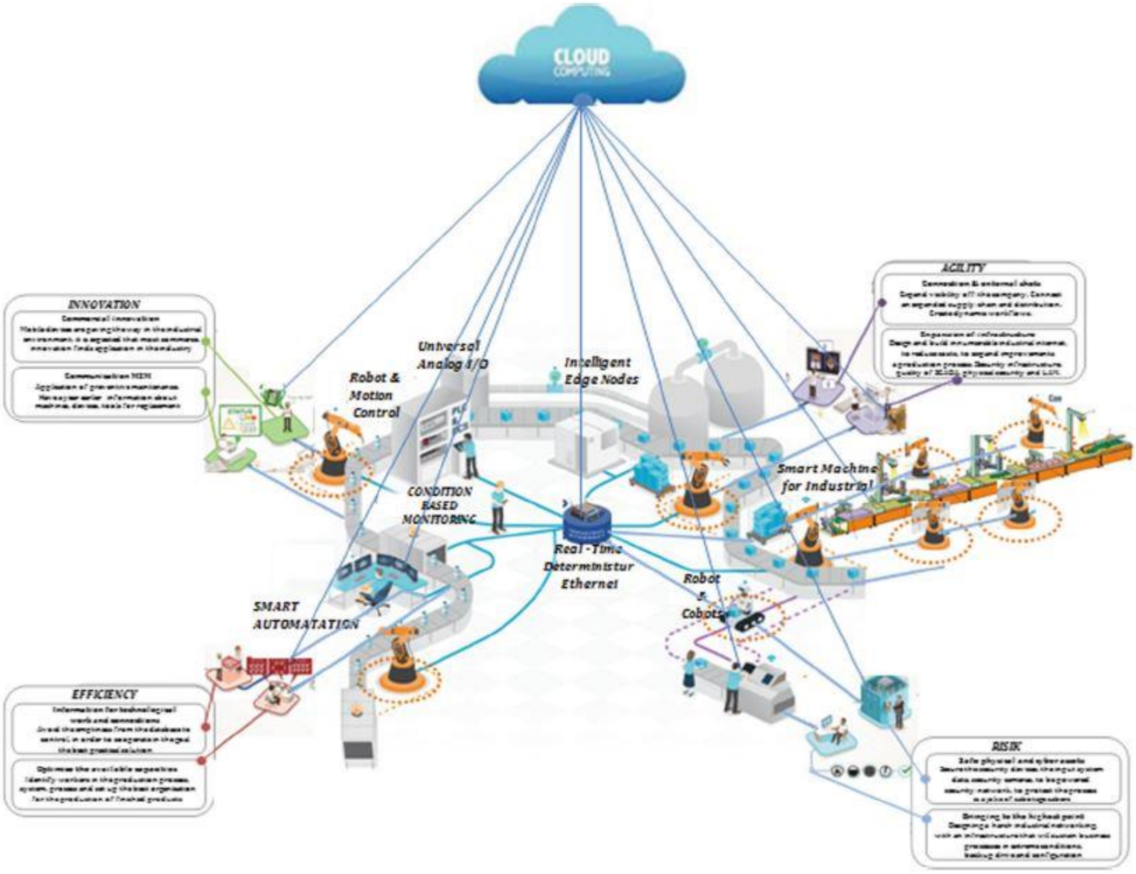

Figure 12 Scheme of Industry 4.0 application in the Manufacturing Process[25]

Figure 12 shows the important components of every industry in the sector of manufacturing that will focus on efficiency, innovation, agility, and risk. Communication between machine to machine helps in preventive maintenance and thus provides the information about machine and equipment for repair before a year.

2.5. Conclusion

This chapter provides an insight towards the concepts of Industry 4.0 i.e. answering question a, such as technologies that are used in the industry and the principles that are used to implement these technologies. Mainly, Industry 4.0 is the fourth industrial revolution that is focusing on merging the cyber world like data and networking to the physical world of manufacturing equipment and process. And one of the main motives of Industry 4.0 is to create a flexible manufacturing system that produces customer-oriented products. In addition to customer-oriented manufacturing, it also focuses on increasing the productivity of the factory economically. And this chapter explains the concept of Industry 4.0 and answer research questions 'a' and 'b'. Those research questions help to achieve the research objective by providing information about Industry 4.0 technologies and methods of implementation. So that, information from this chapter can be compared to the current status of the manufacturing facilities and conclude about the changes that occurred due to the influence of Industry 4.0.

To achieve such motives and objectives, Industry 4.0 brings certain existing technologies to the Industry. That is discussed below

- Cyber-Physical system–It is an embedded system that is responsible for making equipment or machines smarter to adapt to the dynamic condition of the shop floor.
- Internet of Things (IoT) – it is used to connect the system and equipment
- Big Data–It is used for data processing
- Cloud storage – it is used for data storage
- Digital twining – It is used to create a virtual shop floor for monitoring the manufacturing process

But to implement those technologies, Industry 4.0 comes up with 6 basic design principles that are discussed below:

- Interoperability – Using IoT, interoperability focus on connecting the machine and work communicating with each other.
- Decentralisation – With a Cyber-physical system, decentralisation enables the factory equipment's independent working and autonomous decision-making.
- Virtualisation - Virtualisation creates a digital twin of the physical components of the factory that are useful for monitoring and real-time decision making
- Real-time capacity – It is creating smart products with embedded sensors and knowing the information about the product life cycle and its manufacturing process.
- Service orientation – This design principle focuses on creating customer-oriented production through the Internet. This means customers can customize their product through their gadgets and it is directly received by the manufacturer.
- Modularity and Reconfigurability – Modularity and reconfigurability give importance to the facility and facility layout of the factory. In which the manufacturing processes are separated as modules creating modular layout and manufacturing processes are made reconfigurable by the flexible movement of the material to increase product customisation.

Industry 4.0 wants to create a new trend in connecting machines and create an adaptable shop floor for varying production processes. The variation may be either change in products or any disruptions in the machinery. Industry 4.0 tends to connect all the categories or the parts of the company such as business, marketing, and research groups. So that information flow happens, and any information would be updated anytime. The final section 2.4 of this chapter, segregates Industry 4.0 in manufacturing and narrows down the information about industry 4.0 related to manufacturing. In which, that information is the answer for the research question ‘b’. This helps future facility designs to compare and make the right choice in creating an Industry 4.0 factory. Industry 4.0 concepts put efforts to solve one of the major production problems i.e. producing a higher variety of products in larger quantity with lesser time than traditional manufacturing. By creating higher flexibility in the manufacturing system and increasing the efficiency by tracking and tracing the production process. Industry 4.0 allows the factories to use a limited number of skilled operators, resulting in higher autonomous production time. Industry 4.0 keeps all the sections of the Industry connected through horizontal, vertical, and end-to-end integration. This helps to run the Industry efficiently with better connectivity of all the sectors like marketing, sales, warehouse, shop floor, and inventory.

3. Chapter 3 - Manufacturing Facility Design

This chapter is focused on the concept of Manufacturing Facility design (MFD) and section 3.1 starts the chapter with an introduction, explaining what is manufacturing facility design. After the clear introduction about the manufacturing facility and the focusing parts of the facility. Section 3.2 mentions about design components of the facility design and it also explains which components are discussed further in the chapter. Section 3.3 mentions the types of manufacturing systems that are classified according to the production process, product demand, and technology. Section 3.4 discusses the design process of the manufacturing /assembly facilities, explaining the methods followed in each processing step. Relatively, section 3.4 briefs about the type of tools that are used in designing the facilities' design components. Section 3.5 of this chapter briefs about the influence of Industry 4.0 on the manufacturing/assembly facility design process and describes the outcomes of the influence. Section 3.6 concludes the chapter by discussing the major influence of Industry 4.0 on manufacturing/assembly facilities.

3.1. Introduction

Manufacturing Facility Design (MFD) is a process of designing facilities efficiently for a given production process that converts raw material into a finished product. To obtain the best possible design of manufacturing facilities, relative locations of departments and work centres of the facilities should be optimized. In addition, consideration of the different routings of parts and products would help to control the production and inventory. Production capacity, process design, product design, and schedule design provide input data in creating facilities design for all the manufacturing companies. To be simple and convenient the term Facility is classified to be facility layout and Facility Design Components. Facility location refers to the location where all the facilities are conveniently accessible for suppliers, customers, and other facilities. Facility Design components refer to the facility system, facility layout, and Material Handling system. A facility system is a structural system, enclosure system, atmospheric systems, safety systems, sanitation system, lighting and electrical system, communication system. Facility layout is the arrangement of equipment, machining, and furnishings on the shop floor. Material Handling Systems are the mechanisms required for facility interaction[27]. Below Figure 13 represents the facility classification:

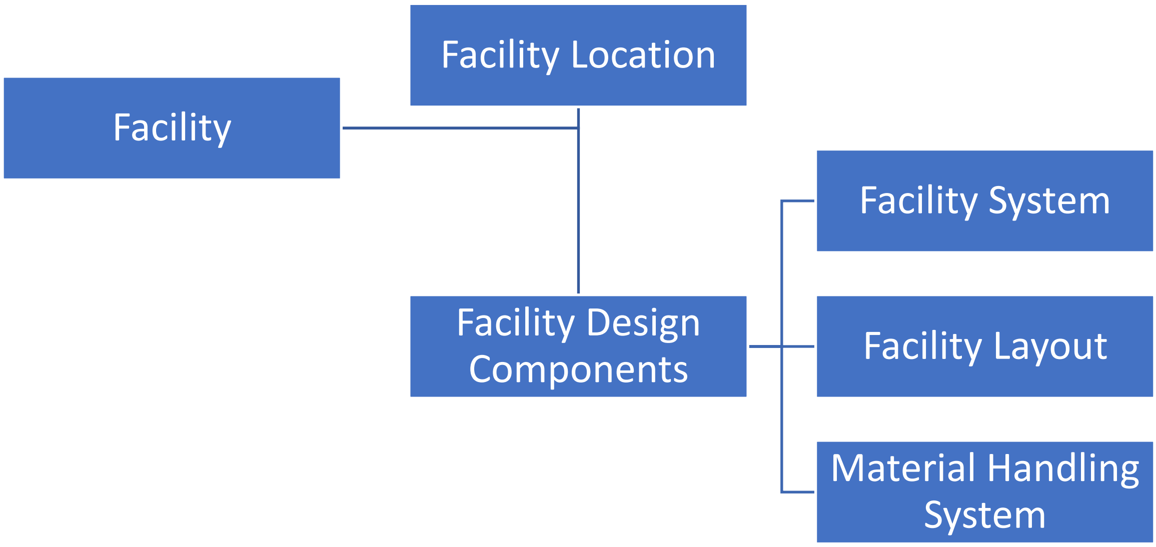

Figure 13 Facility Classification[27]

Before starting any facility designing project, it must be known to which type it belongs. Below are the types of projects that are classified based upon the current state of the manufacturing plant

- New Facility
- New Product
- Design Changes
- Cost Reduction
- Retrofit

A successful facility plan made for any of the above projects should help the company to achieve supply chain excellence. To create a successful facility plan, the designer must consider some of the characteristics in selecting the facilities and they are mentioned below:

- Flexibility
- Modularity
- Upgradability
- Adaptability
- Selective Operability
- Environmental and Energy Friendliness

Facility design objectives indicate the focus point of the planning process. Below are the objectives of the facility design process:

- Improve material handling and material control, so that it helps organizations for better production.
- Efficient utilization of resources such as equipment, space, people, and energy to decrease defects and improve the product or service quality.
- Lower the capital investment
- Flexible to the changes for future development
- Facilitate easy maintenance
- Creating safe working conditions for the employees and supporting job satisfaction

3.2. Facility design Components

Facility Design components are design elements of the manufacturing company apart from the location of the company. In this research project facilities, layout, and material handling system is the focus, and companies' infrastructure or System facilities are out of the project study.

1. **Company Infrastructure**–It is the part of facility design consisting of systems related to structure and environment, lighting, sanitation, safety, building automation, and digital maintenance of the company.

2. **Facilities Layout** - It is an outcome of arranging the production machines and equipment, workstations, location of materials of all kinds and stages, labours, and material handling equipment. Plant layout is defined as the process of obtaining the optimal disposition of the physical facilities of a manufacturing unit. To achieve the best design of the manufacturing facilities, the relative location of the manufacturing facilities should be optimal to the specified criteria. Optimal manufacturing facility layout reduces overall material handling cost, shortens throughput time, improves production planning and control function, efficient utilization of the space available, reduces work-in-progress inventory, and motivates efficient functioning of the manufacturing plant. From [8], basic layouts are mentioned below

- Product layout – It is also known as flow-line layout, assembly-line layout, production-line layout, and layout by product. In this production layout machines and workstations are arranged in the sequence corresponding to the sequence of operations that the product should undergo.
- Process layout – It is also known as job shop layout or layout by the process. In this type of production layout processing machines and workstations are arranged in an order of the process that the product would go through. So, in this layout machines that perform the same process are grouped.
- Fixed position layout – It is also known as project layout. In this layout, the product does not move anywhere on the shop floor. As the products are fixed at a position due to their bulky size, all the necessary machinery and labours are brought near to the product.
- Group Technology-Based Layout – This type of layout is also known as cellular manufacturing layout. In this type of layout, product families are created, and separate groups are created to manufacture those products. The difference between group technology and process layout is that machines in the groups of cells are not necessarily similar in their processing capabilities.

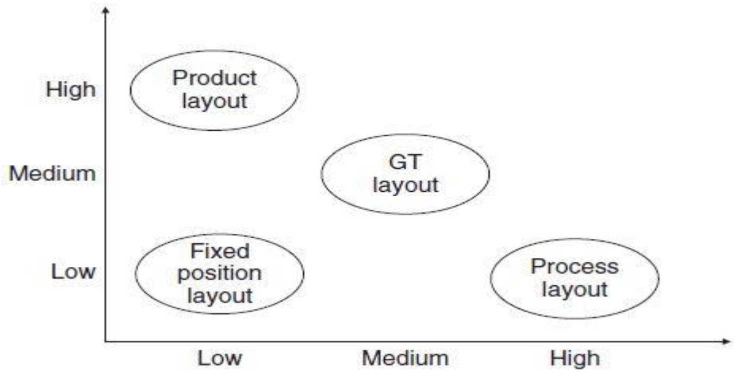

Figure 14 Layout Classification based on Variety-Volume[8]

The above Figure 14represents the different layouts capacities of manufacturing products with the respect to the volume and variety of the product.

3. **Material Handling System**–This part determines the type of material handling equipment to use and routings for the material movement. It's a system that handles the movement of the materials across the manufacturing layouts and the material handling system is the equipment that connects between two workstations. More than the area of work design and ergonomics, improving material handling systems would make a major impact on the betterment of labour comfort. In practice, material handling and facilities planning are single subjects. Improvement in material flow will automatically reduce the cost of production. 50% of industrial injuries and 40% - 80% of operating costs depend upon material handling systems.
In[28], the author mentions the principles that should be kept in mind while selecting material handling equipment for any facilities design.
    - Planning - plan to specify materials, movement, and method of handling before implementation
    - Standardization – standardizing the methods, equipment, controls, and software without dissatisfying the flexibility, modularity, and throughput.
    - Work – measure material handling works by multiplying flow by distance

- Ergonomic – it should be suitable for the working environment and comfortable for workers
- Unit Load – Maximum load that can be carried singly.
- Space Utilization – efficient and effective use of available space
- System – it gathers all interacting independent entities and creates a whole new entity
- Automation – It is the technology to control the movement of the material handling equipment according to multiple operations that are linked together and this whole system is controlled through programming.
- Environmental – material handling activities should be eco-friendly.
- Life cycle cost – It is the cost that includes expenditures spent on buying the material handling equipment until it is disposed of or replaced.

3.3. Types of Manufacturing System

Manufacturing systems differ according to their production process, product demand, and facilities design. From the focus of facilities design, generally categorized manufacturing systems have different facilities designs. So, to discuss those different facilities designs, these types of manufacturing systems are mentioned below:

- Custom Manufacturing System – In this manufacturing system expert craftsmen work on an individual product from the beginning till the finished product. So, the facilities are to be favourable to the skilled worker. For example, Handmade jewellery, handmade furniture, etc
- Intermittent Manufacturing System – This is the manufacturing system where products are manufactured only upon customers' demands and designs. This system uses skilled workers to switch between the products leaving certain machines idle. The clothing industry would be a good example.
- Continuous Manufacturing – This manufacturing system works 24 hours a day for the same production of the same products. Usually, this kind of manufacturing system uses fixed facilities as there won't be any switching off the products. This manufacturing system resembles the assembly lines of any product.
- Flexible Manufacturing – This is an intermittent manufacturing system with a higher level of robotics and automation. So that switching of the products happens with the less dependence on the skilled labours.

3.4. Manufacturing Facility Design Process

The facility Design process is the designing process of facility systems, facility layout, and material handling system with the inputs given by the product design and manufacturing/ assembly process design. There are two kinds of facility design objectives that are defined, and they are Greenfield facility design and facility re-design. Greenfield facility design is creating new facility design for the organization and facility re-design is to optimize the existing facilities. Here in this section facilities design process is explained through Design phase 1 and Design phase 2. Design phase 1 reflects facilities planning and Design phase 2 reflects the detailed design of the Facilities. Initially, the facilities plan gives a rough outcome of company facilities at the desired location. Facilities Planning helps the designing process to be more convenient and hassle-free, by giving structured information about the resources used in facility design. For example, facility designers to generate facility design through any designing software like CRAFT (Computerized relative allocation of facilities technique) would be easier to follow the facilities layout plan and check the outcome. So, any changes in process operations and products can be resolved in the facilities plan and reduce the design process complexity. Facility design is the detailed design of the facilities plan with all the precise measurements. In the current generation, computerized designing software is used to design the facilities of any company and the next topic explains the tools used in detail. There are certain evaluation criteria to evaluate facilities plan and facilities design, they are mentioned below in the evaluation section.

Designing Phase 1 (Facilities Planning)

1. Product Planning – This determines whether the product is manufactured or assembled in the company. Product planning also indicates the sequence of machines visited by the product, production volume, production capacity decision, production space analysis, and labour requirement. The Product Family Approach is one of the methods in designing alternative manufacturing systems for a product and it uses queueing models to get the best outcome[29]. Product operations define the routing of the product that is to be manufactured

2. Process Planning- In manufacturing facility design, the production process is the most concerning part. This data helps to indicate the manufacturing or assembly process for a new product and indicates changes in equipment or methodology for an old product to achieve an efficient manufacturing or assembly process. To design manufacturing process there is a need for certain data product design data, material data, Equipment data, Quality data, and the type of production

3. Layout Planning - Industrial revolution shows the significance of the layout in designing factories[8]. These layout planning steps are based upon Systematic Layout Planning (SLP) from Richard Muther and these general facility layout planning processes are commonly practiced by the manufacturing companies. This is not mandatory facility planning steps to be followed but it helps in bringing an efficient facility layout. As Muther’s SLP provides basic guidance for designing the new facilities, below mentioned design steps are constructed with the basis of SLP. Also, SLP provides several quantitative factors and a systematic approach compared to other schematic and graphical techniques[30]. Apart from SLP, these design steps are also referred to from “Design of Flexible Plant Layouts” [31]

    - Define Objective
    - Flow of materials
    - Determine relationship activities
    - Determine the Space requirements for all the activities
    - Generate alternative facilities plan
    - Evaluate the alternative facilities plan
    - Select the preferred facilities plan

4. Material Handling System Planning –In the planning phase, only the following information is determined.
    - Type of Material handling equipment
    - Purpose of material handling equipment
    - Material handling routing

5. Evaluation of facilities Plan – Certain evaluation criteria are quantifiable to choose the best facilities to plan among multiple alternatives. They are as follows
    - Material Handling cost
    - Labour requirement
    - Productivity
    - Space and Equipment Utilization

Design Phase 2(Detail Design)

In this phase, detailed design of facilities planning is carried out using designing tools that are explained in brief in the next topic. Designing of the facilities would be done with the appropriate measurements of size, shape, area, and height of operating machines, control systems, material handling systems, and personnel requirements. In detailed design practical limits come into the picture and due to this limit planner might make certain adjustments in the previously planned layout. Even in detailed designing of the facilities, Muther's Systematic Layout Planning (SLP) can be repeated but layout representation would be in detail.

