Chapter

# The Impact of Industry 4.0 on Ergonomics

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## Abstract

The fourth industrial revolution (Industry 4.0) has accelerated technology advancement across the manufacturing sector. The technologies of Industry 4.0 make it possible for manufacturing processes to be more efficient while also bringing about changes in human work that may pose new risks to employee wellbeing and test their current abilities. Technologies, such as virtual reality and augmented reality have a significant impact to revise the position and responsibilities of human in the manufacturing environment. Thus, ergonomic perspectives have evolved from focusing solely on adjusting the human to the other components of the work system physically and psychosocially into upgrading cognitive skills to process more information. There are very few ergonomics-related studies in the literature with reference to Industry 4.0 emerging technologies. Especially, research on emphasizing the importance of the concurrent development of technical and ergonomic skills in the industrial setting is a necessity in this modern era. This research aims to explain the modified manufacturing environment, define the role of the human in this new production settings and describe the cognitive modifications required to fit into the Industry 4.0 habitat.

**Keywords:** Ergonomics,, industry 4.0,, I4.0 technologies,, cognitive skills,, operator 4.0,

## 1. Introduction

Human, even though all the advances in the technology, still keeps the key position in any production system. Ergonomics is a multidisciplinary science where the objective is to design the work environment in order to optimize the efficiency of the human operator. Thus, within the production system, ergonomics is the most important science to be considered for the improvement of efficiency, quality, and effectiveness.

The production environment has gone through significant processes where the manufacturing technologies were revolutionized. The first industrial revolution (Industry 1.0) was in the late eighteenth century where the steam engine was used for mechanical production. Assembly lines were incorporated into manufacturing processes at the turn of the twentieth century (Industry 2.0), and soon after, by the mid-1960s computer-controlled production had a significant impact (Industry 3.0) on the manufacturing sector [1].

Customer is the driving force of the modern industry. With the addition of the prosumer to the design of the product, the manufacturing of products is becoming more sophisticated. Thus, technological advancements are a necessity to be applied in order to meet the customer demand in manufacturing processes. However, this is putting new demands on companies' management practices and processes, as well as personnel competencies and skills. So, a revolution in the modern manufacturing methods is inevitable to satisfy the sophisticated customer and to meet the human competencies and skills.

The fourth industrial revolution (Industry 4.0) is linked to a number of technology trends, including digitalization, artificial intelligence, the Internet of Things, additive manufacturing, cyber-physical systems, cloud computing, and a sharp rise in robots and automation in manufacturing [2] (**Figure 1**).

The technologies of Industry 4.0 make it possible for manufacturing processes to be more efficient while also bringing about changes in human work that may pose new risks to employee wellbeing and test their current abilities.

The scientific field of ergonomics applies theory and design methods to improve both human well-being and system performance by understanding how humans interact with other system components. In particular, when it comes to people's needs, capabilities, and limitations, ergonomics maintains a harmonious balance in the interaction of people and things. Yet in the modern industry, the work arrangement and organization are done physically based on the physiological capabilities and limitations of the human operator.

Because the fourth industrial revolution necessitates significant technological advancement and development, the human needs to improve their cognitive skills to meet Industry 4.0 requirements, such as processing large amounts of information and taking appropriate actions.

This chapter aims to explain the modified manufacturing environment, define the role of the human in this new production settings, and describe the cognitive modifications required to fit into the Industry 4.0 habitat.

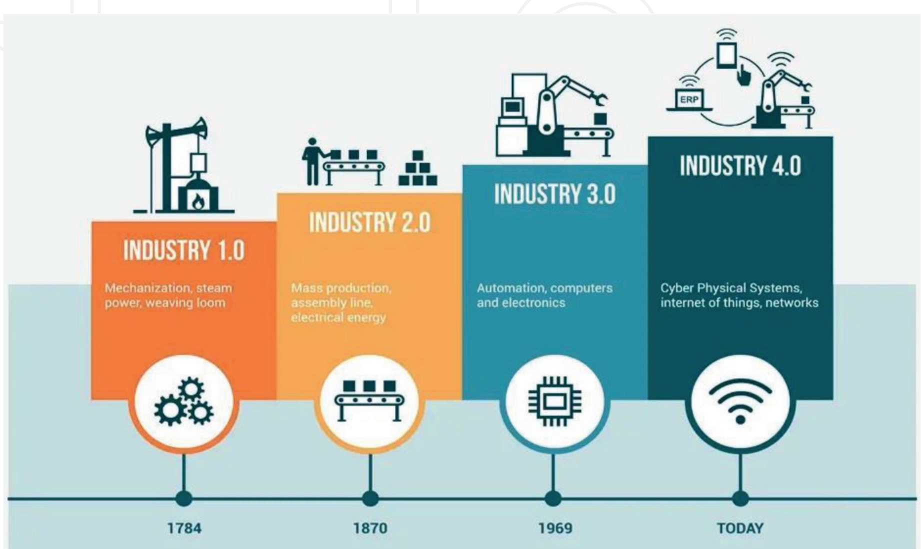


**Figure 1.**
*Industrial revolutions (https://www.btelligent.com/en/portfolio/industry-40/).*

## 2. Industry 4.0

After the industrial revolutions in the manufacturing industry, countries and companies had to keep up with these global changes and developed some strategies in order to maintain their competitive advantage in the increasing competitive conditions. Industry 4.0, which came to the fore in Germany, is the name of one of these strategies [3].