1. Facility layout – The purpose of the detail layout is to locate a piece of equipment and every individual machine in an area. This requires more specific data, granular dimensions, and techniques of analysis. Allocations of personnel requirements like operators, supervisors, managers for each department are finalised in this process.
2. Material Handling system –Scheduling, Inventory, and timing procedures are considered in the detailed designing of the material handling system. While allocating the material handling equipment unit loads are measured. For routing processing steps and their timings are checked.
3. Evaluation of Design Phase 2 - The criteria that are considered to evaluate the detailed facility design are mentioned below and these criteria provide detailed analysis of layout design and efficient material handling equipment performance:
    - WIP (work in progress)
    - Cycle time
    - Lead time
    - Throughput time
    - Material handling capacity
    - Efficient allocation of personnel
    - Buffer time

3.5. Tools used in Manufacturing Facility Design Process

Facilities designing process is usually considered as layout problems in which designers come up with multiple ways to solve the problem. It is almost impossible to define a well-defined optimal solution for these problems. To solve any layout problem designers usually create a model and solve it using algorithms or algorithm-based software. Layout models are representations of the facility layout with 2D or 3D icons of the departments and material handling devices. Modelling is the quantitative approach to practicing facilities planning. These models create a base for developing mathematical algorithms. In some cases, designers might skip the step of modelling and directly develop mathematical algorithms.

1. **Algorithms**

There are two types of algorithms, optimal algorithm and Heuristic algorithm[28]. It is not a major classification, if an algorithm can produce an optimal solution then it is called an optimal algorithm otherwise it is called a heuristic algorithm. Optimal algorithms are recommended for layout problems that take longer computational time and require higher memory. It increases exponentially as the size of the layout problem increase. Therefore, there are several heuristic algorithms to solve medium-sized or smaller-sized layout problems. Even heuristic algorithms can also be developed based on employee experiences with the respective jobs. These algorithms require inputs such as flow matrix, clearance matrix, and length of the machines to design layout. With these inputs either use suitable older algorithms or a new algorithm is developed for the suitable condition of the company. In [28][27], several heuristic algorithms are mentioned for the construction of layout from scratch, algorithms that are improved from the previously developed algorithms, and hybrid algorithms which are more complex than constructing and improved algorithms. Heuristic algorithms are also used to design an efficient material flow for the facility layouts [32].

2. **Layout Software**

Layout software has sophisticated algorithms and a user-friendly interface, and they are used for both designing and evaluation of layouts. Even for this layout software, details such as dimensions of the building, dimensions of the department, material flow are required to develop an improved layout or just layout[30].

3. **Modelling Tools**

There are several models to design and solve layout problems. But Queuing models, Simulation, and Linear Programming (LP) are some of the important tools that arrive at better solutions in designing and planning the facility problems. Even the Quadratic Assignment Problem is an important mathematical model used to solve the interaction problem between existing and new facilities. QAP formulation requires an equal number of locations and departments. In[33], the author gives an example of solving a layout problem from linear programming.

3.6. Industry 4.0 on Manufacturing Facility Design

The following section depicts the influence of the Fourth Industrial revolution on the Manufacturing Facility design of an organization. However, there is no proof of any Industry 4.0 methodology to design a manufacturing plant. But Industry 4.0 design approach incorporates flexibility, modularity, and adapting the changes in the configuration of the production system to the personalised products without incurring the cost. Therefore, the focus will be laid on the facility layout design, material handling system design, and production process design which excludes facility location and facility system design. Already the facility location and facility system are out of the scope of this research study. This concludes to, the fourth industrial revolution is designed on these six principles Interoperability, Virtualization, Modularity and Re-configurability, Decentralization, Capacities in real-time, and Service Orientation. These principles tend to implement new hardware, software, and cyber-ware technologies to the current manufacturing system and make them self-aware, self-adapt, self-evolved, and self-revolutionized smart manufacturing. As a result, these changes make manufacturing facilities more flexible and intelligent. Therefore, the facility designer should focus more on modularity and reconfigurability of the Industry 4.0 design principle while designing the facility Layout and Material Handling system. Wherein facilities operate on information and communication technologies (ICT) and integrated automation, adapting to the constant changes in the product without affecting the production efficiency.

Manufacturing Facility Design Components	Industry 4.0 Design outcomes	Industry 4.0 Technological outcomes
Facility Layout Design	Modular layouts	Virtualization of Layouts
Material Handling System Design	Flexible routing models	Decentralised decision making Advanced Automated Guided Vehicles (AGVs)

Table 2 Influence of Industry 4.0 over Manufacturing Facility Design

Industry 4.0 factories mainly focus on modular, flexible, and reconfigurable designs regarding layout settings. Table 2 shows an overview of industry 4.0 influence over Manufacturing facility design by indicating the design and technological outcomes of Facility layout and Material handling system. The modular approach is creating individual manufacturing cells that are equipped with similar operating equipment. With this approach, it's flexible to alter the production capacities and reconfigure the layout according to the product change. Creating these cells also makes the material movement convenient by avoiding fixed material handling systems.

Currently, Industries are in practice with cellular manufacturing, and Industry 4.0 would enhance that by its technologies like Cyber-Physical Systems (CPS), artificial intelligence, Internet of things (IoT), and much more that are discussed in Chapter 2 of this report. In[34], the author proposes cellular manufacturing for the gateway towards Industry 4.0. Due to the reason that it integrates the flow line and job shop production fulfilling customer's diverse demand integrating higher productivity. Several algorithms and mathematical models are used to solve cellular layout problems, but for Industry 4.0 layouts Principle Component Analysis (PCA), embedded simulated annealing and hybrid algorithms are used to solve the layout problems keeping large scale data in the point of view. Figure 15 represents Automated Cellular Manufacturing Flow Diagram, in which the cell formations are mainly focused to minimize flow time/ total completion time, make span, total tardiness penalty cost, cycle time, operation time, layout area, and maximizing throughput rate. These optimum cell configurations define the position and number of cells in the given layout space. Each cell would be equipped with self-Transportable multi-function robotics and machines will be uploaded with tool changing program according to parts competition sequence. Even one of the leading robotic manufacturers "KUKA" mentions cellular layout also known to be Grid layout on their official website[35]. In both the cases [34] and [35] it is observed that production layout and resource layout are separated, resulting in higher flexibility for the handling system to access the tools. Therefore, while designing layouts for Industry 4.0 the designer should develop algorithms that give higher prominence towards flexibility in reconfiguring the production process and handle a high range of data. So, apart from the output design of the layouts, the designing procedure remains the same as the traditional approach as of now.

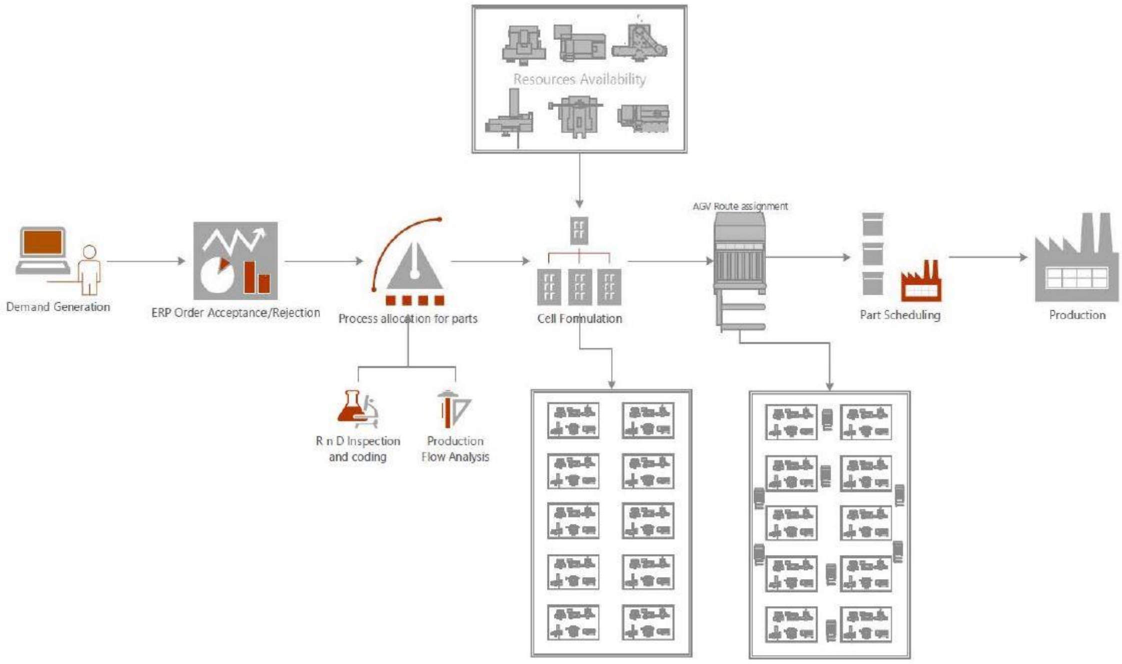

Figure 15 Automated Cellular Manufacturing Flow Diagram[34]

In the present industries, Material Handling System is working based upon sensors and programmed software. This is the current automation level of material handling equipment and some of the material handling equipment is still manual. These material handling systems do not yield higher production efficiency with the variety of product demands. Therefore, computer-based manufacturing system and material handling system offers higher productivity, flexibility in a variety of products, stability, and safety. To update this material handling system, the fourth industrial revolution improved the system with its new technologies like Cyber-Physical system (CPS), Internet of Things (IoT), Artificial Intelligence, etc. The advancements in technologies should be utilized to achieve maximum flexibility and reconfigurability of material movements across the shop floor. Even layout design is focussed on the same Industry 4.0 design principle and based upon that cellular layout configuration is recommended. Manufacturing cells are created with multi-function robotics and it is automated with self-transportation capabilities. For those automated cells, Advanced Automated Guided Vehicles (AGV) are connected and they are programmed to reconfigure and reschedule whenever a new product is added. Figure 16 shows an example of AGV receiving the kind of signal for finished or semi-finished products and AGVs are programmed to do this action autonomously. This product order signal is received from the ERP system based on demand generation.

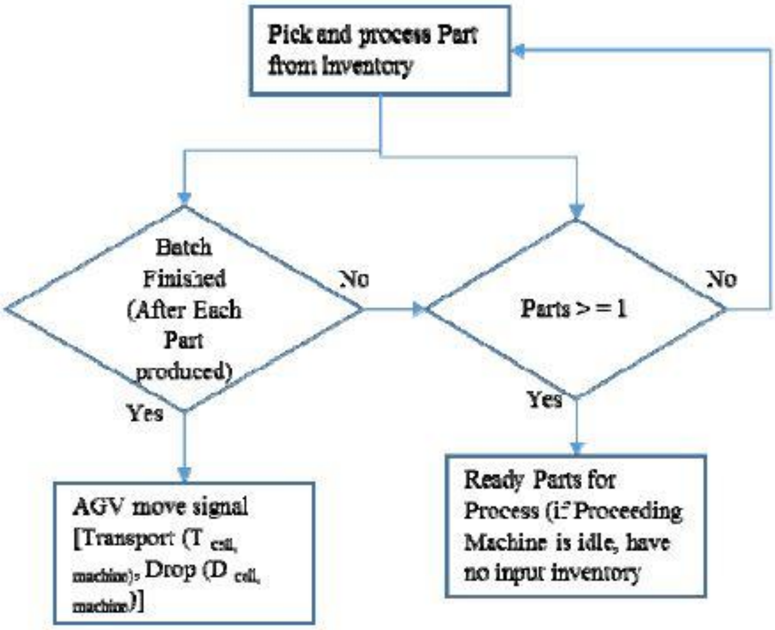

Figure 16 AGV move signal for finished or Unfinished product Batch[34]

Cellular manufacturing provides maximum flexibility for AGVs to do multiple tasks at intercellular and intracellular. Intercellular movement is transferring materials from the warehouse to manufacturing cells and intracellular movement is transferring the materials between the manufacturing cells. Suitable algorithms are developed to create efficient and flexible routing for advanced AGVs. Therefore, while designing a material handling system for any smart factories or Industry 4.0 environment all possible routes must be considered for the material handling equipment. So, handling equipment with the present technology and software can accomplish multiple tasks with its capability of reconfiguration. Below there are certain examples that would show how Industry 4.0 technologies help in creating hybrid mathematical models and algorithms, so that the utilization rate of handling equipment increases:

- In [36], the authors developed a mathematical model and a black hole and floral pollination algorithm-based optimization method to make material handling more flexible and responsive to the Cyber-Physical environment.
- In [37], a model has been formulated under stochastic conditions for an automated flow line. So that Industry 4.0 technologies support these models by making the downstream stations perform operations of the failed stations, in addition to those operations which were assigned originally.
- [38] provides a brief explanation of the proactive material handling method for the Cyber-Physical System (CPS) enabled shop floor. Figure 17 shows the comparison between two material handling strategies in the respective aspects of production monitoring, requirement release, resource allocation, and decision execution. This helps the future designers to have a viewpoint on designing material handling systems for Industry 4.0 environment.

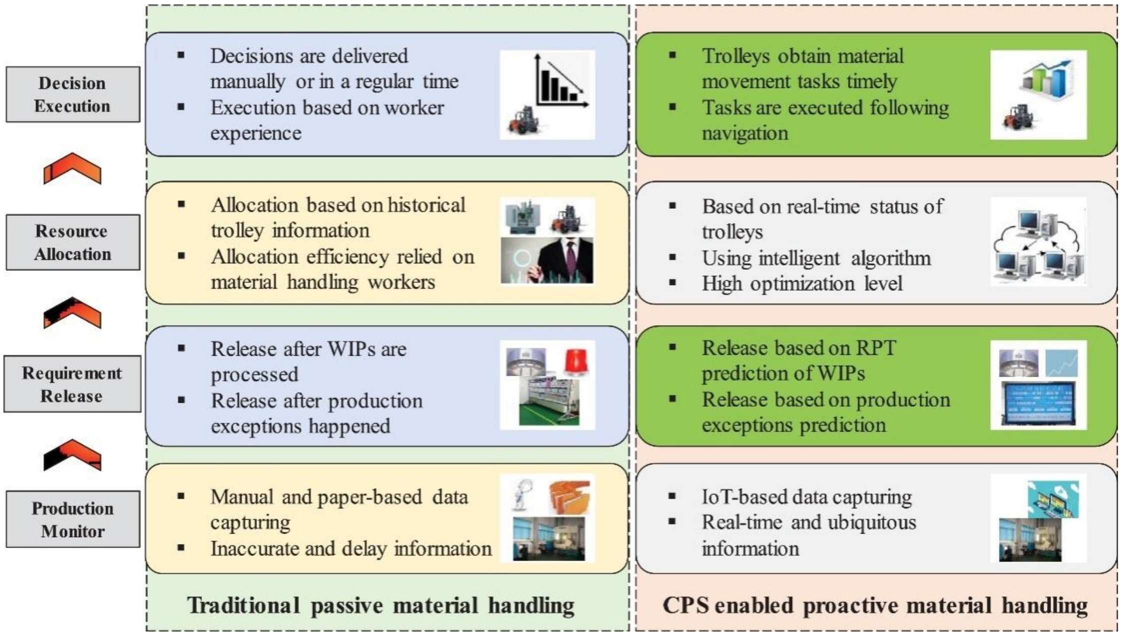

Figure 17 Comparison between Traditional and Industry Material Handling Strategies[38]

- In [39], Cloud computing for robotics is discussed and it helps robots to manage data flow efficiently. These cloud robots can have machine-to-machine interaction and machine-to-cloud interaction through the Local Area Network (LAN) connection. Cloud computing connects multiple robots of the same working environment. Data from multiple equipment, sensors, cameras are processed on the cloud by complex algorithms to generate the path or direction of movement to the robots.

With the above discussion, facilities designing models and algorithms should give higher prominence to modularity and re-configurable flexibility of the manufacturing and material handling facilities. So, the facility designers designing the layout and material handling system should focus on the following factors that will be introduced in Industry 4.0 factories or smart factories.

- Flexible manufacturing cells to change the process according to changing variations of products
- Flexible movement of material handling equipment, that can receive multiple signals and make autonomous decisions.
- Combining operation and information technologies make the manufacturing system agile and optimized.
- Creating a separate personnel control system to monitor the autonomous manufacturing process.

3.7. Conclusion

This chapter explains briefly the concept of Manufacturing/Assembly Facility Design, which supports the research question c. This chapter also mentions the influence of Industry 4.0 on Manufacturing Facility Design, those information answers the research question d. Initially, this chapter provides information about the concept of Manufacturing Facility Design and it is the answer to research question c.

The facility design includes facility layout design, material handling system design, and facility system design. This project does not focus on facility system design due to the reason that it is more related to the architectural structure of the factory. Even the influence of Industry 4.0 on facility systems is highly negligible and it is known from Chapter 2 - Industry 4.0. Facility Layout Design includes an arrangement of Industry facilities like machinery and material handling equipment in an efficient position. To design the layouts tools like heuristic Algorithms, layout software such as CAD, CRAFT, etc, and modelling tools like queuing models, mathematical models, etc are used. With the reference to Muther's Systematic layout planning and other general facility design process, the confined facility designing process is briefed to compare it with Industry 4.0 technologies and design principles mentioned in Chapter 2 - Industry 4.0.

In the facility design process initially planning of the facilities happens depending upon the manufacturing process. In the planning phase, machinery and material handling equipment are known and positioning of the manufacturing processes are made. Therefore, confirmation on machinery placements is done and with the manufacturing process chart, material handling equipment routing is designed. In the detailed facility design phase, layouts are designed with the details of manufacturing cell measurements and spacing between the manufacturing processes. In facilities planning alternative layouts are created from designing tools like CRAFT etc, but for detailed designs, software like simulation is used. From this facility design process, a method to design facilities for a factory is known and this process is used for comparing the changes that occur in the new facility design process for Industry 4.0 in future chapters. This detailed design is evaluated with some of the factors like lead time, cycle time, cost, capacity, space utilization, etc.

Last section 3.6 of this chapter focus upon manufacturing processes are the ones that get more influenced from Industry 4.0 through adaptive scheduling and this would answer the research question d. Industry 4.0 technologies such as Cyber-physical systems, Internet of things (IoT), Cloud storage, Big data analytics, etc make the manufacturing process more efficient with lesser idle times of machines and supplying or ordering the materials on time. From this Industry 4.0 manufacturing process, desired facility layout and material handling system are also known. That is a change of material handling system being more autonomous with the technologies artificial intelligence, cyber-physical system, cloud storage, etc. The facility layout is modular with the separation between the manufacturing process, material handling process, and tool section. Showing the proactive material handling system, which is more responsive to the real-time data of the manufacturing process. But previously it was only based on recorded data or experience of the operator. So, section 3.6 gives a conclusion that the core of the facility design i.e. material handling system and layout design should be modular and reconfigurable to support adaptive scheduling and change in process design when there is an addition of the product or disruption in the production process. Modular and reconfigurability is one of the design principles of Industry 4.0. With this conclusion, future chapters can be worked on building up the new facility design processing steps and comparing the outcomes of the facilities design between traditional and Industry 4.0 factories.

4. Chapter 4 – Manufacturing Process in Industry 4.0

In the previous chapter, it was concluded that Industry 4.0 significantly influences the manufacturing process in the Industry. Therefore, this chapter provides information about the content of the manufacturing process and the changes that occur due to the influence of Industry 4.0. Section 4.1 introduces chapter 4 and after the introduction, section 4.2 shows the parts of the manufacturing process. So that a small note on the parts of the manufacturing system helps to understand the terms that are used while briefing about the Manufacturing system in Industry 4.0 i.e. Section 4.3. The conclusion of this chapter section 4.4delivers the output of this chapter for this research project.

4.1. Introduction

In [40] it is said that the manufacturing process covers the arrangement and optimization of resources, operations equipment, and production operators. So, the conclusion from **Chapter 3 - Manufacturing Facility Design** indicates that Industry 4.0 influences the optimization of resources and production operators. Considering Industry 4.0, its main aim is to create connected manufacturing processes in all aspects of the industry and make manufacturing processes versatile to the change in product demand. The design principles of Industry 4.0 mainly want to keep the manufacturing processes connected and make them autonomous by decentralized decision-making capacity. Based on Industry 4.0 principles, the technologies such as Cyber-Physical Systems, Artificial Intelligence, the Internet of Things, etc make manufacturing operations and handling of manufacturing resources more flexible and efficient. This flexibility and efficiency are attained by rescheduling the tasks and changing the queuing network of the products. This connected smart manufacturing process reduces bottlenecks of the operation and makes better use of machines.