In this respect, I4.0 is the environment in which cyber and physical environments are ultimately interconnected, including self-adaptive and real-time optimized processes to enable customized production under economic constraints. The aim is to create a communication network between all parts of the production system, to create flexible and dynamic self-managed production systems.

Therefore, the I4.0 constitutes certain technologies; autonomous robots, simulation, horizontal and vertical system integration, industrial Internet of Things (IoT), cyber security, additive manufacturing, augmented reality, big data analytics, and cloud computing [4] (**Figure 2**).

### 2.1 Autonomous Robots

Autonomous Robots can be defined as robotic systems with a certain intelligence rather than robots with automatic work. Robots are widely used in production in order to minimize human-induced errors because of their objective analysis capacity. Autonomous robots have the ability to learn about their environment and operate for a long time without human intervention. They can move themselves without human assistance throughout the operation and avoid situations harmful to themselves, people, or property [5].

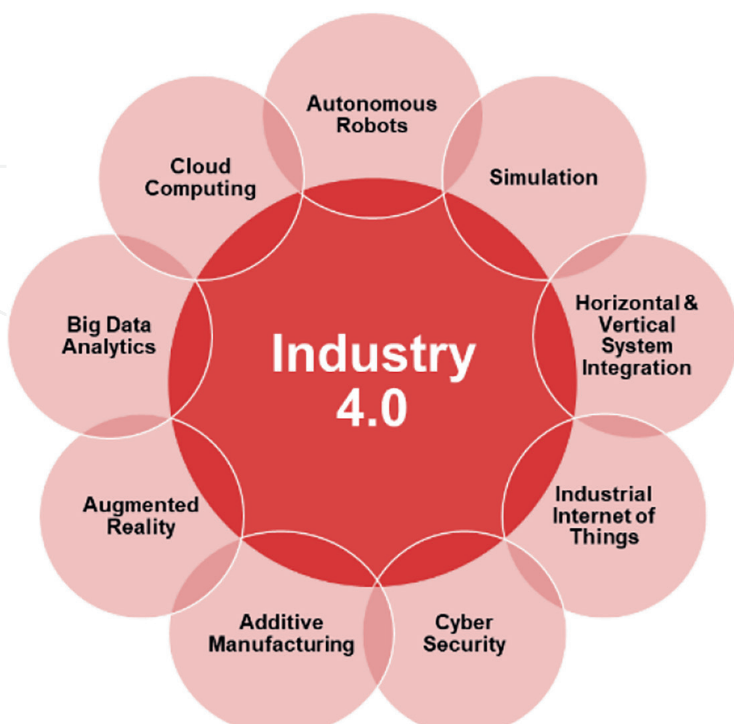


**Figure 2.**
*Technologies of Industry 4.0.*

Autonomous robotics technology enables robots to make their own decisions and act accordingly, just like humans. It is studied as a sub-branch of artificial intelligence technology. An autonomous robot is a robot that senses its environment, can make decisions based on what it perceives, or is programmed to recognize and start/end a movement in that environment [6].

In smart factories, robots can manage production by recognizing each other, sharing work, communicating, analyzing, and adapting to changes faster. They offer cost reductions and productivity gains in the supply chain, from the service industry to agriculture, from the retail industry to warehouse systems [7].

### 2.2 Simulation

Simulation is a modeling technique that creates an infrastructure for monitoring the properties of the real system by transferring the data of a physical system existing in the real world to a virtual environment. It provides advantages in terms of time, cost, and risk management as it can make the development of production processes traceable [8].

The purpose of the simulation is to observe the possibilities in the virtual world beforehand and to plan the necessary preparations. A successful simulation is possible by modeling all the data of the physical system in digital environment [9].

A *digital twin* is a virtual model of a product, process or service. In other words, it means creating a virtual twin, the exact equivalent of something physical. In short, we can say that it is a virtual copy of the physical object. This virtual replica can be a car, a machine, a train, or even a jet engine [10].

Digital twins are virtual replicas that data analysts and IT professionals can simulate before manufacturing real devices. Digital twins are not only used in manufacturing, but also influence the development of technologies such as the internet of things (IOT), artificial intelligence (AI) and data analytics. Digital twins assist computing professionals and data analysts for highest efficiency and optimal allocation of resources [11].

A digital twin uses real data about a real-life object or system as input. It then generates predictions or simulations of how the real object or system will react based on these inputs. In its simplest form, it is a computer program that can simulate. A digital twin begins its life by being programmed, often by data science or applied mathematics experts. These experts first investigate the structure of the real object or system being simulated. It then uses this data to develop a mathematical model, the digital twin, which simulates the real-world original [12].

### 2.3 Horizontal and vertical system integration

Before mentioning about horizontal and vertical integration, it is necessary to find answers to questions, such as why companies want to grow and what are the factors that push companies to grow. The biggest factor in the growth of companies is the economy. Firms always want to protect their assets, reduce risks, increase growth rate, and maximize their market values. In line with these purposes, companies have merged and the concept of horizontal and vertical integration emerged [13].

*Horizontal integration* is a merger between different companies with the same customer type. The main purpose of this merger is to increase the market share of these companies that appeal to the same customer type. It is generally preferred by young entrepreneurs. The reason for this is that customer profiles are not yet formed in the market. This type of integration is because the competition is too high and the rate of product obsolescence is high [14].

When companies want to reduce the uncertainty in the environment and give importance to R&D studies, they prefer horizontal integration. The general characteristic of companies that combine with horizontal integration is that they generally tend to risky investments. The reason for this is that since they are not alone, they can increase the probability of their holding in the market in risky investments [15].

In horizontal mergers, the entire capacity of tools and machines can be put into use. In this type of merger, since more than one company for the same sector is merged, it ensures that the costs in marketing and sales are reduced. Delivery of products or services from the nearest and most convenient centers can reduce transportation costs. A wide distribution network is also a factor that can be considered positive for consumers [15].

On the other hand, *vertical integration* is the merger of companies with customers in the same sector but in different sub-sectors. There are three types: backward vertical integration, forward vertical integration, and balanced vertical integration [16].

Backward integration is the merging of the input sources. Forward integration is the expansion that brings the business one step closer to the users of the goods it produces. It mostly aims to control the sales and distribution channels. In balanced integration, firms merge both for their input sources and with the marketing part. These types of mergers are less compared to others [16].

Horizontal and vertical integration concepts are the concepts brought by the developing industry sector. The continuous flow provided by the interconnected structures underlying Industry 4.0 is a critical point in terms of production. In order to ensure this flow, it is necessary to achieve horizontal and vertical integration at every point, not just at certain points. With the Industry 4.0 revolution, in which horizontal and vertical integration takes place, a change in production processes can be quickly responded to or a solution can be found much faster when a problem is encountered [15].

The other advantages that horizontal and vertical integration can bring to industry 4.0 are: facilitating customer-specific and personalized production, increasing resource efficiency, and achieving optimization in the global supply chain [13]. On the other hand, businesses gain a more flexible structure. Necessary changes can be achieved even with simple interface updates.

### 2.4 Industrial Internet of Things (IIoT)

Internet of Things (IoT) is a communication network in which physical objects are connected with each other or with larger systems. It is embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet [17].

IoT technologies are used in the industry to help business progress and speed up. Machine network and control systems are of great importance in terms of increasing industrial efficiency and using time correctly.

The mission of IoT devices to shortening the process by communicating with each other and exchanging information among themselves. In the case of the human factor, this process takes longer time as the number of workers increases and the operation is reported and passed to the next stage.

The growth of IoT benefits the customers, manufacturers, and organizations. It has a significant impact in a number of areas, including transportation, logistics, business operations, industrial assembly, robotization, and process management [17].

Manufacturing and production are combined with IoT as a consequence of I4.0. With the physical world of sensors, the Industrial Internet of Things (IIoT) is interfacing machines with each other to achieve the M2M connection, progressively expanding the pace of enterprises and exponentially improving the industry in general. It is an internet-connected network of sensors, devices, and machinery. It incorporates the association of industrial networks and service systems to various information storing frameworks through the arrangement of software services and its autonomous control in the cloud. The increased use of sensors, advanced information examination, and decision making is having a profound impact on the worldwide world [18].

There are certain smart wearable arrangements have been designed for a variety of reasons and can be worn on a variety of different human body parts, for example, the head, eyes, wrist, belly, hands, fingers, legs, or installed into various garment components [19] in order to teach users how to improve their physical, sensory, and cerebral capacities. As a result, a wide range of "things" have been integrated with sensors, actuators, software, and network connectivity to enhance their capabilities. This is the position of intelligent machines, which are now capable of acting autonomously (intelligence), avoiding and correcting faults and blunders (security), learning and anticipating future events (management), and interacting with other machines and frameworks (connectivity) [20].

### 2.5 Cyber security

It is the practice of protecting computers, servers, mobile devices, electronic systems, networks, and data from malicious attacks. It is also known as information technology security or electronic information security [21].

It is a great need to protect critical industrial systems and production lines against cyber threats that will increase significantly with the connection and communication protocols that come with Industry 4.0. While providing this security, machines and users, access management, advanced identity security, and communication systems are grounded [22].

I4.0, digitization, IoT, new services, data, and connections are also opening new avenues for hackers to data theft and industrial espionage. With the fourth Industrial Revolution, large companies believe that the threat of cyber risk will increase and they are looking for solutions for this [23].

One of the most common security threats is problems with connections between old devices and new ones. In the I4.0 environment, it is important that the data are only available to authorized persons and that the data sources and integrity can be verified [24].

For example, in a production facility, only authorized persons should have the access to critical data. Every precaution must be taken to ensure that the information entered into the devices in the facility comes from reliable sources and that its accuracy is not at risk.

### 2.6 Additive manufacturing

Additive manufacturing is the process of creating an object by building it one layer at a time. The process is mostly referred to as 3D printing.

In conventional manufacturing, such as turning and milling operations and welded manufacturing, the production techniques are limited when the production of complex parts is required. Additive manufacturing is a new technology, which has many advantages against the conventional methods with the capability of use of many different materials and allows the production of complex parts needed by material addition and integration processes. In this system, powdered raw metal is heated and melted to desired points by energy sources, such as laser or electron beam and sprayed [25].