4.2. Manufacturing Process in Traditional Manufacturing System

Designing the manufacturing process is not an individual task but on the contrary, it is an important part of manufacturing systems that includes multiple tasks, which are discussed here. Below are the components of the manufacturing process that are used for production planning and control:

- Operation Process chart and Assembly chart – These charts give the details about the manufacturing operations that are required to produce the part and they also give information about the sub-assemblies of the main part. These charts lay the foundation to create the route sheet for the parts.
- Route Sheet –It is a document that consists of information about the pathway of the products that go through the number of operations from raw material to finished product. It may also give the setup, processing, and labour times for each operation at each machine.
- Equipment Selection – This provides the information about the machines selected for the required manufacturing operations that are defined operation process and assembly chart. To determine the right equipment, one must know the basic production processes that are required. According to [28], three methods are followed in selecting the equipment and they are as follows:
    - **Traditional Method** – It is a simple approach and based upon the number of products, desired production rate, production efficiency, processing time and availability time of machine below formula is determined.

$$NM = \left\lceil \frac{tP}{\tau\eta} \right\rceil$$

P	Desired production rate in units per day
η	Efficiency of the machine
τ	Time for which machine is available per day in hours
t	Time required to process one unit of product at the machine in hours
NM	Number of units of the machine required

Figure 18 Traditional Method Equation for Selecting Equipment

- **Linear Integer Programming Models** – Apart from selecting the production equipment, these models also consider material handling equipment which is an important link between production equipment. For the equipment selection problem, [28] represents four models with the notations that are shown below:

O_i	Operation type i, $i = 1, 2, \ldots, o$
M_j	Production equipment type j, $j = 1, 2, \ldots, m$
P_k	Part type k, $k = 1, 2, \ldots, p$
MH_l	MHS type l, $l = 1, 2, \ldots, n$
c_{ij}	Cost of performing operation O_i on production equipment type M_j
h_{kl}	Cost of handling part type P_k using MHS type MH_l
t_{ij}	Time required to perform operation O_i on production equipment type M_j
s_{kl}	Time required to transport part type P_k using material-handling carrier type MH_l
τ_j	Time available on production equipment type M_j
σ_l	Time available on material-handling carrier type MH_j
NO_i	Number of operations O_i to be performed
NP_k	Number of units of part type P_k to be manufactured
C_j	Cost of production equipment type M_j
H_l	Cost of MHS MH_l
B	Total budget available

Model 1

Decision variables

x_{ij}	Number of operations O_i to be performed on production equipment type M_j
y_{kl}	Number of units of part type P_k to be transported on MHS type MH_l
NM_j	Number of units of production equipment type M_j selected
NMH_l	Number of units of MHS type MH_l selected

$$\sum_{i=1}^{o}\sum_{j=1}^{m} c_{ij}x_{ij} + \sum_{k=1}^{p}\sum_{l=1}^{n} h_{kl}y_{kl} + \sum_{l=1}^{m} C_i NM_i + \sum_{l=1}^{n} H_l NMH_l$$

Model 2

$$\sum_{k=1}^{p}\sum_{l=1}^{n} h_{kl}y_{kl} + \sum_{l=1}^{n} H_l NMH_l$$

Model 3

$$\sum_{i=1}^{o}\sum_{j=1}^{m} c_{ij}x_{ij} + \sum_{i=1}^{m} C_i NM_i$$

Model 4

$$\sum_{i=1}^{o}\sum_{j=1}^{m}\sum_{k=1}^{p} c_{ijk}x_{ijk} + \sum_{j=1}^{m} C_j NM_j$$

Figure 19Linear Integer Programming Models for Selecting Equipment

- **Queuing Model** – These models are used to solve dynamic problems in determining the number of units of each machine type required. Because traditional and linear programming approaches can solve only static problems which consider all parameters to be constant. This means machine breakdowns are considered by reducing the available time of the machines by a certain percentage.

- Personnel Requirement – This shows a model that determines the labour force required for the production. These models are created based upon the factors such as level of automation, unionized or nonunionized labour force, production rate, management policies on subcontracting and overtimes, salary rates in the area, health insurance rates, and rules set by the OSHA (Occupational Safety and Health Assurance). The number of employees required is directly proportional to the volume and variety of products and it is formulated as:

$$N = \sum_{i=1}^{n} \frac{T_i O_i}{\eta H}$$

n	Number of types of operations
O_i	Aggregate number of operations of type i required on all the pseudo (or real) products manufactured per day
T_i	Standard time required for an average operation O_i
H	Total production time available per day
η	Assumed production efficiency of the plant

Figure 20 Formula to Find the Number of Employees

- Scheduling - It is the process of indicating when and where an operation must be performed for the product to be manufactured. It aims to plan the sequence of operation so that production is arranged systematically at the end of completion of products due date. Usually, charts and boards, priority decision rules, and mathematical programming methods are used for scheduling.
- Capacity Planning – It is the process of matching the level of operations to the level of demand. Capacity planning should be carried out keeping in mind future growth and expansion, market trends, sales forecasting, etc. Because wrong capacity planning might affect meeting the customer demand on-time, operational cost, and scheduling system.
- Material Requirement Planning (MRP) – It is the process of determining the items required for the scheduled production system. From this process, the excessive build-up for inventory is avoided and reduces manufacturing and delivery lead times. MRP also increases production system efficiency and provides realistic delivery commitments.

4.3. Industry 4.0 in Manufacturing Process

As discussed in the previous topics, process design is all about selecting the machinery based upon the manufacturing operations that are linked to production volume and product variety. These decisions provide information on how well the manufacturing process is integrated and flexible enough for production variation. As Industry 4.0 focus on integrated manufacturing system, its technologies and principles would require new considerations while designing and manufacturing process. For example, consider the Cyber-Physical system level while selecting any equipment and make sure they are interconnected through the Internet of things (IoT). Practicing the use of IoT in manufacturing will enable effective and adaptive planning and control of production systems. It can even empower three pillars of modern industry and they are process optimization, optimized resource consumption, and creation of complex autonomous system[41].[42] provides a framework Industry 4.0 assembly of microdevices stating that to implement and design the Industry 4.0 assembly process information-centric modelling approach is necessary for the system collaboration with a basis of data/information. So indirectly mentioning that system is data-centric, where all the parts of the system can access that data and work collaboratively. Industry 4.0 technologies gather real-time data from the shop floor cost-effectively. These data are used in making an adaptive decision-making system that includes multi-criteria decision-making algorithms and condition-based maintenance strategies to improve the performance of the factory. To store this numerous data cloud storage helps a lot and integrates many industrial IT tools[41]. In today's industries data about the products variety and its history are either stored externally or lost due to the lack of a storage facility. But the cloud storage helps the manufacturers to store all the details about the product varieties and make these details accessible to all the departments of the industry.

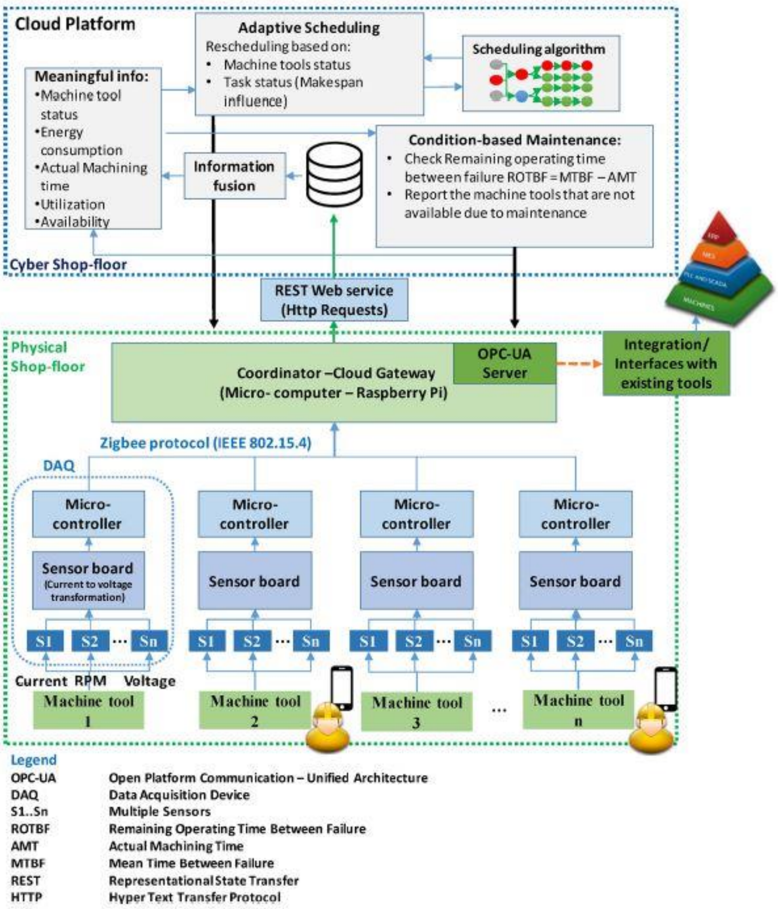

Figure 21 The Cloud-Based Cyber-Physical System[41]

The above Figure 21 represents a framework of a cloud-based cyber-physical system that has been developed for overall adaptiveness of the manufacturing system because it is capable of monitoring the production shop-floor and analysing the monitoring data and utilizing it as an input for scheduling algorithm as well as a condition-based maintenance approach. Its main purpose is to improve the awareness of the shop-floor.

The above developed cyber-physical system consists of a monitoring system that includes wireless network, information fusion, Data acquisition device (DQA), and Integrating cloud database. This system helps to provide information about machine tool status, machine tool energy consumption, utilization, availability of machines, machining time, and task status of the machining process. This information can be used for process development, adaptive scheduling, easily changing of processes for product variety and condition-based maintenance. Some of the existing IT tools may also provide some of this information but they do not provide the current status of the production. As a result, higher awareness of production conditions lowers the breakdowns and increases productivity. Therefore, DAQ with sensors and microcontrollers are installed in the machine to get the data and this data is transmitted to cloud storage/cloud server through WSN (wireless network) 'The DIGI XBee ZigBee'. To be much more precise about the data each DAQ has its unique address and the receiver end can easily detect from which machine and what process. Apart from this internal data, OPC-UA (Open-Platform Communication-Unified Architecture) creates interoperability with other IT tools in production. OPC-UA also serves the purpose of machine-to-machine communication where machines communicate with machines, workpieces, and components so that it creates an adaptive and decentralised production system. After receiving data from wireless networks and operators, they are processed through information fusion. In [41], the Information fusion technique consists of Analytic Hierarchy Process (AHP) and Dempster Shafer (DS) Theory. Initially, benefits of each alternative (data source) are considered through AHP and it also gives ranking and reliability of each source of data with the criteria that include accuracy, flexibility, error probability, and real-time response. After AHP, DS theory is used to determine the machine-tool operating status by combining the evidence from the different sources. Figure 22 gives an overview of the logic behind the process of determining the machine-tool status. The overall proposed cyber-physical system serves the key aspect of industry 4.0 i.e., Integration and Interoperability. Cloud database stores the facilities data like machine-tool specifications, cutting-tool specifications, as well as the monitoring data, and these data can be updated through integrating with other systems and tool manufacturers, to keep the cutting-tool specifications updated.

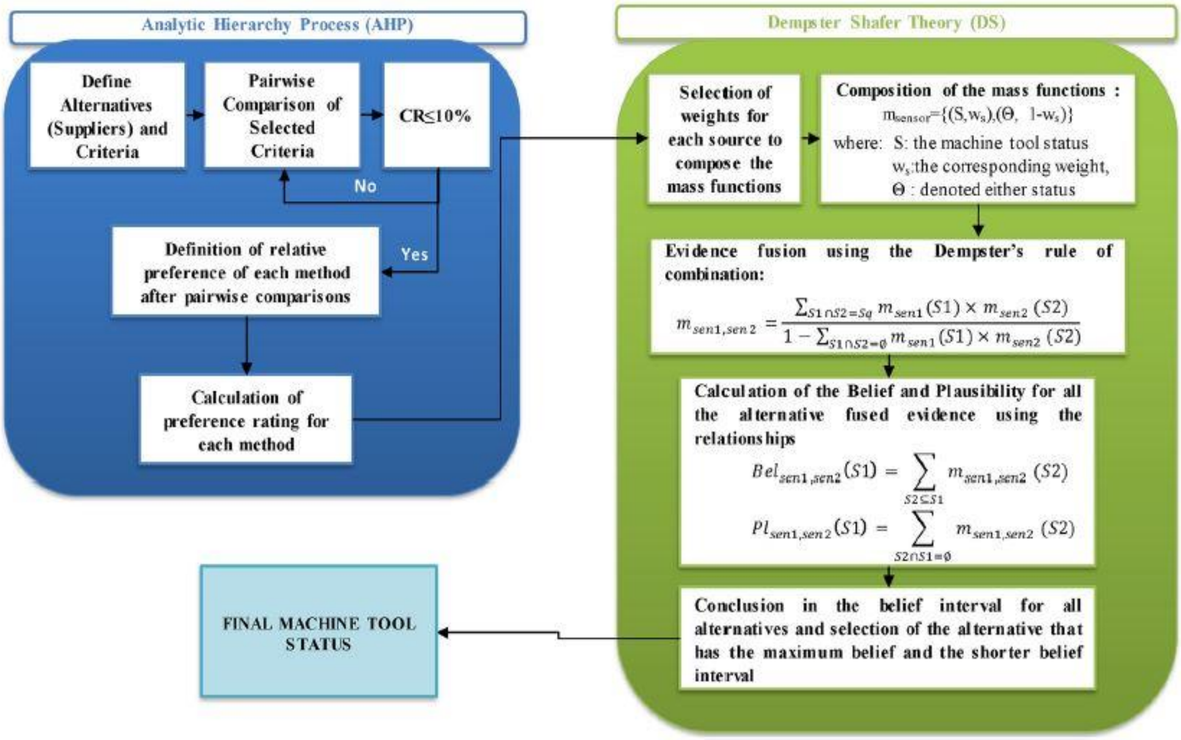

Figure 22 Information Fusion Technique[41]

This cloud-based system[41], can also create adaptive manufacturing schedules. In which it helps to reduce uncertainties and turbulence in shop-floor due to high product varieties. This could only happen if there is an awareness of what's happening on the shop floor through the fluent information flow. Adaptive manufacturing re-generates alternative and feasible schedules based on real-time shop-floor condition

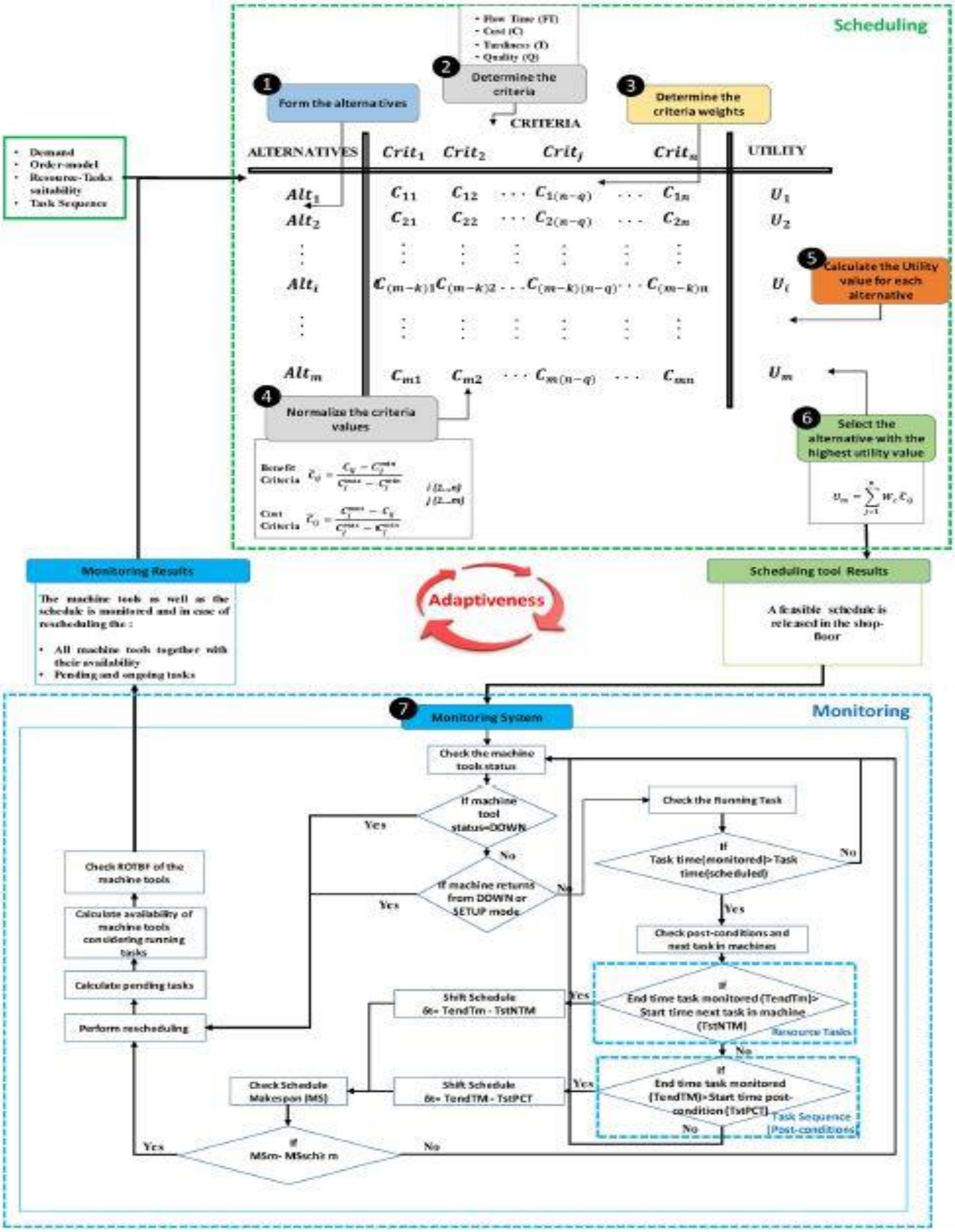

Figure 23 The workflow of the developed Adaptive Scheduling[41]

The above Figure 23 represents the adaptive scheduling workflow. That is useful for re-scheduling of tasks whenever a change is required, and it is driven by the feedback from the monitoring system. Figure 23 only explains the logic behind the scheduling process in cloud-based cyber-physical system shop-floor. Therefore, an explanation about the equations in Figure 23 is not necessary except the explanation of the re-scheduling process in the cyber-physical system shop-floor. In [41], 2 occasions of re-scheduling are explained. Firstly, when the state of the machine tool is detected to be down as well as when a machine tool returns from down or setup mode. Secondly, when the monitored processing time is higher than the scheduled time and from this make span is highly influenced. So, to keep the manufacturing processes interactive and adaptive to the varying scenarios like variation in the product demand, human errors, change in certain processes, or design of the product.

Traditional Manufacturing Process	**Industry 4.0 Manufacturing Process**
Recorded Scheduling – Scheduling of the products are based upon recorded data	Adaptive Scheduling – Scheduling of the products are based upon current data from the shop floor
Manufacturing Processes are not connected through any digital connection. Therefore, change in process or scheduling should be made autonomously	Change of manufacturing process or scheduling can be made digitally with less human interference or autonomously by machine-to-machine connectivity.
Fixed data scheduling algorithms	Current varying data scheduling algorithms
Manufacturing process data are stored in drives and limit the access of the data.	Data are stored in cloud storage and provide access to every equipment and person in the Industry
Workload balance should be made manually depending on the analysis machine availability during the disruption in the manufacturing process	Workload balance is made autonomously due to the interoperability of the machines

Table 3 Difference between Industry 4.0 and Traditional Manufacturing Process

The above Table 3 represents the difference in the manufacturing process under influence of Industry 4.0 technology and design principles. These differences are only for the overview of the changes. So that, it supports the development of a new Industry 4.0 facility design process. Because Manufacturing process design is the base for designing the facilities of the Industry.

4.4. Conclusion

This chapter briefs about the changes that occur in the manufacturing process due to the influence of Industry 4.0 technologies and design principles. This chapter is add-on information for the research question d i.e., about the influence of Industry 4.0 on Manufacturing Facility Design.

From Chapter 3 - Manufacturing Facility Design it is more evident that Industry 4.0 technologies such as Cyber-physical systems, the Internet of Things, etc influence the operating systems like controlling the production process, scheduling process, and dispatching of the product in the manufacturing system. As the equipment and machinery are connected through the internet of things, the manufacturing process becomes more flexible and adaptable than before. Industry 4.0 principles tend to make the manufacturing process more modular, digitalised, and adaptable to the fluctuating demands of the product. Through the technologies like cyber-physical systems, the Internet of things, cloud storage, automated material handling equipment, etc. Initially, the introduction of the manufacturing process is explained and in the final part of this chapter, the influence of Industry 4.0 on the manufacturing process is briefed. It states how digital technologies make the manufacturing process more flexible for product variations and manufacturing disruptions. Manufacturing disruptions are when a machine is broken down, the adaptive scheduling creates a new schedule and balances the product flow within the machine available. To access all the information about the availability of machines and other data, cloud technology is used. Even before cloud storage was used to store the recorded data. But now it is used for storing current data and making it accessible to all the equipment and people of the Industry. All the processing machines and other equipment are connected through the internet and create machine-to-machine communication. This creates an interoperable environment and keeps the process continuous and autonomous. This is the working condition of the manufacturing process in the smart factory or Industry 4.0 factory. This smart manufacturing process shows that Industry 4.0 influences more on controlling systems such as modification in scheduling, capacity, and material movement of the manufacturing process than the designing of the manufacturing process. This creates an ideology on how the facility design should be, to support the interconnected, flexible, and smart manufacturing processes.