In additive manufacturing, parts can be produced in a short time, according to the requirements, and no cost or time is required for design changes. Additive manufacturing removes design boundaries, creating complex geometries and difficult-to-make parts. The model, which is prepared virtually with a CAD program, is sliced into layers with special software, and then transformed into a physical model layer by layer, starting from the base, by means of a 3D printer [26].

### 2.7 Augmented reality

Augmented reality (AR) is a live direct or indirect view of a new perception environment created by combining computer-generated elements, such as audio, video, graphics or GPS data, augmented and animated by sensory input, with the physical, real-world environment [15].

With augmented reality, the inputs that will appeal to the human senses and activate their feelings are modified and enriched by the computer, and the new reality that emerges is presented to the user's perception. Enrichment takes place in real time and interacts with surrounding elements [27].

With Augmented Reality, the user can interact with the information and other elements that make up the reality environment. Artificial information and elements about the environment can be compatible with the real world [27].

Augmented reality and virtual reality are not the same. In virtual reality, image, hologram, sound, location, and similar sensory elements are created as an imitation of the real world. It is a technology where users will feel themselves in a different place from the environment they are in, and in addition, they will experience a different environment in 3D. Virtual reality environments usually consist of visual experiences acquired through a computer screen [28].

Augmented reality, on the other hand, is the result of the interaction of the created sensory elements with the physical world by enriching them in real time. It is a type of experience that is created by combining the physical elements we perceive around us with computer-based data such as graphics, video, sound, GPS and enriches the existing reality. In other words, it is a reality where the real and the virtual are not completely separated from each other, on the contrary, they are even more intertwined [29].

### 2.8 Big data analytics

Although the concept of big data is seen as a new concept for many people, its origins actually date back to the 1970s, when relational databases were developed. They are the data obtained over time, structured or unstructured, that is, not yet made usable by processing with traditional methods or tools. In short, it means data that is too large for the computer to process. In the early 2000s, it gained popularity with the beginning of researching and analyzing the data produced by users through social media [30].

Since the introduction of the internet, humanity generates an incredible amount of data. The data are stored on our mobile devices, software recordings, cameras, microphones, social media, all our movements on the internet currently to be

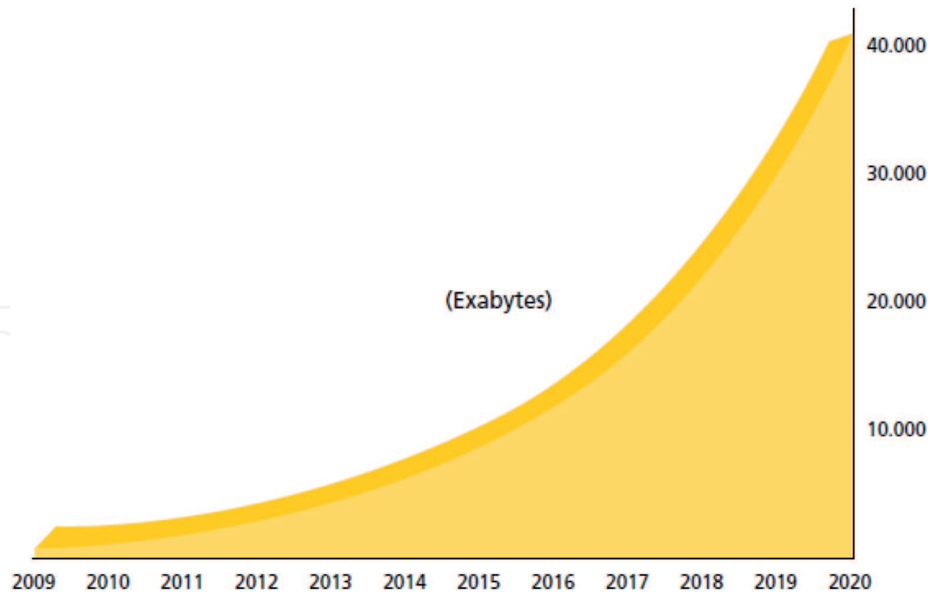


**Figure 3.**
*Exponential data growth between 2010 and 2020. Source: IDC'S Digital Universe Study, sponsored by EMC, December 2012 [31].*

processed in the information flow. Since the beginning of the internet, 90% of all available data is generated just in the last few years [32] (**Figure 3**).

In addition to increasing customer satisfaction, which is known to be the most common use, it is now possible to predict new disasters with advertising trends, early diagnosis of diseases, strategy development of law enforcement and even advanced analytical interpretation of natural disasters. The possibilities offered by big data are virtually limitless. Huge amounts of data have become properties to buy and sell [32].

When the term big data was relatively new, it took a very long time to collect and store big information for analysis to conclude. The concept gained momentum in the 2000s, when industry analyst Doug Laney defined "big data" as 3Vs: volume, velocity, and variety [33].

There are several analysis methods for big analysis. *A/B Test* is a measurement method used to identify the best performing model among two or more versions of online assets. A/B tests, which have gained importance with the increase in digital competition, are mostly prepared for websites, online applications, and digital marketing campaigns. It is the analysis made to determine the version that will reach the targeted conversion rate among different variants.

*Data Fusion and Data Integration* are essentially a knowledge integration problem. This method combines the data from multiple sensors and provides a better analysis and better decisions for the relevant situation than using a single sensor.

*Data mining* is a technique to discover correlations, patterns or trends by analyzing large amounts of data stored in repositories, such as databases and storage devices. The general purpose of data mining is to extract the most relevant information from a given dataset and have that data structured for later use.

*Machine Learning* is an application of artificial intelligence in which computer programs can learn patterns through algorithms and training data. Machine learning applications, also called machine learning, learn through experience, just as humans do, without direct programming. A machine learning software based on the training data provided to the algorithm. It may detect data, make predictions, and learn how to improve, not automatically completing tasks.

*Natural language processing (NLP)* is a form of artificial intelligence that helps machines "read" text by simulating the human ability to understand language. NLP techniques include a variety of methods, including linguistics, semantics, statistics, and machine learning, to extract entities, relationships, and understand context; this provides a comprehensive understanding of what is said or written. Instead of understanding individual words or their combinations, NLP helps computers understand sentences as they are spoken or written by a human.

The data we work with in *statistical analysis* applications are defined according to the number of observations and variables. If the number of observations in the data is equal to or less than the number of variables, then high-dimensional data will be used. Big data and big data are not the same thing. High dimensional data is precisely defined as "high dimensional data" while big data is defined as "big data". High-dimensional data requires special approaches, especially when applying the following techniques: statistical hypothesis testing, regression analyzes, factor analysis, and clustering techniques [34].

### 2.9 Cloud computing

Hosting capacity causes big problems as users want to store more and more personal data and data on existing devices in today's technology. However, the features and capacities of the devices are increasing day by day. With the increase in the technology and capacity of computers, notebooks, netbooks, and portable smart devices, prices also increase [25].

Cloud Technology, which emerged as a solution to all these problems, is defined as software applications, data storage service, and processing capacity that are accessed over the internet. It provides access to all kinds of information and personal data from anywhere, even with the lowest capacity device [14].

Cloud technology is not only used by companies, universities, but also it is established and shared by large organizations. Using this technology reduces the burden of personal computers and a variety of applications are provided by the cloud server. Usually, users do not want to download and install applications on their computer. All processing and storage is provided by the cloud system [35].

All the applications, programs, and data that are hosted on the internet are stored on a virtual machine, that is, in the cloud, with the most commonly used name, and this information, programs, and data can be easily accessed at any location with the device connected to the internet.

There are a number of types of cloud computing. In *Public cloud*, a cloud technology established with servers on the internet. For small and medium-sized companies, e-mails can be shown as an example of this model, which is paid as you use and pay as you go. *Private cloud* is a cloud technology preferred by large companies whose information is important. All information is in the hands of the founder and access security and confidentiality is high. *Hybrid cloud* is a cloud technology that emerges from the combination of public and private cloud. There are differences in the combination rates according to the volume of the companies. *Community cloud* is a cloud technology that hosts services shared with several companies. Community members have access to applications and data [13].

There are certain advantages of cloud computing. They provide fast ease of use with APIs (Application Programming Interface) and a number of possibilities such as more storage space, fast data transfer and cost savings on this backup. Infrastructure confusion caused by issues, such as archiving of constantly increasing data, authorization, and tracking of users is eliminated. Since cloud technology software works through web browsers, it protects from platform dependency by using computers, tablets, smartphones, and smart TVs. The servers of the companies that provide cloud software services, where the data are kept, are more secure than the main computer because they take security measures 24/7 in terms of software and hardware [14].

However, there are certain disadvantages are available, which should not be neglected as well. Data storage using cloud technology service, risking the user's data cannot provide information security and user privacy. Security vulnerabilities abound. Due to the economic situation of the countries, it will increase the digital divide, which creates international, political, and economic problems. The most important problem is that an internet connection is required in order to access the stored data. In other words, it is not possible to access our information in cases where there is no internet. If you have a low speed internet connected to the internet, your data exchange speed will be slower as well. One of the last disadvantages is that the hardware and software maintenance and repair costs will decrease with the development of their services, and accordingly the narrowing of the work areas of information technology (IT) specialists who do this job [14].

### 2.10 Strategies for Industry 4.0

Towards the future, the I4.0 technologies provide a vast area for progress. These include innovative approaches, abrasive designs, functional software, hardware and smart robots, artificial intelligence, complex organizations and automation systems, functional materials, intelligent/autonomous manufacturing/fabrication, common cultural values, compatible ecosystem, capital and its regular use, and lean manufacturing (6 sigma and automatic standardization/validation).

Thus, the strategies which should be applied towards the I4.0 are:

i. Blue ocean strategy (creating a new company with a new business model, following the green field strategy using disruptive innovation).

ii. Solution of conventional problems with new technologies (nanotechnology, additive manufacturing, integrated smart factories).

iii. Factory islands (all workstations are connected to the internet and can self-check and repair with material flow sensors).

iv. Product lifecycle and open islands of innovation (reorganizes the product development department).

v. Logistics islands (end-to-end reorganization of supply chain management, smart service delivery).

vi. Consulting industrial companies, gaining experience with new technologies, and forms of organization can pass this on to other companies.

vii. Product-related services: the internet connection of complex products provides important information about the performance of these products in different operating conditions worldwide.