5. Chapter 5 – Industry 4.0 Facility Design Process

This chapter proposes a modified facility design process, to achieve Industry 4.0 Facility Layout outcomes. This modified facility design process is proposed by analysing the data, from Chapter 3 - Manufacturing Facility Design about Manufacturing Facility Design process and Industry 4.0 influence on Manufacturing Facility Design from Chapter 3 - Manufacturing Facility Design and Chapter 4 – Manufacturing Process in Industry 4.0. Section 5.1 introduces the changes in the traditional facility design process to build a smart factory. Section 5.2 explains the expected outcomes of the facility layout and material handling system due to the influence of Industry design principles and technologies. Section 5.3 shows the changes in the facility design process due to Industry 4.0. Section 5.4 gives the Industry 4.0 facility designing steps, that are followed to design a smart factory. Section 5.5 concludes with the outcomes of this chapter.

5.1. Introduction

The facility design process is designing an efficient facilities arrangement of the manufacturing Industry. From Chapter 2 - Industry 4.0, Industry 4.0 is referred to be the next industrial revolution which brings up new information technologies (IT) and new equipment for the current Industries to execute better flexible and efficient manufacturing. In Chapter 3 - Manufacturing Facility Design traditional facility design process is explained and currently, most of the companies use that facility design process to develop an efficient facility design. With the traditional facility design process as the basis, a modified facility design process is necessary to support the technologies and equipment introduced by Industry 4.0 that are discussed in Chapter 2 - Industry 4.0. Therefore, this chapter focus on providing the modified facility designing steps that can make a traditional factory into a smart factory. Regarding the facilities of the Industry, Industry 4.0 expects it to be more flexible for new configurations of facility design conveniently compared to conventional facility design, and facilities reconfiguration will be much easier when the facilities are modular. Modular means creating separate modules that are not connected. For example, while manufacturing a monitor, the screen is manufactured separately, and the monitor frame is manufactured separately. This is a part module. Same way Industry 4.0 gets modularity in the manufacturing and material handling system. Implementing modularity in the facility designs would help to reconfigure the facilities of the Industry by rearranging the modules to the desired product or process. So, Modularity and reconfigurability are some of the design principles of Industry 4.0. This is also one of the conclusions of Chapter 3 - Manufacturing Facility Design. Therefore, the Facility design process should consider Modularity and reconfigurability, and the new autonomous equipment to develop Industry 4.0 facility design.

5.2. Industry 4.0 Layouts and Material Handling System

From Chapter 2 - Industry 4.0, an overview of Industry 4.0 in the manufacturing system is known. Chapter 3 - Manufacturing Facility Design shows the influence of Industry 4.0 on the facilities of the manufacturing industry. So, with this background information, outcomes of Industry 4.0 layout and Material handling system are discussed below, and this might help in developing Industry 4.0 facility design steps:

- **Industry 4.0 Layouts**

Industry 4.0 layouts focussed on being modular in design. The layout consists of modules that are essentially groups of machines and those machines are grouped based on either product, process, or part family. The modules are also formed based upon clustering of operations by considering operation distance measure or similarity of operations. It indicates if multiple types of products have similar operations, they are grouped to form modules and if the operations distance is short to travel, even those kinds of operations are grouped to form modules. Industry 4.0 layouts focus on adapting flexible and reconfigurable layouts. So that product customisation for producing multiple products suitable for customer demands can be satisfied cost-efficiency and higher productivity. From Chapter 2 - Industry 4.0, it is known that modularity and reconfigurability are some of the design principles of Industry 4.0. and Chapter 3 - Manufacturing Facility Design indicates that Industry 4.0 layouts should be modular and reconfigurable in design. Modular layouts are layouts that consist of multiple modules of operation in different layout patterns inside every module. The layout patterns are said to be flowline, branched, patterned flowline, cellular or functional layout. These modules are created by clustering the operations which have similar substrings. This means the product has a similar line of operations. These modules are connected through the Internet of Things for communication purposes and use AGV for material transfer. Each module is supervised by an individual operator, as the manufacturing processes are carried out autonomously through artificial intelligence. It is monitored through the visualisation technique. So, modularity is all about creating different manufacturing process modules, so that those modules support reconfiguration of the production process according to the customisation of the product. The modular layouts also provide space for flexible movement of the raw material or unfinished product, to adapt to the changes in the production process at any point of production time.

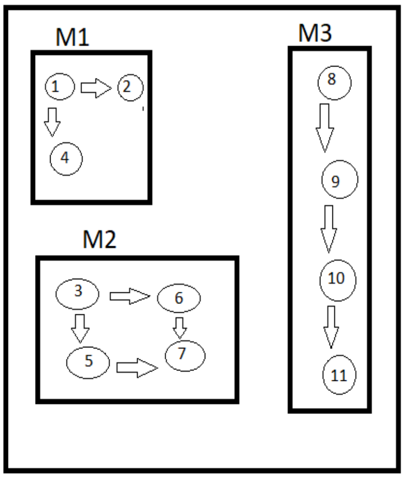

Figure 24 Modular layout Representation

Figure 24 is an example of the representation of the modular layout. It consists of 11 processes and all those processes are split into M1, M2, M3 modules depending upon the frequency of the routings. This means higher the frequency of the material movement between the two processes, it is more likely to be clustered in one module. Modules are reconfigurable at any point in time.

- **Industry 4.0 Material Handling System**

Material Handling System in Industry 4.0 factories mainly focus on flexibility and adaptive scheduling of the shop floor and work through the information technologies that are embedded into the equipment. Industry 4.0 majorly involves analytics, which makes equipment work through the data that are received in the current operations through internet connectivity and work accordingly. There are certain additional functions are added to the material handling system and they are said to be sorting of the works, decision making, data transfer, data collection, organisation, administration of storage sites, product recognition, mastering the models, security intelligence, intelligent situational responses(like emergency stop, various modes of implementation) and warehouse administration. In Industry 4.0 material handling system all the logistics process is traceable, and every movement is recorded reliably. Figure 25 shows the characteristics of material handling systems in smart factories that discussed below:

- Connectivity of the system – It is the connection between material handling equipment and manufacturing machines and between material handling equipment with each other. Connection is created through the technologies like wi-fi, ethernet, and/or Bluetooth.
- Task analysis – Through cloud storage and Big data analytics, manufacturing processing time, work-in-progress time, raw material, and finished product information is stored and shared to all material handling equipment of the factory.
- future logistics prediction – Intelligent algorithms which assign the tasks for the material handling equipment, predict future assignments based on the factors such as time, capacity, space, cost, and energy. This makes the material handling system smarter for adapting to the current situation of the shop floor.
- status prediction – This feature in the material handling system indicates the current status of the trolleys or AGVs whether it is waiting, moving, or in the trolley parking space ready for availability.
- physical shop floor–The conditions for the physical shop floor should be the installation of sensing devices along with physical devices of the manufacturing system and material handling system.

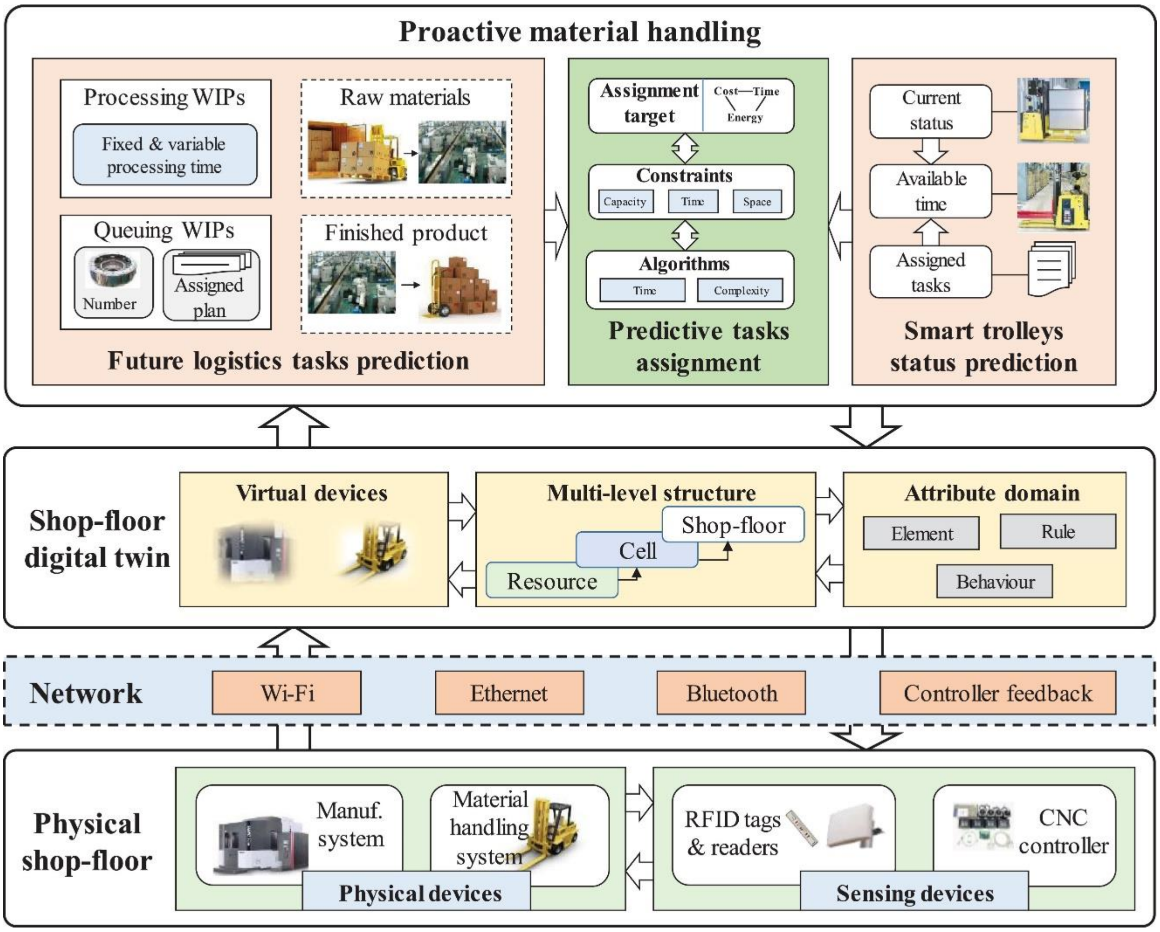

Figure 25 Characteristics of Pro-active Material Handling System[38]

For this kind of adaptive shop-floor, smart factories or Industry 4.0 factories use AGVs as their material transporting equipment. These AGVs are uploaded with dynamic scheduling algorithms and routing jobs to make adaptive decisions with efficient routing through the shortest routes. With regards to the jobs, AGVs are smart enough to prioritize the jobs and move accordingly. So, Industry 4.0 AGVs can access all the data like work in progress of all the operations and this makes respective AGVs take action that is nearby. Instead of returning empty like older AGVs. Apart from AGVs, robots are used more in number in Industry 4.0 factories. Because present generation robots are collaborative to the workers and more efficient than before due to Cyber-Physical Systems. Below there is an example of comparing traditional robots and Industry 4.0 robots. This example is to show the changes in material handling equipment due to Industry 4.0 technologies.

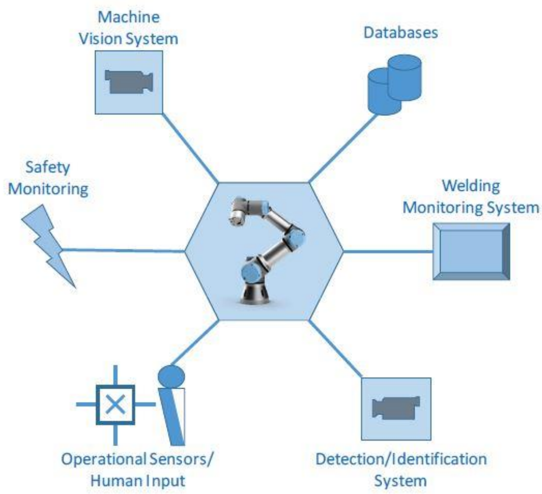

Figure 26 Robot Networks[43]

The above Figure 26 shows the networks that are connected to the traditional manufacturing robot that is used for the welding process.

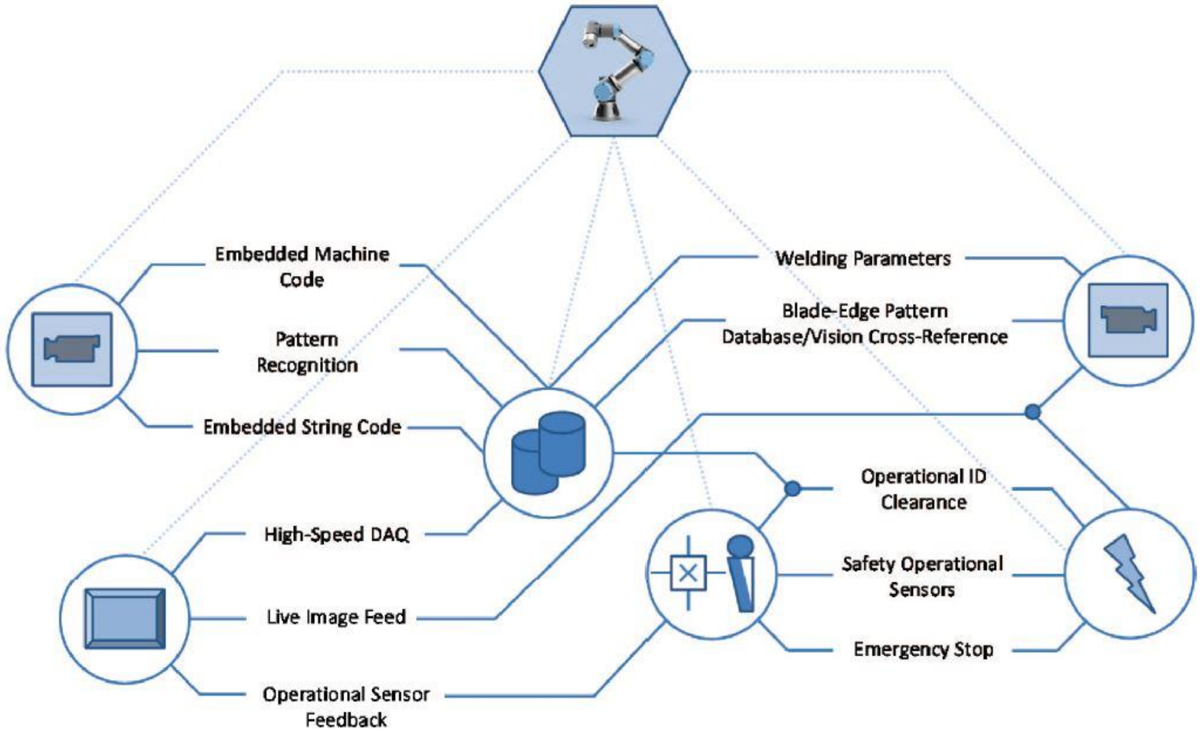

Figure 27 Industry 4.0 Robotic Interconnections[43]

Figure 27 is an example to show the Industry 4.0 manufacturing robot's outermost systems that are interconnected after the update to get adapted for the cyber-physical system environment. These robots recognize the product through machine codes or patterns or embedded string codes and after recognition IoT (Internet of Things) and Data Management system allows the robots to access all the necessary information. Internet of Things (IoT) helps to access the history and way of production. The Data Management system allows the robot to access the database of the product that are acquired from the manufacturing history of that product and the database also consists of types of products that have to be manufactured so that robots can cross verify the products that arrive into the system in real-time. Apart from product information, the database can also help in detecting errors by comparing the known malfunctions or fluctuations that are incorporated. This can also store personnel information like face IDs or fingerprints of the specifically trained person for security reasons. These robots can also be used for manufacturing operations and material handling purposes.

Overall, the Industry 4.0 material handling system should work interacting with equipment to the machinery and create an adaptive shop floor. Therefore, Industry 4.0 implements technologies like Cyber-physical systems, Cloud storage, Big data, and the Internet of things (IoT) to the material handling system. To make it more flexible, autonomous decision making and smart recognition of the products or pallets. So, it is evident that material handling systems that are interconnected and smart enough to make their own decisions are said to be in Industry 4.0 factories.

5.3. Facility Design Process for Industry 4.0 Factory

As many of the technologies like Cyber-physical system, the Internet of Things (IoT), big data, cloud storage, digital twin, etc makes the manufacturing process more adaptable for the current product demand. Industry 4.0 design principle mainly expects core facility design should be flexible, connected, and modular. It means if the layout is modular, material handling and process changes could be flexible while being connected. Because Modular Layouts are next-generation layouts that combine or make use of all traditional layouts like functional, flowline, and cellular layouts. The modular layout is a network of modules that consist of either similar or different processes and represent a part of the complete facility. Initially, product processes are listed, and common substrings are classified between all the pairs of operations. Those common substrings are clustered to create modules. Each module may consist of any traditional layout design of the processes. Those layout designs are dependent on the processing machines that are in the module. These modules are flexible enough to expand or reduce layout size and also flexible for multiple product manufacturing.[44]suggests a heuristic approach in creating layouts with modules. Therefore, while designing the layouts, modularity should be the point of focus and multiples flexible routings for material handling systems. [35] refers to some of the robotic cellular layouts that are not specific for any operations. Depending Upon the products these robotic cells are fed with tools and products to carry out the necessary process. This makes the production process flexible to product changes and produces according to the demand.

For this modular layout, Industry 4.0 uses a connective and interactive material handling system. So, material handling equipment is built with a Cyber-physical system and fed with intelligent algorithms to make smart decisions. Smart decisions are like predicting the status of the Manufacturing system, task, and trolley status. Scheduling algorithms are developed with a focus on the time and complexity of the task. It means, while these Industry 4.0 scheduling algorithms add on task and depending upon the importance of the task material handling equipment makes the decision and works upon the operator's permission. Decision-making factors are WIP (work in progress) of the machine, completed operations, and several active machines. To be adaptable for this flexible layout, material handling equipment is selected only if they possess certain features. The features are said to be the Internet of Things (IoT), cloud storage, Cyber-physical system, big data analytics, etc. So, in the initial step of designing a material handling system, equipment should be checked for these technologies. Apart from technologies, intelligent heuristic algorithms are developed with the input information of a total number of new jobs added to the system, jobs operations precedence relationship, jobs due date, available machine operations, processing time, active machines, and layout guide path network. So, these intelligent algorithms make the material handling systems adaptable for the Cyber-physical Shop floor that has dynamic scheduling and flexible routing.

Facilities Designing Process	Systematic Layout Designing	Industry 4.0 Layout Designing
Facilities Planning	Decide the layout designs within the choices of traditional layouts such as functional, flowline, or cellular layouts.	In Industry 4.0 next-generation layouts like modular layouts are focused. Which creates modules with regards to part or process focused. Each module is designed based on the traditional layout designs. Modular layouts result in better flexibility in manufacturing compared to traditional layouts.
	The material handling system is designed based on task and unit load.	The material handling system is designed based upon the Cyber-physical system, Internet of things, cloud storage, etc technologies
Facilities Detailed Design	Allocation of departments or manufacturing cells is based upon material handling cost and lower lead times.	Modular layouts are designed for better flexibility in material movement and expansion of the modules depending upon fluctuating product demand or product variety.
	Design possible shortest routes with constant WIP (work in progress) time, cycle time, and lead time.	Design material handling system with intelligent algorithms for adaptive shop floor and create connectivity between material handling system and base stations.

Table 4 Comparing Traditional Systematic layout and Industry 4.0 Layout design process

With the above Table 4 changes from the traditional systematic layout planning are shown with regards to Industry 4.0 and this helps in developing new facility design processing steps.