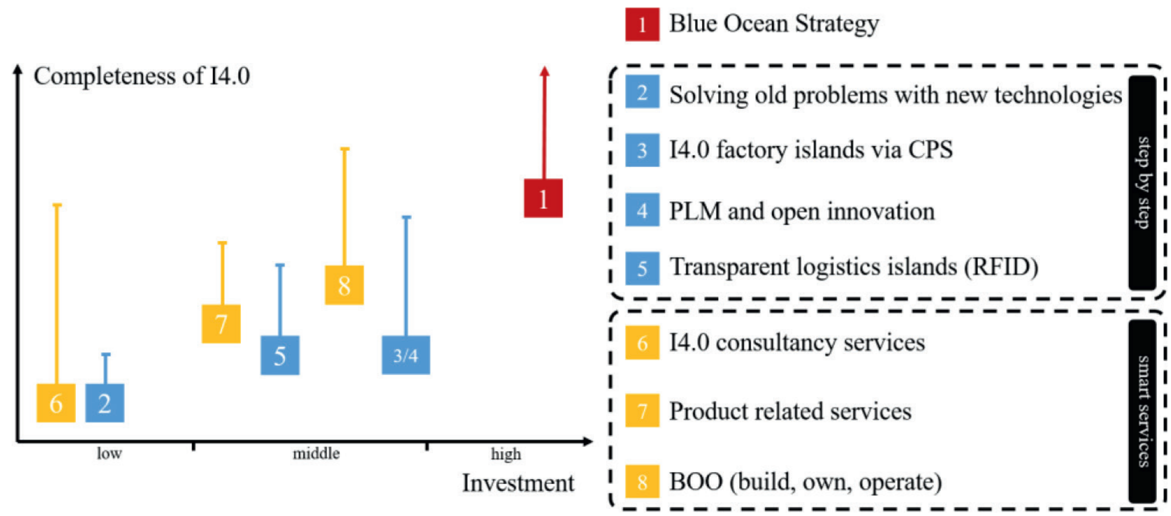


**Figure 4.**
*Strategies towards Industry 4.0 (https://www.endustri40.com/endustri-4-0-uygulama-stratejileri/).*

viii. Build, Own, Operate (BOO): describes the transition of an industrial company to full service provide [36] (**Figure 4**).

The fourth Industrial Revolution will undoubtedly lead to the opening of new sectors and the disappearance of lagging sectors. This is the case not only for sectors, but also for people, companies and countries, anything that cannot keep up with the new industry will be adversely affected by this situation.

Producing smart products in smart factories and making these products easier for our lives and doing this with less energy is a big plus. With the production of smart products, these products can be adapted to different areas according to needs and developments can be achieved.

It is another positive aspect that is imagined today that everyone can produce products with a simple structure with three-dimensional printers, and that the producer and the consumer are the same.

Consequently, technologies such as autonomous robots, augmented reality, simulation, Internet of Things (IoT), and big data analysis has a significant impact to revise the position and responsibilities of human in the manufacturing environment.



## 3. Ergonomics in the Industry 4.0

Ergonomics is a multidisciplinary science, which applies theory and design methods to improve both human well-being and system performance by understanding how humans interact with other system components. In particular, when it comes to people's requirements, capabilities, and limits, ergonomics maintains a harmonic balance in the interaction of people and things. Three categories of ergonomics exist: organizational, cognitive, and physical ergonomics.

Organizational ergonomics is concerned with the enhancement of sociotechnical systems, which includes organizational policies, processes, and structures. The important topics include teamwork, communication among team members, participatory design, and telework [37].

Cognitive ergonomics covers all mental processes, such as reasoning, observation, memory, and reaction; thus, it has an impact on how people interact with other elements and systems. Other important topics in cognitive ergonomics include decision-making, stress at work, mental workload, and training [37].

Physical ergonomics is related to physiological and biomechanical elements pertaining to physical activity, such as materials handling, work-related musculoskeletal disorders, postures, workshop layout, safety, and repetitive movements [38].

The application of ergonomics in the industry until the third revolution is based on physical ergonomics, which can be explained by the anatomical, anthropometric, physiological, and biomechanical aspects of human physical activity [39].

Technologies such as autonomous robots, augmented reality, simulation, Internet of Things (IoT), and big data analysis have a significant impact to revise the position and responsibilities of human in the manufacturing environment. Thus, ergonomic perspectives have evolved from focusing solely on adjusting the human to the other components of the work system physically and psychosocially into upgrading cognitive skills to process more information. Thus, cognitive ergonomics, which concentrate on mental processes as perception, memory, information processing, reasoning, and reactions, have received a lot of attention in Industry 4.0 [40].

### 3.1 Cognitive ergonomics

Modern manufacturing facilities are undoubtedly highly dynamic work environments due to the rising need for customer sophistication that are resilient and adaptable. As a result, the modernized shop floors are needed to have cognitive aid installed to help operators do tasks requiring mental cognition, such as smart human machine interfaces (HMI) or augmented reality (AR) technology. These technologies support the future operator's ability to handle the increased cognitive effort (such as decision-making, planning, situational knowledge, etc.). It is predicted that this support will improve worker dependability, particularly when both the efficiency of the production system and the operator's health are taken into account [20].

Cognitive ergonomics is a synthesis of two concepts in which cognition focuses on human brain processes, such as processing, providing information, and observing. These tasks demand for the ability of humans to transform, practice, store, and recall information, which depends on the task at hand to maintain the working environment [41].

Cognition and ergonomics work together to connect human interaction with machine components in an industrial setting. Cognitive ergonomics primarily affects mental processes, including memory, reasoning, perception, and response that come from interactions between people and various system fundamentals. In order to ensure that proper communication on human wants, abilities, tasks, products, and settings occurs, the interaction between humans and machines is integrated with human cognitive capabilities and constraints [42].

The concept of cognitive ergonomics can reduce unneeded workload and boost worker efficiency [43]. As a result of the fundamental understanding of the principles of just cognitive design, it also reduces errors and misinterpretations. In order to assure proper development of the workplace, operator safety, and behaviors while avoiding workloads and stress, the types of human capabilities and constraints that are judged feasible were evaluation with an aid of illustration [44, 45].

High information flow requires significant amount of mental process for the operations. Thus, the operator requires new professional skills for decision making. In the context of advanced manufacturing and industrial internet, specifically the so-called Engineer 4.0, the proper application of engineering knowledge allows for the critical analysis of the required employee's qualifications, allowing for the listing of four

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essential requirements: (1) interdisciplinary training; (2) adaptability; (3) sense of urgency; and (4) good interpersonal relationships. In fact, the engineer will need to go beyond simply looking for technical solutions to a problem, which calls for collaboration with experts from a variety of fields as well as for creativity and adaptability [46].

### 3.2 Human factor in Industry 4.0

Due to the significant modifications and changes being implemented in I4.0, all previous advancements in precautionary management for workplace safety and health are jeopardized. This increases the risks and have a negative impact on the occupational health and safety (OHS) principles if the development of technologies leading to Industry 4.0 continues without taking human roles into account [47].

The following are some of the methods provided for reducing multidimensional data complexity:

- Filtering, factual strategies, collapsing, arranging illustrations, Andrews bends, and parallel axes representations are some methods for reducing measurement.
- Entropy discovery and low pass channel for pattern recognition.
- Information rotation as a third measurement, drill-down, suggestion, perusal, instrument tips, device turn, and distraction-based methodologies are interaction strategies.
- Natural mapping of association and perception techniques [48].

The techniques used to simplify multidimensional data must be compatible with both the data that is currently available and the future worker's area of expertise. It is discovered that complex mental models must develop concurrently with interaction, making interaction through interrogative methods extremely helpful in developing a suitable mental model [49].

Collective-intelligence-as-a-service is a mechanism that allows human decision models to be cloned with the sole purpose of approaching automatic decision making while still requiring the assistance of humans. Its main focus is on evaluating, sharing, appreciating, digitizing, and utilizing professional decision-making expertise and experience; finding ways to incorporate the cognitive sides of problem solving and decision making into current sketches of industrial operations; improving cooperation between humans and machines; and making cognizant decisions [50].

Thus, Operator 4.0 is an intelligent worker that utilizes cognitive information to connects to H-CPS (human cyber-physical systems), enabling it to cooperate with robots and assisted machines as needed in I4.0 environment. Along with adaptive automation, it also makes use of progressive human-machine interaction technologies to achieve this [51].

The classification of duties for Operator 4.0 can be described as;

- Analytical: Analysis of big data information in-depth for enhanced industrial production.
- Augmented: Improving the state of the manufacturing plant using augmented reality techniques like data trade-offs between the real world and the sophisticated digital world.

- Cooperative: Supportive automation (CoBots) and operator collaboration are used to complete daily non-ergonomic tasks.

- Hygienic: Wearable trackers that measure well-being and compute performance, pulse, and other personal data.

- Intelligent: artificial intelligence (AI) powered intelligent personal assistant (IPA).

- Social: enterprise social network services (E-SNS) aim to integrate intelligent operators with smart industrial facility assets in the workplace by using simply adaptable and social collaborative ways.

- Powerful: lightweight, motorized exoskeletons that can function as multifunctional biomechanical devices.

- Virtual: virtual reality (VR) is a computer simulation that can mimic a realistic digital layout, assembly line, or production line while allowing the operator to virtually interact with and try out the replicated work environment [41].

The operator 4.0's tasks are divided into two categories [52]. These are positions in manufacturing as well as jobs in information technology (IT).

In manufacturing, the physical work will be significantly reduced as a result of technological advancements, especially in the relationship between human operators and robots in the workplace, which will enable operators to make the most of their exceptional abilities to innovate, take part in, and adapt to new circumstances [53].

Having employees wear exoskeletons is one of the easiest ways to improve their strengths. The use of a "super-strength operator," which enables people to control big robots, is one way to accomplish this. By doing this, the high risk of injury and exhaustion that workers who lift heavy objects in warehouses and construction sites face can be decreased. Workers may occasionally be required to lift heavy objects using rigid tools like a forklift, depending on the tasks at hand. The advantages of these advances in robotics for workers are numerous. For instance, powered robotic suits give workers the power to lift very heavy objects while still allowing them to maintain their natural flexibility. These powered robotic suits shield wearers from serious injuries caused by accidents or overexertion [53].

However, for IT based jobs competences, and expertise requirements will gain significance in the I4.0 environment. **Table 1** provides a summary of these configurations.

Thus, humans do not need to live in constant fear that machines will replace them and render them jobless because this will only lead to conflicts between the two. For businesses and employees to benefit from the advantages of both machines and people, collaboration must be at the forefront of new technological advancement. The future of work will have adaptable and changeable work environments thanks to Operator 4.0's flexibility, which implies that as new technologies are adopted, the workplace will also change for the better in terms of safety and productivity.