5.4. Facility Design Processing Steps

Industry 4.0 facility design steps are developed to accommodate the technological advancements that are happening in Manufacturing Industry. As the new revolution brings up autonomous robots and smart AGVs that can communicate with each other and handle disruptions autonomously. This reduces human interruption in the manufacturing process. Therefore, in the current facility design process, more robots and AGVs are used instead of human labours. So, arrangements of robots and creating good space for material handling movement plays an important role in design Industry 4.0 facilities. Proposed Industry 4.0 facility Design steps are mentioned below:

1. Create modules based on clustering analysis of operations. Cluster analyses consider distance measure/similarity of operations for grouping the process and creating a module.
2. Draw or Design the layout planning by any methods like Graph-based, CORELAP method, or any other. This design is based upon the adjacency of modules. Here module areas can also be known apart from the positions.
3. Planning for material handling system. This means deciding about the type and number of equipment that is required for material movement. From Chapter 2 - Industry 4.0, autonomous robots and AGVs are the preferred material handling equipment. Due to their

increase in flexibility. The number of AGVs can be calculated by the sum of loaded and unloaded travel time divided by the time an AGV is available. But in Industry 4.0 factory loaded and unloaded travel time of tools and fixtures are also considered. Because in Industry 4.0 layout tools and fixtures are separated from the production area. To calculate robots there are no specific formulations to follow. The number of robots is decided on the operations like repetitive tasks, multi-shift operations, operation with a long time, responding in automated operations. Material handling systems in Industry 4.0 should mainly possess technologies like Cyber-physical systems, the Internet of Things, cloud storage, big data analytics, etc.

4. Detailed design of the layout is created with all the measurements of the machines and material handling equipment, for creating the path. To design a detailed layout software like CRAFT tool and much more software is used. The tool needs inputs like flow matrix, cost matrix, Total area measurement, number of departments, fixed points (entry and exit), and each department measurement. In industry 4.0 factory departments are the modules, which means each module is independent and can be replaced by any other module at any time. This results in the final block layout and with this block layout, the further 2D layout could be drawn with AutoCAD for better representation.
5. Detail Design of material handling system includes creating intelligent algorithms for the material handling system to be flexible and adaptable for the dynamic shop floor. Consider input data like a total number of new jobs added to the system, jobs operation precedence relationship, jobs due date, available machines, operation processing time, active machines, and layout guide path network.
6. Create connectivity between machine to machine, machine to material handling system, and material handling system to base stations.

With the above design processing steps, manufacturers can look forward to creating an Industry 4.0 shop floor. These design processing steps should make the layout and material handling system convenient for the software components like cyber-physical systems and IoT to work efficiently. Because Industry 4.0 is mainly focussing on merging most of the software technology to the Mechanical equipment and making the whole manufacturing process completely automated. This reduces labour requirement and vanishes labour problems intervening Manufacturing process.

5.5. Conclusion

This chapter proposes a modified Industry 4.0 facility design process, based upon the analysis of the data from the Traditional Manufacturing Facility Design process and influence of Industry 4.0 on Manufacturing Facility Design discussed in Chapter 3 and Chapter 4 of this project report.

The proposed Industry 4.0 Facility Design process is used to design the Industry 4.0 Facility layout and it is one of the designing processes to achieve the outcomes of Industry 4.0 Facility Layout. So that, outcomes of Industry 4.0 layout are used for the evaluation of the changes in manufacturing facility design due to Industry 4.0. This results in answering the research question 'e'. From Chapter 3 - Manufacturing Facility Design, it is evident that Industry 4.0 focuses on modularity and reconfigurable layouts and proactive material handling system. Modular and reconfigurable layouts are next-generation layouts that are more flexible and adaptable to dynamic manufacturing processes compared to traditional layouts like flowline, functional and cellular layouts. Proactive material handling system focus on adapting the tasks in the dynamic condition of the shop floor. These are the expected outcomes from Industry 4.0 Facility Layout.

For Modular layouts, a flexible material handling system is implemented for adaptable scheduling and efficient material handling. The flexibility of the material handling system is obtained from Industry 4.0 technologies like Cyber-physical systems, Internet of Things (IoT), cloud storage, big data analytics, etc. As they help the material handling system to connect and with machines to work collaboratively with the access to all the prior information about product and process. So, to design a facility layout for Industry 4.0 factories modularity is considered. To design a modular layout, modules are created using clustering analysis. And these modular layouts are designed for flexibility and reconfigurability of the manufacturing process. So, there are no changes in the design process of the layout from the influence of Industry 4.0.

For material handling system planning, material handling equipment having technologies of Cyber-physical system, cloud storage, Internet of Things (IoT), big data, etc are chosen for connectivity and flexible movement. In the detailed design of the layout, spacing is considered for flexible movement and further expansion of the modules. For material handling system detail designing routing and scheduling is designed with intelligent algorithms. These algorithms are designed with the input information about newly added jobs, active machines, processing time, jobs due date, available machines, and layout guide path network. This input information keeps the material handling system updated with the current working process of the shop floor and makes it adaptive to any changing conditions like adding new jobs or disruptions due to machine breakdown. This adaptive condition makes the process decentralised and allows the material handling equipment to make smarter decisions based upon processing time, travel time and distance, and energy efficiency.

6. Chapter 6- Case Study

This is the case study of a virtual company to implement the modified Industry 4.0 facility design process i.e. shown in Chapter 5 – Industry 4.0 Facility Design Process and compare with traditional facility layout. Then evaluate facility design process and outcomes of both traditional layout and Industry 4.0 Layout. Section 6.1 briefs about the company introduction, providing basic information about the company and the requirements of the company. Section 6.2 shows the inputs and assumptions made to solve this case study, which is required to keep the case study focusing on the research objective. With these inputs and assumptions, Section 6.3 shows the traditional facility design process and its outcomes. Section 6.4 shows up Industry 4.0 facility design process and its outcomes. Comparing section 6.3 and section 6.4, the case study is analysed by section 6.5 briefing the changes in the facility design process and its outcomes. After the analysis, the chapter concludes with section 6.6.

6.1. Introduction

Consider a case study with the virtual company, which is planning to construct a new facility for manufacturing parts for the agriculture, automobile, energy, and aircraft sectors. The products would arrive at this company for the machining process and the processes are discussed in assumptions. So, the factory facility must be built from the stage of a greenfield, which means a new facility layout from the scratch. Using the traditional facility design processing steps from Chapter 3 - Manufacturing Facility Design, the manufacturing layout, and material handling system are designed. Implementing the changes mentioned in Chapter 4 – Manufacturing Process in Industry 4.0, Industry 4.0 based layout and material handling system is designed. After designing the respective layout, it is evaluated quantitatively through the cost calculation of the facility layout. Because evaluation through flexibility, production time, etc in a quantitative way would be complex and time-consuming. Therefore, the evaluation process is conducted through cost, and in the case study analysis, qualitative analysis is made concerning the Facility design process of both layouts. So, in the case study analysis evaluation of outcomes of the Facility layout and changes of the facility design process is discussed. In addition to that key performance technologies that are used for Industry 4.0 facility layout are also discussed. So that it shows the technologies of Industry 4.0 used for this case study. From this analysis, the case study wanted to conclude the efficient Facility layout from the outcomes of the facility layout and show the impact of facility layout from the two facility design processes.

6.2. Assumptions of the Case Study

To design any facility layout, production data is necessary. Production data include types, volume, demand, and production processes of the product. As the company picked for the case study is just a virtual company. Production data are assumed and tabulated below. Details represent the assumed production processes of the specified types of products and demand per year. Considering 250 working days per year, product demand per day is calculated and tabulated in Table 5. This demand per day information helps to calculate the several machines required. With this production process, the machines required are known and machine details are tabulated in Table 6. The cost of the production hall is assumed to be 800$ per m^2. This assumed information about the production process is input for the facility design process. Those are discussed in the next Section 6.3.

Manufacturing Types	Total Products demand (per year)	Product Demand (Per day)	Product Routings
Agriculture	5000	20	SM, TM, MC, DM, GM
Automobile	5000	20	SM, TM, MM, GM
Aircraft	5000	20	TM, MC, MM, DM
Energy	10000	40	TM, MM, MC, DM, GM

Table 5 Product Details

Operations	Machines	Surface (LxWxH mm3)	Availability of Machine (%)	Purchase Cost (€)
Sawing	Sawing machine (SM)	1600x700x1700	90	2000
Turning	NC turning lathe (TM)	5300x3400x2500	75	17000
Milling	NC milling machine (MM)	1600x2300x2300	75	22000
Machining	Machining center (MC)	1900x2100x2500	75	30000
Drilling	Drilling machine (DM)	600x1000x2200	80	1500
Grinding	Grinding machine (GM)	2100x2400x2500	75	15000

Table 6Machine Details

	Sawing (min)	Turning (min)	Milling (min)	Machining (min)	Drilling (min)	Grinding (min)
Agriculture	10	50	40	30	20	30
Automobile	15	40	50	30	30	40
Aircraft	10	30	40	50	25	30
Energy	20	30	40	30	20	30

Table 7 Processing Time (mins)

Table 7 shows the processing time taken to perform the specific operation for the specific kind of product. This helps to find out the number of machines required to meet the product demand.

Depending upon the availability of machines and demand per day. A number of machines are calculated, and the calculations can be referred to the Appendix - Ⅱ. The resulted number of tabulated below:

	Sawing Machine	Turning Machine	Milling Machine	Machining center	Drilling Machine	Grinding Machine
Total	4	10	12	10	6	9

Table 8Total Number of Machines Required

6.3. Traditional Facility Design Process

With the reference of Chapter 3, which provides a brief explanation of traditional facility design and its design process. That facility designing process is implemented in this case to get the traditional facility design of the factory. To implement this factory design, inputs, and assumptions that are mentioned in section 6.2 are utilised. The facility design process is briefed below with the available inputs and assumptions like product types, volume, and production processes. Depending upon demand and machine capacity, the number of machines is decided. Assuming a single machine can meet the production demand, for each process single machines are used for production.

Facilities Planning

In the Planning phase, inputs required for designing the facilities are gathered. Means from production process planning details about the production like the type of products, the volume of the products, machines used, number of machines, production operations, and manufacturing timings are known. Depending upon the number of product types and production quantity, a Process or Functional layout has been chosen. Arrangement of these manufacturing machines and the required material handling system is planned in this planning section. After this planning, this will be the input for detailed designing of the facilities.

- Initially for layout planning From-To chart or relationship chart or any tool can be used to show the product movement intensity and it helps to check the adjacency of the machines. It is derived from the product routing and product demand per year. Depending upon the total products that go to the respective department are arranged nearby to the consecutive department, that has consecutive operations.

	SM	TM	MM	MC	DM	GM	TCR
SM	X	15000	0	0	0	0	15000
TM	0	X	10000	15000	0	0	25000
MM	0	0	X	5000	5000	10000	20000
MC	0	0	0	X	10000	0	10000
DM	0	0	0	0	X	10000	10000
GM	0	0	0	0	0	X	0

Table 9 Total Closeness Rating (TCR) Table

- Using Graph-based method or CORELAP method facility layout planning is made using 2D drawing. Depending upon the Total Closeness Rating (TCR), the adjacency of the machines is known. Resulting in the arrangement of the machining departments. Irrespective of the methods that are used, roughly departmental arrangements are represented. Departments in this facility layout consist of the tools section, machining section, and production section.

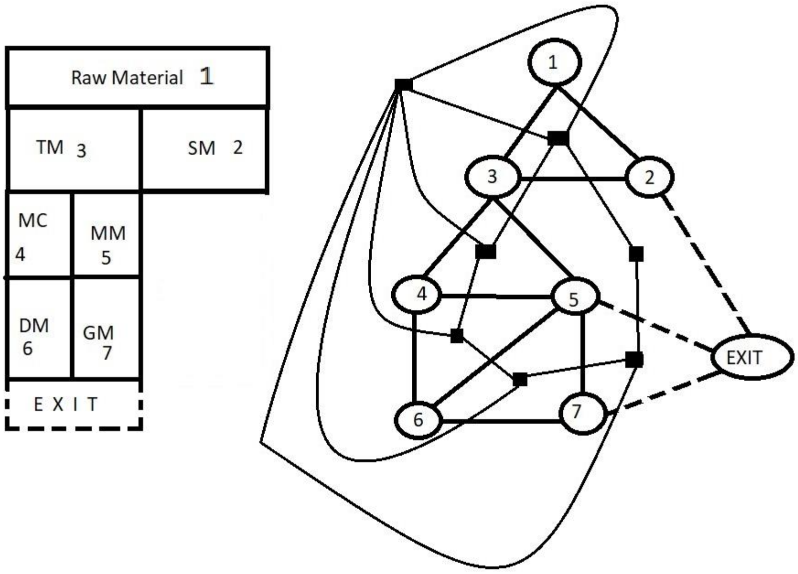

Figure 28 Graph Method Layout Design

From Figure 28 layout design, department placements are known and the even size of the areas can also be indicated in the above 2D Figure 28. In the detailed design, the layout can be designed with all the department measurements, pathways to material handling equipment, and even the positioning of the machines.

- After the layout design, the selection of the material handling system is done. To select a material handling system Apple (1997) suggested a material handling equation was followed [28]. For the right material handling system methods like the Rule of Thumb Approach, deterministic approach, or Probabilistic approaches can be used[28]. Assuming that the material handling system for this case study is selected using the Online Rule of Thumb approach. Before selecting the material handling system through this method, this material handling system should satisfy the material handling principles mentioned in Chapter 3 - Manufacturing Facility Design. So, material handling equipment for this case is selected upon unit load-carrying between departments, flexibility, cost, and space utilization. Below is the material handling equipment used in this case study and detailed features about the equipment is shown in Appendix - Ⅰ:
    - ➢ Pallet Jack– This material handling equipment is used to transfer finished products and raw materials arranged in pallet boxes from one department to another. Further details and images of the equipment can be seen in the Appendix - Ⅰ. The total number of pallet jacks used is 8. The number of pallet jacks is calculated by multiplying the number of labours for material transferring to 2 [45].

Pallet Jack	Specifications
Load Capacity	2000 to 2500kgs
Power	Electric
Cost	400$

Table 10 Pallet Jack Specifications

- ➢ Pallets and pallet boxes–These are used for collecting the finished products in bulk and transfer either to other manufacturing cells or to the warehouse.

Pallet and Pallet boxes	Specifications
Number of pallets	15
Cost of each pallet	100$
Number of pallet boxes	15
Cost of each pallet box	100$
Total	3000$

Table 11 Pallet and Pallet boxes Specifications

- ➢ Labour requirement – Manpower is used for driving the forklifts and operating machining processes like a change of tools, changing the operations, loading-unloading or products and raw materials.

Labour	Specifications
Machine operators	26
Material handling operators	4
Total Labours	30
Working hours	8hrs/day
Labour cost per hour	15$
Labour cost per day	120$/day

Table 12 Labour Specification

Detailed Design

From facilities planning, placement of the departments and required material handling system is known. With this information, using design tools like CRAFT facilities layout is created with much more detailed information like size of the departments, overall layout measurement, and cost of the layout. As this project is mainly focussed on the facility design process, the layout outcome is shown as a 2D Drawing for reference. After designing the block layout by CRAFT designing software, many detailed designs like material movement, buffer storage, lead times are all analysed through Simulation software. Referring to Figure 29, the movement of the product begins with raw materials moving from temporary storage to turning machine department and sawing machine department through pallet jack driven by material handling operator. Raw materials enter through Entry and finished products move out through Exit. An electric pallet jack is used to transfer the finished product and those finished products are arranged to a pallet box by the Machine operator. So, in every department after the machining process, the products are arranged in the pallet box by the machine operator. Those pallet boxes are transferred to respective departments for further processing by the material handling operator through the pallet jack. Here machine operator's work is to load and unload the products. The material handling operator moves the material to the next processing department. The enclosed layout, semi-closed temporary storage, and processing departments are all indicated to be the walls of the layout. The path that indicates the way from temporary storage to every processing department is the path for Electric pallet jack movement. The rest of the layout space is allowed for operator walking or for any human activities like cleaning of the shop floor.

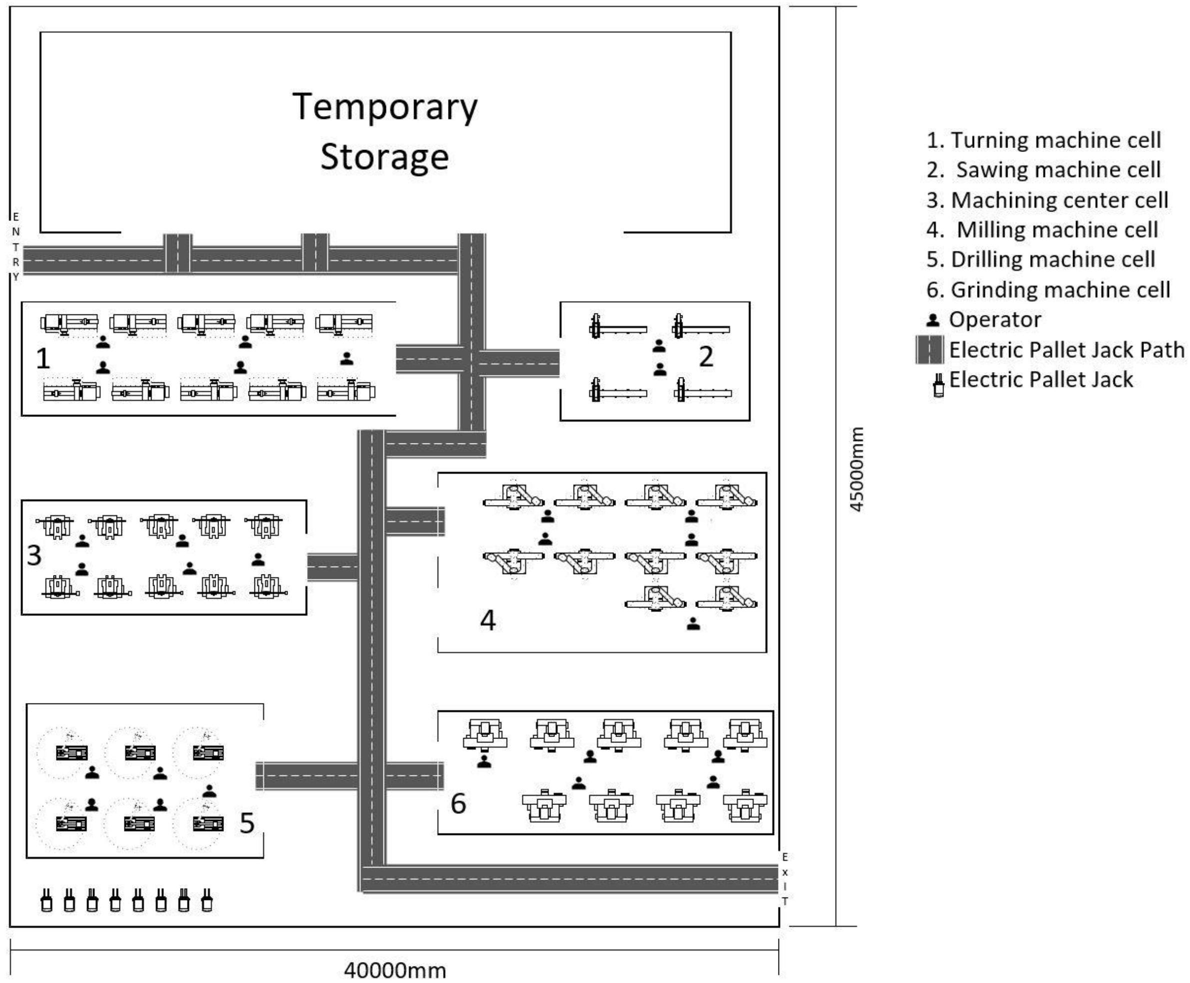

Figure 29Functional Layout Representation

Evaluation of the Facilities Layout Design

The layout is evaluated with the costs that are required as an initial investment for this manufacturing Industry. Due to the uncertainties in the data availability, carrying out other evaluation processes like production time, material handling cost, etc was not possible.

Initial Investment costs of machines and material handling equipment are tabulated below in Table 13, and these costs are an approximated value from an established website:

Machinery and Material Handling	Cost ($)
Sawing machine	9600
Turning Machine	203000
Machining Center	360000
Milling Machine	315600
Grinding Machine	162000
Drilling Machine	10800
Pallet boxes	3000
Pallet jacks	3200
Cost of 30 Labour (per year)	900000
Cost of Production Hall	36000
Approximate Total Cost	**2003200**

Table 13 Cost of Monthly Expenditure

6.4. Industry 4.0 Facility Design Process

Industry 4.0 majorly focuses on connectivity, smart and flexible facilities that require minimal human intervention. So, to design facilities for Industry 4.0 factory the designer should make the layout modular, flexible, and spacious for future production process expansion. Designing the material handling system by prioritizing autonomous robots and autonomous AGVs, that are supportive of the technologies like Cyber-physical systems, the Internet of things, Big data analytics, etc. In the previous section6.3, the traditional facility design process is followed to design facilities for the parts manufacturing company. In this section 6.4, the Smart Factory or Industry 4.0 factory is designed for the same company with similar inputs and assumptions about the products that are considered in the traditional facility design process.

1. *Create Modules based upon a clustering analysis of the operation*

The modular layout is designed through clustering analysis. By considering distance measure/similarity of operations, modules of production operations are created and arranged on the shop floor. In [44], a complex method has been used to create the modular layout and cluster analysis.

With a simple heuristic method, layout modules are created based upon the manufacturing process. Means modules are designed with machines that perform a single operation and it is shown below in Table 14. These modules are arranged based upon the operation flow of the product that is referred from Table 9.

Modules	Manufacturing Process
Module 1 (M1)	Turning Process
Module 2 (M2)	Sawing Process
Module 3 (M3)	Machining Center Process
Module 4 (M4)	Milling Process
Module 5 (M5)	Drilling Process
Module 6 (M6)	Grinding Process

Table 14 List of Modules

2. *Draw or Design the layout planning by any methods like Graph-based, CORELAP method, or any other. This design is based upon the adjacency of modules. Here module areas can also be known apart from the positions*.

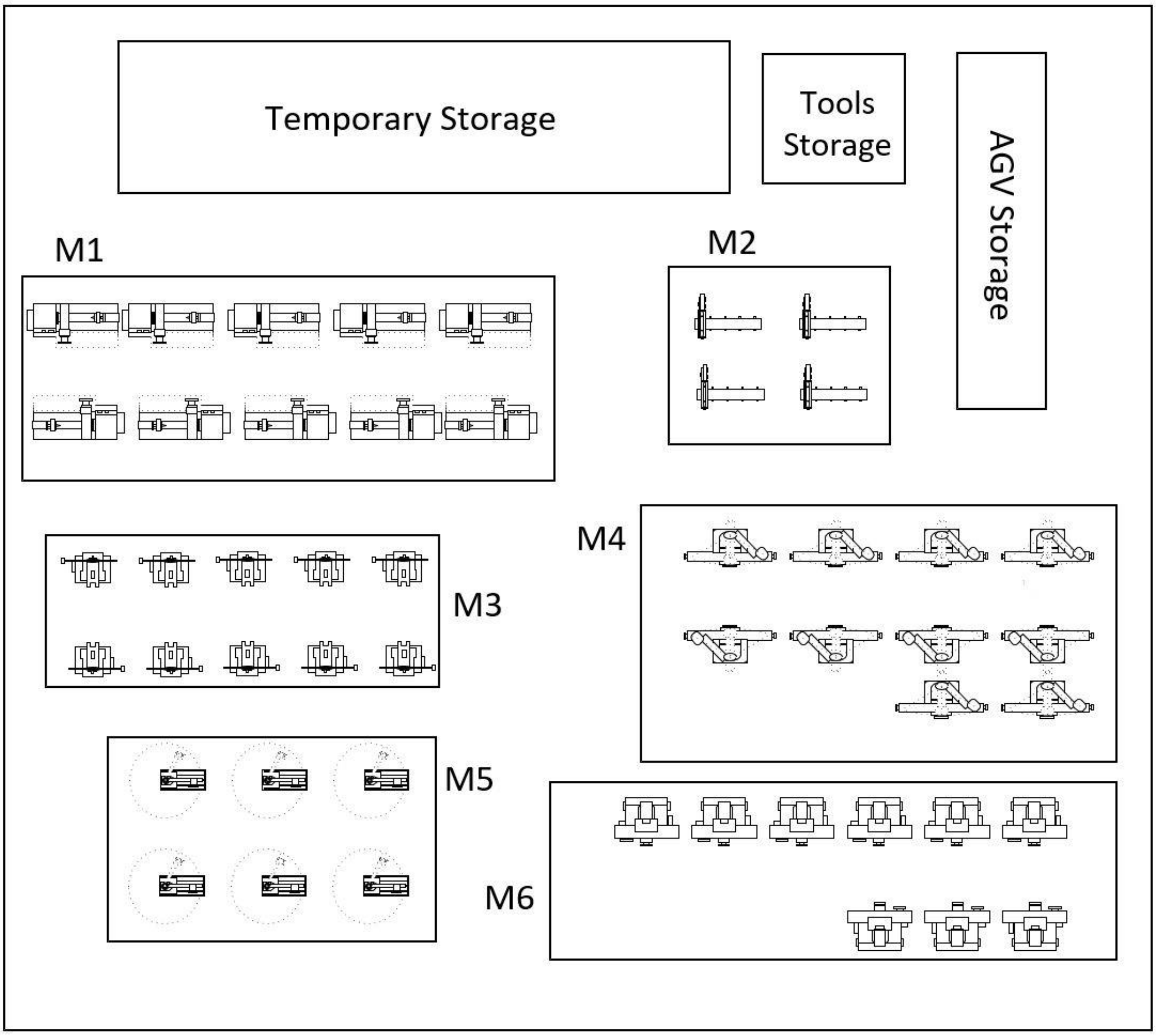

Figure 30 Representation of Modules in Modular Layout

Figure 30 represents the layout configuration of the modular layout with the modules consisting of single manufacturing operations and showing the positions of the tool room and AGV storage. Designing a separate tool room is much more comfortable for the robots to access the tools for changing it whenever it is necessary. AGV storage and tools room are placed near to the Temporary storage area, for easy access of materials and tools.

3. *Planning for Material Handling System*

Material Handling equipment planning – AGVs and Smart Robots are selected as the material handling equipment for transferring and moving the products. This material handling equipment is checked for embedded Cyber-physical systems, Internet connectivity, cloud computing, and big data analytics. Production objects like pallets, trolleys, robot arms, and containers are equipped with sensors to identify real-time status. All the material handling equipment is connected, and it is also connected to machines through the Internet. Equipment is made to access all the product details such as customer orders, product type, raw material requirement, and processing time through the Internet of Things, Cloud storage, and Big data analytics. All the material handling equipment works with an Intelligent algorithm to work on the adaptive shop floor. Intelligent algorithms are the ones that accept the new jobs in between the jobs that are in the queue and assign to the material handling equipment and assigned to the respective equipment would be based on cost, time, the importance of the job, and capacity.

Material handling equipment selected for this case study is discussed below:

- Autonomous Robots–These robots are used for multiple tasks such as material handling tasks, changing machine tools, and inspection jobs. Robots are connected to the machines and AGVs through the internet and they provide product status update whether the production is completed or not. Robots are attached with sensors to identify the type of product and do the necessary job for that product. The robot arm can reach up to 2.1m to 3.1m. With this purpose in mind, every machine in this case is assigned with a robot to change the tools for the machine and even does loading and unloading of the materials to the pallet box and AGV. So, according to the assigned work, the number of robots is determined and is mentioned in the below table. Below are the specifications of the robot to check during the selection of the robot and further detailed representations of robots are shown in Appendix - Ⅰ:

Autonomous Robot	Specifications
Purpose	Material handling and tool change
Payload	20kg – 70kg
Maximum reach or Arm length	2100mm–3100mm
Cost	45000$
Number of robots	20

Table 15 Autonomous Robot Specification[35]

- Automated Guided Vehicles (AGV)- Automated guided vehicles are not new to the industries but in Industry 4.0 factory they are programmed with flexible and adaptable scheduling and routing system. While calculating the number of AGVs for material handling systems in Industry 4.0, Loading and Unloading travel time of tools and fixtures should also be considered with product loading and unloading travelling time. Loading and unloading of tools fixtures from the robots and machines should also be considered. Several genetic and heuristic algorithms are created with the additional information of alternative jobs for the AGVs in Industry 4.0. Whenever there is an indication of the change in the process the machines immediately communicate with AGV through Internet connectivity and change the process of work. These jobs for AGVs are prioritized based upon the type of job, travel time, and processing time. For example, if machines publish a task in a cloud storage platform the nearest available AGV is assigned if it's unloading in the next machine and have no other task. Specifications of the AGV are shown below and detailed features can be referred to Appendix - Ⅰ:

Automated Guided Vehicle (AGV)	Specifications
Load	3000kg
Average Speed	60 m/min
Cost	100000$

Table 16 AGV Specification

	Temporary Storage	Turning Machine	Sawing machine	Machine center	Milling machine	Drilling machine	Grinding machine
Temporary Storage	0	0.16	0.16	0	0	0	0
Turning machine	0	0	0.08	0.08	0.08	0.16	0.16
Sawing machine	0	0.08	0	0.08	0.08	0.16	0.16
Machine center	0	0.08	0.08	0	0.05	0.08	0.08
Milling machine	0	0.08	0.08	0.05	0	0.08	0.08
Drilling machine	0	0.16	0.16	0.08	0.08	0	0.08
Grinding machine	0	0.16	0.16	0.08	0.08	0.08	0

Table 17 Travel Times of AGV (mins)

The travel time of AGV is calculated from the speed, time, and distance formula. The calculation is mentioned in Appendix - Ⅱ of this report.

	Temporary Storage	Turning machine	Sawing machine	Machining center	Milling machine	Drilling machine	Grinding machine
Temporary Storage	0	15	15	0	0	0	0
Turning machine	15	0	0	10	20	0	0
Sawing machine	15	0	0	0	0	0	0
Machine center	0	10	0	0	10	10	10
Milling machine	0	20	0	10	0	10	10
Drilling machine	0	0	0	10	10	0	20
Grinding machine	0	0	0	10	10	20	0

Table 18 Number Loaded Trips of AGV (mins)

Above Table 17and Table 18 shows the travel timings and loaded trips of AGV respectively and the calculations for travel time values are shown in Appendix - Ⅱ. The calculation for the number of AGVs is shown below:

Assuming AGV available time for the shift = 7.5 hrs = 450 mins

Total loaded travel time is travel time multiplied by the number of loaded trips of an AGV

Total Loaded travel time = 275mins

Total unloaded travel time is AGV travelling back empty and it assumed that the unloaded travel route is efficient in this case study.

Total Unloaded travel time = 250min

Total loading and unloading time of products = 165mins

Due to unknown information about the wear and tear of the tools and change of fixtures. The loaded and unloaded travel will be assumed.

Total loaded travel time for tools and fixtures = 150mins

Total unloaded travel time for tools and fixtures = 140mins

Loading and unloading time for tools and fixtures = 130 mins

Total working time of an AGV = Total loaded travel time + Total unloaded travel time + Total loading and unloading of products + Total loaded travel time for tools and fixtures + Total unloaded travel time for tools and fixtures + loading and unloading time for tools and fixtures

$$Number\ of\ AGV = \frac{Total\ working\ time\ of\ an\ AGV}{Availability\ of\ an\ AGV}$$

$$Number\ of\ AGV = \frac{275 + 250 + 165 + 150 + 140 + 130}{450} = 2.46 = 3$$

Approximately 3 AGV is required

- Labour requirement – In this Smart factory material handling operators are not required as the layout is fully automated. Therefore, this smart factory requires highly skilled cell operators for monitoring the production process. A highly skilled operator possesses knowledge about the present technology and programming capacity to monitor the process. So, one highly skilled operator is enough to monitor the whole cell or shop floor production process. Assume skilled Operator cost is 250$ per day.

Labour	Specification
Level	Highly Skilled
Cost	250$ per day
Number of Operators	6

Table 19 Labour Specification

4. *Detailed design of the layout is created with all the measurements of the machines and material handling equipment, for creating the path*

In the detailed design of the layout position of the robots and AGV traveling routes are designed. Apart from the machine locations that are shown previously in the traditional facility design. While designing the Industry 4.0 modular layouts, machining modules size should be considered only with the machine size, robot, and AGV parking. This means that using any computerised methods like CRAFT or any other software to design layout, module or department measurement should only be with the machine, autonomous robot, and AGV parking. Layouts are designed by separating logistics, tools, and production areas. Separate tools room makes it easier to load and unload AGVs and those tools are supplied to the modules where robots access those tools to change for the machining operation.

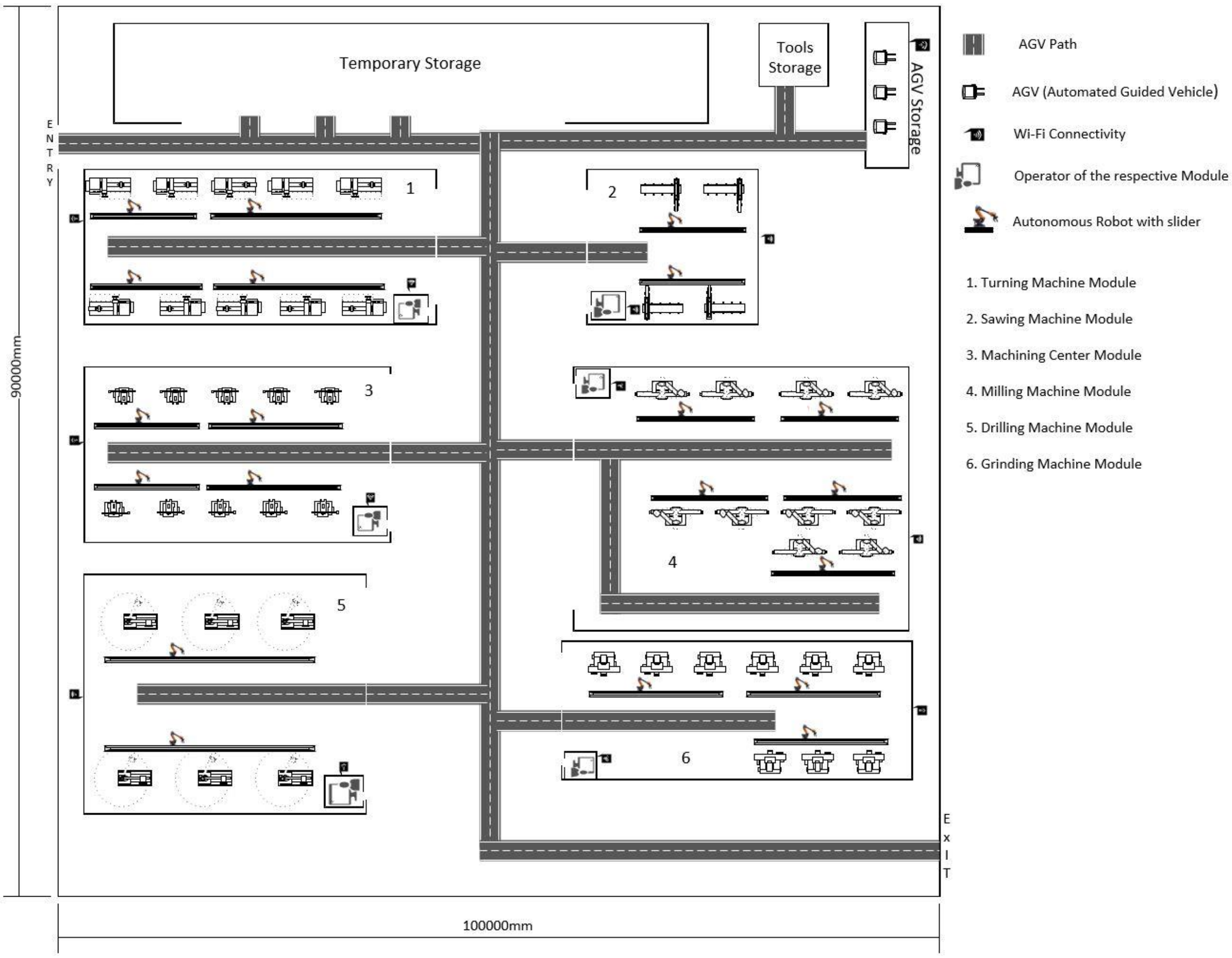

Figure 31Representation of Industry 4.0 Layout

With the above Figure 31 layout representation of smart factory is shown, and it is only for this case study reference. The modules such as temporary storage, AGV storage, tools storage, and all the machine modules are surrounded by brick walls. The layout is also covered by a brick wall. Apart from the AGV path, the rest of the space is utilised by human operators walking space. Human operator space in every module is designed for maintaining the operations smoothly. It is of the size that can accommodate a monitoring computer system and one or two persons. Temporary storage is the space required to store the raw materials temporarily. From temporary storage, all the raw materials are supplied to the respective operating modules by AGV. Autonomous robots assigned for the machines take care of changing the tools in the machine and loading and unloading materials from the AGV. Robots also handle the products to load and unload the operating machine. After the layout Design is finalised material handling equipment and machines are connected through the Internet of Things for the machine to machine connectivity. The Wi-fi indication in the layout shows that machines, robots, and AGVs are interconnected to each other through the internet. Scheduling and routing systems for AGVs are modelled with the algorithms that prioritize the work depending upon manufacturing time, manufacturing cost, and energy consumption. All the material handling equipment, machines, and operators are made to access the cloud storage information about the products such as delivery time, inventory details, cycle time, product history, etc, all the information related to product and product manufacturing. Even raw material suppliers are also connected for cloud storage information to have an update about the raw material orders.

5. *Detailed Design of Material Handling System*

Detailed designing of the material handling system is to create intelligent algorithms for working of the material handling equipment i.e. robots and AGVs. In this case, robots are programmed for multiple tasks such as tool changing and picking and place of the products. AGVs are programmed for transferring the tools and products from one destination to another. These tasks for the material handling equipment are made to work autonomously through intelligent algorithms. Intelligent algorithms prioritise the tasks based upon the availability of machines, task size and travel, and operation time of the task. For this research project, this process is limited to mention the factors dependent on developing intelligent algorithms. Due to the difficulty level and this work is recommended for future work.

6. *Create connectivity between machine to machine, machine to material handling system, and material handling system to base stations.*

In Figure 31, connectivity of the layout is observed through the Wi-fi symbol. Detailed work about creating the connectivity is recommended for future work. Due to the time constraint of the research project and lack of information availability.

Evaluation of the Facilities Layout Design

As it was discussed in the section 6.3 evaluation process, Industry 4.0 facility design is also evaluated by investment cost.

Initial Investment costs of machines and material handling equipment are tabulated below, and these costs are an approximated value from an established website.

Machines and Material Handling Equipment	Cost $
Turning machine	203000
Sawing machine	9600
Milling machine	315600
Machine center	360000
Drilling machine	10800
Grinding machine	162000
Total Robot cost	900000
Total AGV cost	300000
Total Labour cost	375000
Total cost of pallet boxes	3000
Cost of Production Hall	92100
Total Cost of the Layout	**2731100**

Table 20 Industry 4.0 Layout cost

6.5. Case Study Analysis

This case study is mainly conducted to evaluate the change in the facility design process that is mentioned in Chapter 4 – Manufacturing Process in Industry 4.0. Certain factors are complicated to quantify, and they are said to be flexibility, throughput time, material handling cost, etc. So with the above case study, there are certain changes in the performance and the outcome of the layout. Key performance indicators are also known and discussed in this section. The changes and key performance indicators are discussed below:

1. **Evaluating the changes regarding the Performance and the Outcome of the Industry 4.0 Facility Layout**

Changes in the facility design process may include changes in the technologies that influence the facility's layout to become more flexible and reconfigurable. The factors that are used for evaluation of the facility design process change are discussed below:

- Cost estimation – Comparing the initial setup costs of the two layouts in sections 6.3 and 6.4, the Industry 4.0 layout cost more expensive than the traditional layout. But usually, all the industries look for long-term investment while building any facility. Therefore, cost evaluation is made for both the layouts keeping a minimum of 2year's expenditure. These costs are close approximation values and not the exact numbers. Because some of the material handling equipment are customised according to the need of the factory.

Layout	Total Cost ($)
Traditional Layout	2003200
Industry 4.0 Layout	2731100

Table 21 Layout Investment Cost

The initial Investment cost of the Industry 4.0 layout is 727,900$ expensive than the traditional layout. Considering the maintenance cost and cost of the labour, yearly expenditures are calculated and expenditures for 2yrs apart from the invested year are calculated below:

Traditional Layout yearly Expenditures	Cost ($)
Cost of Labour	1800000
Maintenance of material handling Equipment	1000
Total Cost	1801000

Table 22 Traditional Layout yearly Expenditure Cost

Industry 4.0 Layout yearly Expenditures	Cost ($)
Cost of Labour	750000
Maintenance of material handling Equipment	415000
Total Cost	1165000

Table 23 Industry 4.0 layout Yearly Expenditure Cost

Comparing Table 22 and Table 23, there is a cost difference of 636000$ for 2 years and it shows Industry 4.0 layout is 636000$ cheaper to maintain the layout than the traditional layout. Industry 4.0 seems cost-efficient compared to the traditional layouts for a longer period, with the use of a greater number of robots and AGVs than operators. Industry 4.0 factories encourage the use of a greater number of robots for manufacturing and in return reduce human operators and labour costs.

- Production capacity – Using more human force reduces the production capacity of the factory. Due to this reason, their production capacity is low compared to robots. Because the human force needs more breaks such as lunch breaks, coffee/tea breaks, etc. That will gradually reduce their working time. For example, sum up all the breaks and conclude that if an operator takes 45mins of breaks per shift. It almost reduces 9-10% production capacity from the operator. While robots have almost 100% working capacity and increase the production capacity. Even though minor breakdowns happen, that can sum up to 3-4% of the available time. In [46], it is also proven that robotization has increased their productivity by 30%. But in this case, almost 4500 hrs of working time are saved from avoiding 24 operators from the traditional layout and using only 6 operators for Industry 4.0 Layout.
- Layout –From the case, it is observed that both layouts satisfy the concept of modularity. By creating modules of the individual operations or disintegrating a bigger process into the smaller individual processes. But Industry 4.0 layout seems 10 square meters bigger than the traditional layout. Due to the reason of using more robots than operators. Robots need bigger space than the operator. In Industry 4.0 layout separate tools section is created for easy access of tools for the AGVs. From this bigger layout, production hall cost also increases. In this case, it has increased by 56100$.
- Design of Material handling system design –In Industry 4.0 layout robots are used more than human operators for operating machines. For material transfer, AGVs are used. Present material handling equipment with updated technologies such as Cyber-Physical systems and the Internet of things are more expensive than the traditional material handling equipment. In this case, intuitively the number of robots is 20, expecting a robot would be able to handle a maximum of 3 machines per shift. Industry 4.0 material handling system requires only 6 operators, but traditional layout requires 24 operators. So, with the traditional layout operator numbers, the Industry 4.0 layout can run for 3 shifts and increase productivity.

Qualitative analysis is made on the Dynamic Shop floor efficiency and autonomous level of the Industry 4.0 layout compared with the traditional layout. Because the quantitative evaluation of these factors is complex because of the lack of detailed information and due to the time constraint of this project. This would support the evaluation process for the facility design process followed to create a smart factory. So, qualitative analysis for Dynamic shop floor efficiency and autonomous level is stated below:

- Dynamic shop floor efficiency – Dynamic shop floor efficiency is the rate at which the material handling system responds to the higher frequency of change in processes for the product. It is more evident Industry 4.0 material handling systems with the technologies such as Cyber-physical systems, the Internet of Things, and cloud storage access the data quicker and respond immediately. But in traditional layout, due to improper connectivity and manual operators, the information transfer might be slower. This might directly or indirectly affect the setup-time, by increasing in traditional facility layout and lowering in Industry 4.0 layout. Even for material movement, AGVs can respond immediately to the jobs that are added in between the regular job. But manual operators need to make regular checks from each machining department and then perform the action. This might cause a time delay in the material transfer time. So, material handling systems designed from Industry 4.0 facility design process are quicker in responding to the dynamic condition of the shop floor. As a result, throughput time, waiting time, material movement time, cycle time, and delivery time of product or material might be reduced.
- Autonomous Level – Autonomous manufacturing companies provide efficient and economical manufacturing processes through higher production time. Because autonomous machines or

robots have lower fatigue levels with higher working efficiency. Comparing the material handling system of the two layouts, the Industry 4.0 facility layout has a higher autonomous level than the traditional facility layout. In Industry 4.0 facility layout no human interferes from the time of supplying the raw material to the delivery stage. Only an operator will be monitoring the actions of material handling equipment and machines. Even for the change of products or change of process, respective products consist of sensors like RFID tags that have all the information for the production process. AGVs supply the right tools for the robots and robots set the machine to the respective job production. But in traditional facility layout, apart from the machining process rest of all work is dependent on humans. So, this level of autonomy in the factory reduces human interference, increases productive hours, reduces the cost of hiring operators for easy jobs, and tries to keep the production process continuous.

2. Evaluating the changes regarding the Facility design Process

Traditional Facilities layout and Industry 4.0 Facilities layout has its own distinctive facilities layout with their facilities layout design process. To evaluate the facility design process of both the layouts, those changes in the facility design are observed and the changes are discussed. The changes are mentioned below and evaluated qualitatively:

- Layout Design –Depending upon product demand and variety, a traditional functional layout is designed with machining departments using a graph-based method. In Industry 4.0 layout design, modules are created by grouping the machines based upon operations. In traditional layout, it is focussed on reducing the material movement in arranging the departments. But in Industry 4.0 layout, it is focussed on flexibility in process change and flexible efficient material movement in arranging the modules. So that the layout supports the dynamic condition of the shop floor. Traditional layout department spacing is made based upon operator movement and electric pallet jack movement. For Industry 4.0 modules, spacing is made based upon AGV and robot movements mainly. Because the operator in Industry 4.0 is provided with separate space to monitor the process in the respective modules. Creating modules would help the layout to reconfigure the process and create a greater number of different products. It is easier to include in the intelligent algorithms about the travelling route of AGVs to the respective modules.
- Material Handling System design - Traditional facility layout design process focus on material handling system to be flexible and cost-efficient. But in Industry 4.0 facility layout design process the focus is more towards flexible, adaptable, and connected material handling systems. Because of these reasons, traditional material handling system uses operators and electric semi-autonomous pallet jacks, and Industry 4.0 material handling system uses Robots and AGVs. These AGVs and robots are connected through the internet of things and to the cloud storage to access all the information about the product, process, and jobs. This interconnected material handling system with access to information about the manufacturing process and products would enhance the response towards the dynamic working condition of the shop floor. Creating this kind of response in a traditional material handling system is difficult and it would not be efficient as Industry 4.0 material handling system. The traditional material handling system is simpler to design without any complex algorithms to develop. But Industry 4.0 material handling system requires intelligent algorithms that drive the equipment to do multiple jobs depending upon the factors such as capacity, time, complexity, and cost. These intelligent algorithms make the material handling system adaptable for the dynamic

shop floor. But there is no discussion about these algorithms in the case study due to their working complexity and lack of detailed information.

3. Key Technologies of Industry 4.0 Facility Layout

Depending upon the functions of the technologies introduced by Industry 4.0 into the manufacturing and case study goal of producing products per year. The technologies of Industry 4.0 used in this case are tabulated in Table 24. The key technologies that are mainly important to make the factory a smart factory are highlighted. Key technologies are either known from the opinions of other manufacturing companies or by following the motive of Industry 4.0 i.e. flexible and reconfigurable manufacturing. Means key technologies to achieve adaptable manufacturing shop floor for the dynamic market condition. Because rest of the technologies apart from key technologies depends upon the Individual manufacturing company. So that, they can decide whether the rest of the technologies are needed for their manufacturing Industry and thus reduce the cost of the Industry.

Technologies Used in the case study	Importance in Industry 4.0 Facility Layout
AGVs	Important
Autonomous Smart Robots	Important
Artificial Intelligence with Intelligent Algorithm	Key technology
Digital twin	Optional
Sensors	Key Technology
Internet	Key Technology
Cloud Storage	Key technology
Big Data Analytics	Key technology
Apps	optional
Websites	Important

Table 24 Key Technologies

The above-mentioned technologies in Table 24 classify the technologies based upon the importance of their function in making facility layout flexible and reconfigurable. Technologies under the category of important are mainly necessary but not key technology of smart factory. Technologies under key technology are the most important technologies of Industry 4.0 in making traditional factories into smart factories. Without these key technologies, it cannot be called a smart factory or Industry 4.0 facility layout. The technologies under optional are either be implemented, or they can be replaced by any other means.

6.6. Conclusion

This chapter is about a case study of a virtual small-scale Industry, to show the implementation of Industry 4.0 facility design steps from

Chapter 5 – Industry 4.0 Facility Design Process. Later discuss the changes in the outcome of the facility layout by comparing the Industry 4.0 facility layout with the traditional facility layout. This would be an answer to the research question 'f'. Traditional Facility layout design includes:

- Initially, a traditional Functional layout is designed using traditional design processes such as the From-To chart, 2D drawing, and Graph-based method. From this process manufacturing operations and storage, space positions are known.
- For this case traditional material handling system is designed based upon the principles discussed in Chapter 3 - Manufacturing Facility Design i.e. unit load, automation, space utilization, cost, etc. The number of operators was decided based upon the number of machines and semi-automated trolleys.
- After planning for the layout, a detailed layout is designed to indicate the layout measurement and material movement on the shop floor.

To design an Industry 4.0 factory, facility design steps from

Chapter 5 – Industry 4.0 Facility Design Process are followed. To design an Industry 4.0 layout there is nothing Industry 4.0 concept that is influencing the layout design process. Instead, the Industry 4.0 layout design process is based upon the design principle of Industry 4.0 i.e. Modularity and Reconfigurability. A modular layout exists to create flexible and reconfiguring manufacturing for any Industry even though they aren't aiming for smart factories. This means even Industries without the Industry 4.0 smart technologies such as cyber-physical system, IoT, etc can also use this modular layout designing method.

- Modular layout designing includes creating modules through clustering analysis and clustering analysis is dependent on distance measure or similarity of operations. Clustering analysis is a complex method of designing the layout. Therefore, due to time constraints, the modular layout is designed with a heuristic method. By creating modules based upon the manufacturing process and is arranged according to the production flow of the product. These modules represent a part of the whole layout. This means in every module, machines arrangement follows either of the traditional layout design i.e. process layout, product layout, or cellular layout. Each module is independent of other module and the changes that are made to one module doesn't affect any other modules. Therefore, reconfiguring such layouts is more comfortable than the traditional layouts. To represent the layout, a 2D drawing is used.
- Material handling system for Industry 4.0 is designed from planning the material handling equipment that possesses a Cyber-physical system, Internet connectivity through IoT, access to cloud storage, Big data analytics, and intelligent algorithms. Intelligent algorithms are advanced algorithms that make material handling equipment work according to dynamic scheduling and adaptive shop floor condition. For this case, AGV and autonomous robots are used as material handling equipment. Robots are used for loading and unloading of the product between machines and AGV and it is also used for tool changing. The number of Robots is calculated intuitively by considering a robot that would handle a maximum of 3 machines with its working capacity. There are very limited operators are used for monitoring the process. All the pallets and other production-related things are attached with RFID and

sensors to keep an update about their positions and work. For the adaptive shop floor and dynamic scheduling working conditions, robots and AGVs work under intelligent algorithms that are developed to prioritize the jobs according to the factors such as work in progress time, distance, delivery time, and availability of the equipment. So, the Industry 4.0 material handling system majorly changes with operating technologies and operating inputs compared to physical changes of the equipment.

- After planning for the layout, a detailed layout is designed to indicate the layout measurement and material movement on the shop floor.

Comparing the outcomes of traditional layout and industry 4.0 layout, it is concluded that with the cost comparison Industry 4.0 layout is more economical for the long run of the Industry with the higher Initial Investment. To evaluate the layouts either cost or flexibility or lead time or all the 3 is used and compared to select the best layout. But in this case due to a lot of assumptions, lower confirmed information, time constraint, and higher complexity in calculating and comparing the flexibility and lead times. Therefore, the cost is considered and evaluated for the layouts. But qualitative analysis on the outcomes of the facility layout concludes that Industry 4.0 facility layout is more autonomous and responds quickly to the dynamic manufacturing process than the traditional Facility Layout. Due to changes in the facility design process that focus on designing modular and reconfigurable layouts, and flexible and adaptable material handling systems. Achieving modularity would help the manufacturing process to reconfigure the modules according to the product specification. A flexible and adaptable material handling system is obtained by selecting material handling equipment such as robots and AGVs and making them work under the technologies such as the Internet of things, Cyber-physical system, cloud storage, big data analytics, and artificial intelligence like intelligent algorithms. This case study also results in providing key technologies of Industry 4.0 such as Artificial intelligence, sensors, cloud storage, Internet, and Big data analytics, changing traditional facility layout to Industry 4.0 Facility layout.

7. Conclusions and Recommendations

This chapter provides the conclusions and recommendations of this project. Section 7.1 briefs about the conclusions of each chapter of this report and indicates the outputs that are gained for the reader. It provides an overview of how each chapter's outcomes are supportive or linked to the further chapters. The limitations and the scope of further work are discussed in section 7.2

7.1. Conclusions

This project focuses upon the changes in the designing process of the facilities that occur due to the Fourth Industrial Revolution. The conclusion is briefed chapter-wise by highlighting the research question and research sub-question that are answered and explaining the outputs that are obtained from the respective chapters. So that, it shows the reason behind the order of the chapter and the link between the chapters.

Chapter 1 – Introduction

Initially,

Chapter **1** gives an overview of the project and report structure. By providing:

- Introduction about the project topic
- Research objective
- Research questions that are to be answered in the report
- Literature review of the project
- Research framework.

From

Chapter **1**, the reader could have an idea about the goal of the project and the step-by-step process to achieve that goal. It also gives an explanation about the methodology followed to achieve the objectives or goal of the project, through the resources that are shortlisted for the project. So finally, this Introduction

Chapter **1** is helpful for readers to know the objective of the research project and the process of the research project in a nutshell.

Chapter 2 – Industry 4.0

Chapter **1** is the project and reports overview, Chapter 2 - Industry 4.0discuss about the concept "Industry 4.0". Answering the research sub-questions and questions related to Industry 4.0 mentioned below:

- *What is industry 4.0?*
- *What are its design principles?*
- *What are its components?*
- *How it's affecting the manufacturing sector of an Industry?*

As Industry 4.0 is the fourth industrial revolution, it's is to change manufacturing from automated systems to the cyber-physical system which means merging cyber system and physical system with the existing technologies such as the Internet of Things, Artificial intelligence, Big Data, Digital twin, etc. These technologies tend to make the manufacturing shop floor more flexible, adaptable, and efficient to the dynamic condition of the market demand. To implement these technologies into the factory, design principles such as Interoperability, Decentralisation, Virtualisation, Service orientation, Real-time capacity, and Modularity and reconfigurability are used. These principles are used during the design phase of the factory. The concept of Industry 4.0 makes the manufacturing process more flexible with a higher level of automation and creates customer-oriented factories. From this Chapter 2 - Industry 4.0, Industry 4.0 motive, principles and technologies can be used to compare the present facilities and facility design process that helps to achieve the main objective of this research project.

Chapter 3 – Manufacturing Facility Design

Chapter 3 - Manufacturing Facility Design provides an answer for the sub-questions such as:

- *What is manufacturing facility design?*
- *Which is the current facility design process?*
- *What methods and tools are used for designing facilities of an Industry?*
- *What are the influences of Industry 4.0 on Manufacturing Facility Design?*

So that the findings found from Chapter 3 - Manufacturing Facility Design are used for comparing the impacts of Industry 4.0 concepts such as technologies and design principles. This helps for the future development of the Industry 4.0 facility design process, in the upcoming chapters. From the comparison of Industry 4.0 concepts and Manufacturing Facility design, it is also observed that Fourth Industrial Revolution brings out a major influence on the manufacturing process apart from manufacturing layout and material handling system. By making the manufacturing process flexible and adaptable for the dynamic conditions of the shop floor.

Chapter 4 – Manufacturing Process in Industry 4.0

Chapter 4 – Manufacturing Process in Industry 4.0 provides add-on information about the influence of Industry 4.0 on the manufacturing process. That will be an extended answer for the research objective i.e.:

- *What are the influences of Industry 4.0 on Manufacturing Facility Design?*

From the conclusion of Chapter 3 - Manufacturing Facility Design there might be chances of getting confused about the influence of Industry 4.0 on the manufacturing process. Thinking that Industry 4.0 might influence manufacturing operations in the manufacturing process. But from Chapter 4 – Manufacturing Process in Industry 4.0 it is clear that Industry 4.0 mainly influences the scheduling time of the manufacturing process. By supplying the right material to the right machine at the right time. With the support of technologies such as Cyber-physical system, the Internet of Things, and Big

Data Analytics. Even altering the operation queuing networks by changing the process or machine immediately during the breakdown of the current machine. This leads to reduced lead time and increases the efficiency of the manufacturing process by avoiding bottlenecks during the manufacturing process. Information from this Chapter 4 – Manufacturing Process in Industry 4.0 gives a clear vision of the outcomes of the facilities of the factory such as modular and reconfigurable layout design with flexible and adaptable material handling equipment.

Chapter 5 – Industry 4.0 Facility Design Process

This

Chapter 5 – Industry 4.0 Facility Design Process proposes a modified Industry 4.0 facility design process, from the analysis of data discussed in Chapter 3 and Chapter 4. This results in answering the research sub-question mentioned below:

- *What are the outcomes of the Manufacturing Facility Design after considering the influence of Industry 4.0? and what are the modified processing design steps to be followed to achieve the Industry 4.0 Manufacturing Facility Design outcomes?*

This chapter reflects the influence of Industry 4.0 on the current Facility design process, it also shows a proposed modified Industry 4.0 facility designing steps that were derived from the analysis of the conclusions Chapter 3 - Manufacturing Facility Design and Chapter 4 – Manufacturing Process in Industry 4.0. From Chapter 3 - Manufacturing Facility Design it is known that the manufacturing process would influence the designing of the facility design of the factory. Therefore, the manufacturing process in Industry 4.0 from Chapter 4 – Manufacturing Process in Industry 4.0would contribute to the outcome of the facility design in the smart factory. Irrespective of the methods that are used, the facility layout should be modular in design. By creating modules consisting of group machines, that are independent of the rest of the modules. So that the manufacturing processes are reconfigurable for the dynamic condition of the customer demand. Material handling should be flexible with its movement so that any new jobs assigned to the equipment should be able to respond immediately without waiting for the operator to configure the job. To attain this flexibility in material handling equipment, equipment should be able to possess the technologies such as Cyber-Physical system, Internet connectivity, access to big data analytics, and cloud storage. The algorithms that are used for the working of the equipment should be flexible enough to accept new jobs and prioritize based upon time, cost, capacity, and importance or complexity of the job. Due to this higher flexibility of the material handling system, more robots and AGVs are preferred to use than human operators.

Chapter 6 – Case Study

Chapter 6 is a case study about a virtual company, assuming they produce multiple products that go through 6 different operations. This case study is used to implement the Traditional Facility Design process from Chapter 3 - Manufacturing Facility Design and proposed modified Facility Design process from

Chapter 5 – Industry 4.0 Facility Design Process to the virtual company production inputs and compare the outcomes of the layout. In return, this chapter is an answer for the research sub-question that is mentioned below:

- *How do the Industry 4.0 Manufacturing Facility Design outcomes and modified facility design process is analysed and evaluated?*

While comparing the facility layout of both the facility design processes, changes in the outcome and the designing process of manufacturing facilities are analysed and evaluated. This analysis and evaluation are to validate this research project's findings. Using the From-To chart and graph-based method, a traditional functional layout is designed. Based upon unit load, space, and working complexity material handling equipment are selected and with a heuristic method material handling system was designed. To create an Industry 4.0 modular layout, modules are designed by clustering machines based upon machining operations. That results in creating modules of individual operations. Even the tools section is also considered to be a separate module so that it is easier to load and unload material moving equipment autonomously. Due to the implementation of Industry 4.0 technologies such as Cyber-Physical Systems, the Internet of Things, and more, it is necessary to use more robots than the traditional layout. Therefore, robots are used to change the tools, load and unload the material to AGVs and machines. Replacing a human operator, robots create a connected manufacturing process and supports to create an autonomous smart factory. Using AGVs and robots with intelligent algorithms to work as material handling equipment makes the factory smarter compared to a traditional factory. Intelligent algorithms are designed for material handling equipment to recognize and prioritize the jobs based on time, cost, job complexity, and capacity. But in this case, none of the algorithms are discussed due to their higher complexity and can be suggested for future work. Depending upon the working capacity of the robot and AGVs, the number of robots and AGVs are calculated. Operators are assigned to look after each module, and it requires only approximately 6 operators. With both facility layout inputs, 2D layout representation is shown in this case study. Comparing the outcomes of the Facility layout Industry 4.0 layout needs more space than the traditional layout, due to the reason that robot requires more space than operators. From Industry 4.0 layout, more production time is available due to the higher availability time of robots than human operators. This might increase production efficiency. Finally, both layouts are compared for cost comparison, to look at cost-efficiency. It is observed that initial investment cost is higher in Industry 4.0 facility layout due to higher material handling equipment cost. But compared to 2 years of maintaining the factory, Industry 4.0 is lower in maintenance cost due to lesser operators and lower maintenance of robots and AGVs. Therefore, the Industry 4.0 Facility layout is cost-efficient for the long run of the factory. To evaluate these facility layouts factors such as flexibility and lead time can also be used. But due to time constraints and complexity of the evaluation process, they are suggested for future works. But qualitative analysis is made on the facility design process of both layouts. Showing that Industry 4.0 facility design process results in modular and reconfigurable layouts with flexible and adaptable material handling systems to work for the dynamic conditions of the production processes. It shows Industry 4.0 facility layout is more responsive to the dynamic conditions of the shop floor with a higher level of the autonomous material handling system. As a result, the case study also provides key technologies of Industry 4.0 such as Artificial intelligence, sensors, cloud storage, Internet, and Big data analytics, changing traditional facility layout to Industry 4.0 Facility layout. This research project would provide hope for future Industries to focus on Industry 4.0 facility layout by considering the lower maintenance cost. It also reflects the parts of the facility design process influenced by Industry 4.0 technologies, so that future Industries can directly focus on those parts without deviating and wasting time to do this research.

7.2. Limitations of This Research Project

Due to time constraints and lack of feasibility in the research work, there are certain limitations for this project work. They are mentioned below:

- The proposed design process is not suitable for mass production industries such as the food industry etc.

- It is limited to the greenfield designing process. So, the proposed Industry 4.0 Facility design process cannot be used for altering the existing Facilities Layout.
- The costs of the Facility layout mentioned in the case study are not the exact cost of the Facilities layout. It might differ concerning the Industries.
- Alternative methods of the Industry 4.0 Facility Designing process are not discussed.
- This project is limited to the Designing process of the Industry 4.0 facilities layout. But does not mention any detailed information about the methods or the working procedure of the Industry 4.0 facilities layout. For example, the proposed design process might suggest a robot for flexible material handling equipment but does not mention what methods and procedures must be followed to make it flexible.
- Industry 4.0 concept is limited to the manufacturing sector apart from any Industry 4.0 concepts related to Industrial business models and warehouses.

7.3. Recommendations

These recommendations can be either the further development of this project – Influence of Industry 4.0 on Manufacturing Facility Design Process or help another project. Due to time constraints, some of the aspects of the project were left out for future works. These works are recommended below:

- Detailed explanation of the logistics that are used in Industry 4.0 factory
- Production performance of the facility layouts could be used in a case study for evaluation.
- Checking the flexibility of the layouts for the change in products design or product features.
- Using Multiple case studies for indicating Industry 4.0 changes apart from the single case study.
- Simulate Industry 4.0 factory to check the throughput time of the production. To check for the increase in productivity by the new Industry 4.0 technology.
- Discuss if there is any other material handling equipment other than AGV and robots.
- Discuss the energy consumption of the new Industry 4.0 machines and material handling equipment. That adds to the cost savings from the factory.
- Discuss in detail, the shortened setup times in manufacturing after implementing new technologies like artificial intelligence in the machines and material handling equipment.
- Calculation of energy consumption between the traditional layout and Industry 4.0 layout can be calculated and checked for Facility layout efficiency.
- Detailed analysis about maintaining the Facilities could be carried out to check whether traditional layout or Industry 4.0 layout is feasible for predictive maintenance. This means the facilities which provide prior indications for predictive maintenance. Because predictive maintenance helps to avoid disruptions in the production process.
- Discuss the efficiency of the facility layouts, whether it is with more labours or more robots. Considering the working time and quality of work.

The above recommendations can be considered to improvise or develop this present project. So that it might give a better picture of the influence of Industry 4.0 in facilities design. It might also help in the process of implementation of Industry 4.0.

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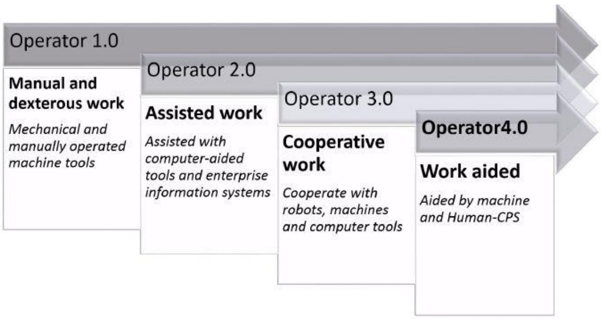
Appendix - I

1. Operator 4.0

For all the technological advancements and new concepts of Industry 4.0, there is no human interference is the first misconception that has been come across. There is a need for a labour force with certain criteria to be satisfied and “Operator 4.0” explains the qualities of the labour force that must be prepared for the mass customization of the Industries. The Operator 4.0 typology represents how the technologies of the fourth industrial revolution will assist the work of Operators. During the first generation, humans were conducting manual work and in the second generation it turned out to be using Computer Numerical Control (CNC) machine tools. In the third generation, automation was started with human-robot interaction.[4]



Some of the types of Operators are mentioned in below table and their work is mentioned in the description column.

Type of Operator 4.0	Description
Analytical Operator	Operator working on the application of big data analytics in real-time smart manufacturing and discovering useful information to make relevant events.
Augmented operator	Augmented Reality enriched factory helps to transfer information from digital to the physical world better.
Collaborative Operator	Collaborative Robots (CoBots) are designed to the comfort of Operators to perform repetitive and non-ergonomic tasks.
Healthy Operator	Wearable trackers measure heart rate, activities, stress, and other health-related measures to keep the operator healthy.
Smarter Operator	Solutions based on Intelligent Personal Assistant (IPA) that make use of Artificial Intelligence.
Social Operator	Enterprise Social Networking Services (E-SNS) connects smart operators on the shop floor with smart factory resources by social collaborative methods.
Super-Strength Operator	Powered mechanics like powered exoskeletons and flexible biomechanical systems

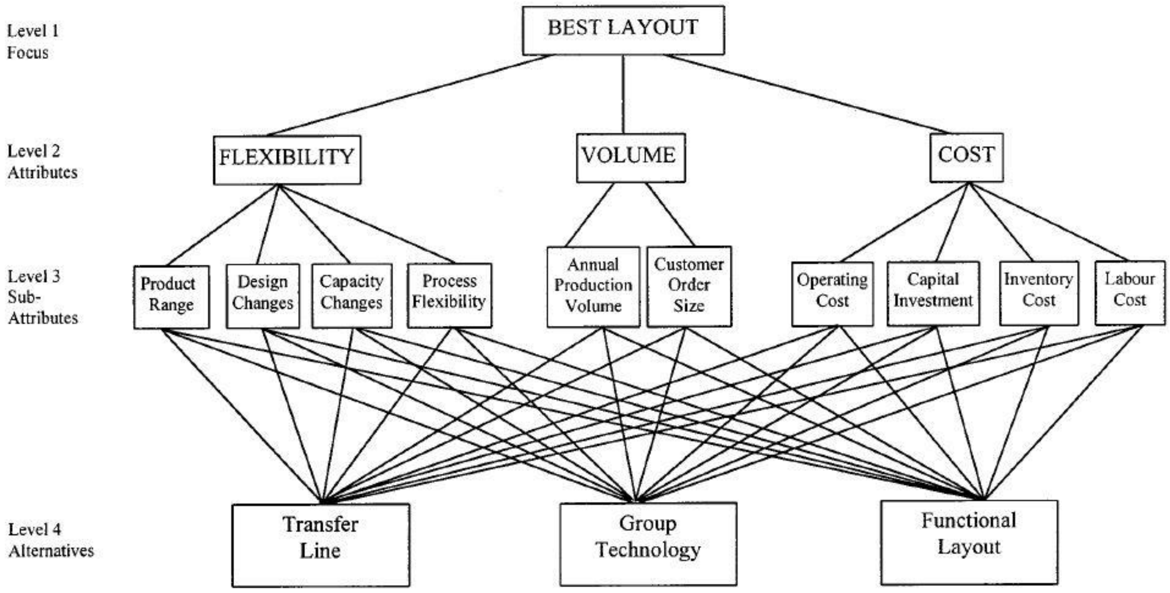
	help human operators to work comfortably.
Virtual Operator	VR is a highly developed computer-simulated technology that replicates a real manufacturing environment and allows the operator to explore the environment without putting the operator or environment at risk.

Certain design principles must be followed by the Industry 4.0 solutions for the development of Operator 4.0-based automation systems. Below, the table implementation process of these design principles is mentioned.

Design Principles	Description	Application
System Integration	Combining all subsystems into one system. Horizontal integration connects functions and data across the supply chain; Vertical integration connects manufacturing systems and technologies.	Analytical Operator
Modularity	It is important for the ability of the manufacturing system to adapt to continuous changes	Augmented Operator
Interoperability	Allowing smart factories, smart products, and human resources to connect, operate and communicate with each other.	Collaborative Operator
Product Personalisation	The system has to be adapted for frequent product changes.	
Decentralization	It is the process of making the system work independently with autonomous parts.	Smarter Operator
Corporate Social Responsibility	It's about the regulations of labour and the environment	Social Operator
Virtualization	It represents physical world data in the cyber-physical model	Virtual Operator

2. Hierarchies for Best Plant Layout Selection

There are four levels of hierarchies to select the best plant layout. The first level consists of the main objective of the focus of the layout that is suitable for the production. The second level consists of three main attributes, which are a major consideration for all manufacturers affecting directly the selected layout and they are flexibility, volume, and cost. The third level consists of sub-attributes for these three attributes. The fourth and last level consists of 3 alternative layouts: Transfer lines (product layout), group technology, and functional layout (process layout).



In the following sections, three main attributes and their sub-attributes are discussed with the comparison of three different types of layouts concerning attributes and sub-attributes.[47]

Flexibility – It is the attribute that measures the flexibility of the layout in the manufacturing plant. Flexibility also considers the capability of the layout as to how easily it can accommodate the changes adopted by the manufacturing plant. Four sub-attributes are considered to check the flexibility of three alternative layouts. They are:

- Wide range of products: This shows the capability of the manufacturing plant to produce a wide range of products with a variety of processing requirements.
- Design changes: This shows the capability of the plant to accommodate design changes for the manufacturing products.
- Changes in capacity: This is the flexibility in the production volume i.e. in demand for the manufacturing products and measures the ability of the plant for different production volumes.
- Process Flexibility: This is to change the products with low set-up time. This aspect helps in just-in-time manufacturing systems, where the batch size is to be small and the set-up time of machines should be short.

Functional layout and group technology layout are the best for satisfying the first three aspects of flexibility owing to the generality of machines, the ease of changing processing routes in such systems and the ease of duplicating resources, and in the assignment or removal of resources for the production of specific products. On the other hand, it is nearly impossible for such aspects of flexibility to be satisfied in transfer lines. Transfer lines are designed and built to manufacture only a very few and a limited number of standard parts, with specific production volumes. For the fourth aspect of flexibility, group technology layouts are the best in gaining high process flexibility. A short set-up time is one of the main requirements and characteristics of GT layouts. Transfer lines are in the other extreme position, where changing the set-up (if it is possible) is very difficult and long. Changing the setup in functional layouts is much easier than in transfer lines but more difficult than ingroup technology or cellular layouts.

Production volume: This is the second attribute in the hierarchy, and the plant can manufacture a high number of parts to meet the high demand of the products in the market. This attribute is gauged according to the following two sub-attributes.

- High annual production volume: This indicates the ability of the plant to manufacture the products annually.
- Large customer order size (batch size): It represents the number of products that can be manufactured by the plant without the interruption of the machines.

For this attribute, transfer lines are preferable to other layouts because of their design ability to manufacture a high volume of products, with few standards and short cycle times. In contrast, functional and group layouts are suitable for medium and small production volumes where throughput times are longer.

Cost reduction: This attribute indicates the ability of the alternative plant layouts that reduce the cost of manufacturing the products. The following are the sub-attributes that are considered:

- Reduction in operating cost: It is the cost to run the plant efficiency by reducing maintenance and repair costs, material handling costs, overhead costs, and cost of materials used by machines indirectly.
- Reduction in Capital investment: It is the total cost of the manufacturing plant, which includes the cost of buildings, machines, and engineering costs.
- Reduction in Inventory cost: This cost includes raw materials, work-in-progress, and finished goods inventories.
- Reduction in Labour cost: This is the cost of labours who directly work with the machine and indirect labours who do the work of maintenance, cleaning, and others.

Transfer lines have the lower manufacturing cost and functional layouts have the highest. But in contrast transfer lines have a higher investment cost because of the automated machines used to manufacture certain specific parts. Due to two major factors, the functional layout requires less capital than the group technology layout. First is the need to establish part families and machine groups. Second, possibly the need to replicate some machines in more than one cell.

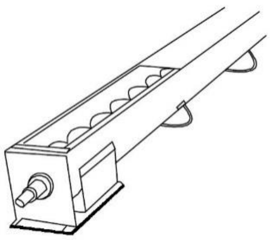
3. Types of Material Handling Equipment's

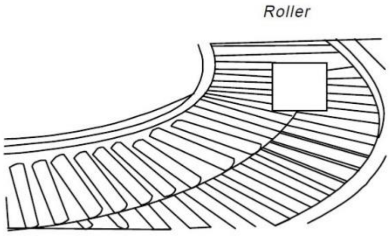
There are two categories of traditional material handling equipment, where the types of equipment are classified into. The categories are

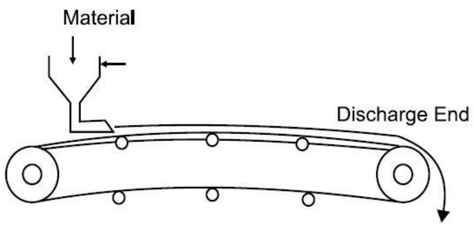
- **Variable path equipment**: They are the equipment that does not have any restriction in movements inside the plant layout, although the size factor is considered. Trucks, forklifts mobile cranes, and industrial tractors belong to this category.
- **Fixed path equipment**: These are equipment in which their path or direction of the movement is fixed. Conveyors, monorail devices, chutes, and pulley drive equipment belong to this category. A slight variation in this category is provided by an overhead crane, which can move materials in any direction even though it is restricted.

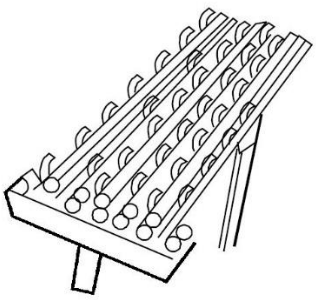
Types of Material Handling Equipment's are as follows:

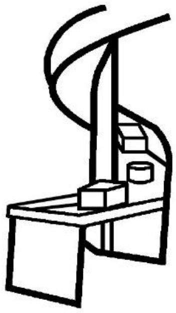
- **Conveyors**: They are the equipment used to move materials between two fixed workstations, either continuously or periodically. It is mainly used for mass production where processes are continuous and fixed. There are various types of conveyors, with rollers, wheels, or belts. The initial investment is high and is less flexible, therefore the right decisions should be made before buying or installing the conveyor.



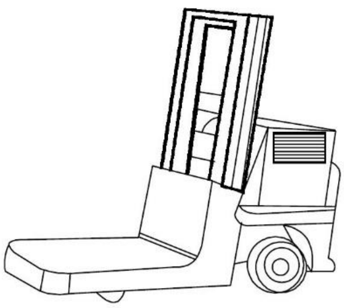


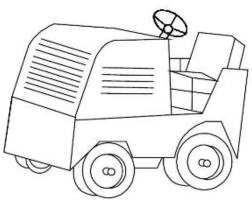


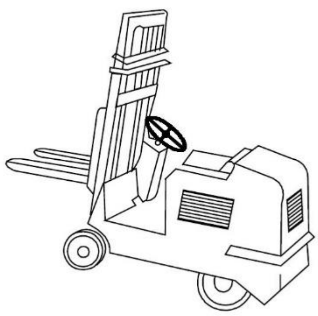




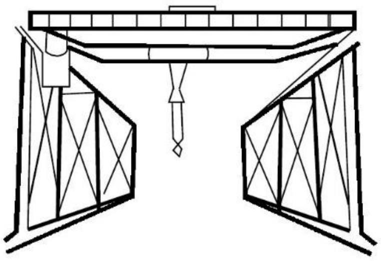
- **Industrial Trucks**: These trucks are not fixed to any path in the layout and they can move anywhere and in any direction. Therefore, they are more suitable for intermittent production by handling any size and shape of materials. They are powered by petrol, electric, hand-powered and so on.

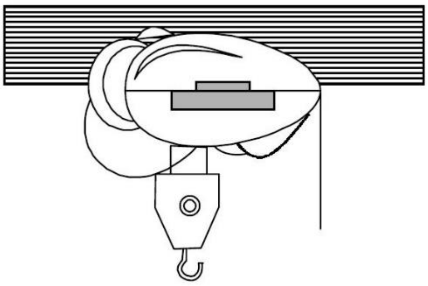


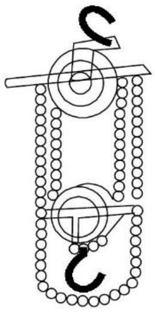




➢ **Cranes and Hoists**: Their major advantage is that they can move heavy material through overhead space. They can be used for both intermittent and continuous production, but they serve only a limited area.







➢ **Containers**: They are equipment's like cartons, barrels, wagons, and so on, they hold the materials inside, but they should operate manually.

➢ **Robots**: There are many types of robots varying in size and function, and manoeuvrability. Many robots are used for handling and material transporting but some are also used to perform many operations.

KR IONTEC
_the robot for every task in the medium-payload range

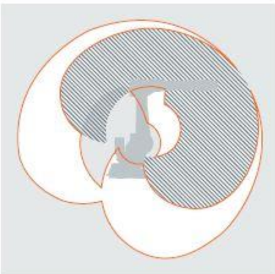
Utmost flexibility during the life cycle
- Extremely easy planning and selection
- Best-in-class work envelope
- Mounting possible in any installation position
- On-site conversion of payload capacity possible
- Motion Modes allow adaptation to any production process
- Lowest maintenance requirements in its class
- Fully digitalized – for all future applications

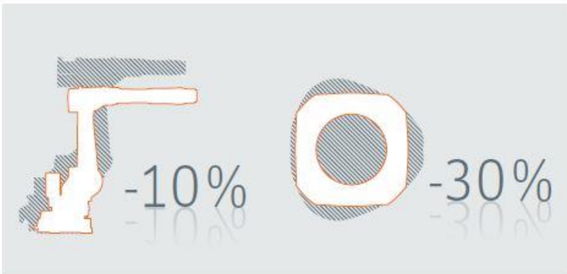
Sustainably cost-efficient

The KR IONTEC impresses with top-class values for total cost of ownership (TCO) and enables significant cost reductions:

- Lower investment costs
- Lower operating costs
- Lower maintenance costs

For nearly all applications
- Loading and unloading
- Handling
- Assembly
- Machining
- Laser welding and arc welding
- Soldering
- Adhesive bonding
- Sealing





Largest work envelope in its class
- Working range below the robot increased to 1,232 mm
- Reach increased to 2,100 mm
- 10% larger working range about axis 2

Performance redefined
- Easier integration into compact cells
- More economical cell planning
- Lower space requirements

- 30% smaller footprint
- 10% more streamlined disruptive contour
- 20% less weight
- Top dynamic performance
- A1 hollow shaft with Ø 119 mm for optimized energy supply

- AGV –Autonomous Guided Vehicle is the material handling equipment that moves the products autonomously with artificial intelligence. With the safety technology, they can take any transportation task by sharing human operator passageways and conventional industrial trucks. They can easily integrate into existing production environments with camera-based 3D object detection. It is ideally equipped for the tough everyday environment of industrial production, that can detect obstacles that are located between 30 mm distance and 4 m above the ground.

Appendix - Ⅱ

1. **Calculation for AGV travel time from one cell to another**

AGV travel time is calculated by using the speed, time, and distance formula. Distance and speed are known, and time is calculated from the below formula:

$$Travel\ time = \frac{Distance}{Speed}$$

- AGV travel time from temporary storage to Turning machine cell and sawing machine cell = 10/60 = 0.16 mins
- AGV travel time from Turning machine cell to sawing machine cell = 5/60= 0.08mins
- AGV travel time from Turning machine to machine center cell and milling machine cell = 5/60 = 0.08mins
- AGV travel time from machining center to milling machine = 3/60 = 0.05mins
- AGV travel time from machining center and milling machine to Grinding machine and drilling machine = 5/60 = 0.08mins
- AGV travel time from Grinding machine to Drilling machine = 5/60 = 0.08 mins.

2. **Calculation for number of machines required to meet the product demand**

Depending upon the total time to manufacture the products per shift and machine availability time per shift. The number of machines is calculated below:

Number of minutes per shift = 480 mins

Availability of machine per shift = (machine availability (%)/100) * 480mins

Machines	Availability	Availability time in mins
Sawing machine	90%	432
Turning machine	75%	360
Milling machine	75%	360
Machining center	75%	360
Drilling machine	80%	384
Grinding machine	75%	360

From the given inputs number of products per day is known and the processing time of each product is also known. Therefore, multiplying processing time and products per day would give the total time used by the machine to process that product.

Number of Sawing machines = ((10*20) +(10*20) +(15*20) +(20*40))/432 = 4 machines approx.

Number of Turning machines = ((50*20) +(40*20) +(30*20) +(30*40)/360 = 10 machines approx.

Number of Milling machines = ((40*20) +(50*20) +(40*20) +(40*40))/360 = 12 machines approx.

Number of Machine center machines = ((20*30) +(20*30) +(20*50) +(40*30))/360 = 10 machines approx.

Number of Drilling machines = ((20*20) +(30*20) +(25*20) +(20*40))/384 = 6 machines approx.

Number of Grinding machines = ((30*20) +(40*20) +(30*20) +(30*40))/360 = 9 machines approx.