### 3.3 Human role in virtual reality and augmented reality

VR creates non-physical experiences by establishing an artificial reality. VR can improve the reliability of neuropsychological analysis by continuously manipulating

| Job/Role | Competence | Expertise |
|---|---|---|
| Informatics Specialist | • High school degree + higher education degree in IT<br>• Practical experience in the same field<br>• Comprehension in large domains and network management<br>• Fundamental information of dealing with database, virtualization, and cloud services | • Language skills<br>• Independence<br>• Obligation<br>• Adaptability<br>• Communicativeness<br>• Reliability<br>• Planning experience<br>• Team leader<br>• Organizational aptitudes |
| PLC Programmer | • High school degree<br>• Practical experience in PLC and PLC programming.<br>• Proof of experience in machine programming | • Language skills<br>• Experience in BeckhoffTwinCAT<br>• Obligation<br>• Adaptability<br>• Communicativeness<br>• Reliability<br>• Capacity and eagerness to memo-rize unused things |
| Robot Programmer | • High school degree + higher education degree in automation<br>• Comprehension in programming online and offline robots<br>• Experience with essential robot parameters and settings<br>• Project administration, adjustment of robot software engineer group and knowledge with PLC programmers<br>• Installation of the gadget into operation | • Language skills<br>• Analytical and logic reasoning<br>• Obligation<br>• Adaptability<br>• Communicativeness<br>• Reliability<br>• Experienced in simulation process<br>• Ability to solve problems |
| Software Engineer | • High school degree + higher education degree in IT<br>• Comprehension of programming C and C++<br>• Practical experience in the same field<br>• Fundamental information of dealing with database, such as SQL | • Language skills<br>• Autonomy<br>• Inventiveness<br>• Adaptability<br>• Analytical and logic reasoning<br>• Ability to solve problems |
| Data Analyst | • High school degree + higher education degree in mathematics and/or statistical analysis<br>• Experienced with PL, SQL, and UML | • Language skills<br>• Autonomy<br>• Inventiveness<br>• Adaptability<br>• Analytical and logic reasoning<br>• Ability to make excel sheets<br>• Ability to solve problems<br>• Comprehensive statistical knowledge<br>• Ability to solve problems |

| Job/Role | Competence | Expertise |
|---|---|---|
| Cyber security | • High school degree + higher education degree in IT | • Language skills<br>• Autonomy<br>• Inventiveness<br>• Adaptability<br>• Analytical and logic reasoning<br>• Capacity and eagerness to memorize unused things<br>• Aware of security and communication<br>• Awareness of server management level |

**Table 1.**
*Information technology related operator figuration [52].*

complex test stimuli and precisely measuring participant reactions. Due to VR technology's capacity to more subtly quantify reactions, the validity of the testing of various cognitive regions may rise. These cognitive areas include executive functions, visuospatial skills, and improved levels of problem-solving, attention, and memory. Direct performance analysis in a computer-simulated human setting is a second strategy for doing this. In order to increase the ecological legitimacy of neuropsychological analysis, VR therefore offers the opportunity for cognitive analysis inside a simulation of a real-world practical testing area [54].

The primary crucial feature in cognitive skills is attentional abilities, which is because attentional issues are commonly identified as the primary shortfall in brain damaged employees [55]. Attention and cognitive abilities are categorized into five groups [56]:

- Focused: The basic capacity to respond to a specific event in the early stages.
- Sustained: The capacity to consistently respond to repeated performance and activities is known as concentration (i.e., visual quality control).
- Selective: The ability to maintain an appropriate behavioral and cognitive state despite distractions.
- Alternating: The capacity of the mind to shift between tasks requiring various levels of alertness and focus (i.e., taking notes while listening to a lecture).
- Divided: The capacity to perform multiple tasks simultaneously (i.e., driving and listening to music).

Moreover, the cognitive skills required by Operator 4.0 within VR are:

- Memory: The person is asked to gradually recall responses that happened at particular times, settings on gauges, the locations of tools, and behavioral patterns in order to complete various tasks.

- Sensory processing: visual and auditory; humans rely heavily on their senses of touch, taste, and smell, and problems with hearing and vision can affect daily activities. When dealing with these issues, a VR environment would be helpful.

- Higher cognitive functions: problem-solving skills, organizational and conceptual thinking, executive function, critical thinking, and more [56].

Thus, the main actor in the Industry 4.0 virtual environment is the production operator who interacts with the various pieces of equipment in the line. In an era of constant change and technological experimentation, design plays a central role in the new manufacturing environment, where ergonomics is the focal point for the improvement in terms of product and production process with a focus on user well-being and safety (**Figure 5**).

When used on machines, augmented reality (AR) can provide analytical intelligence derived from real-time data sensors to determine when equipment needs to be repaired or maintained. Factory managers can clearly see key performance indicators (KPIs) thanks to AR. In addition, AR gives managers a real-time overview of the various areas of a factory. This enables managers to quickly find, assess, diagnose, track down, and fix flaws (such as alerting on deviations) so that manufacturing processes can continue to run smoothly. Additionally, acting as a "tag reader" may result in initial human-product exchanges using technologies like QR codes, GPS, OCR, barcodes, RFID, and NFC, which give the smart operator access to current and historical information about a product [58].

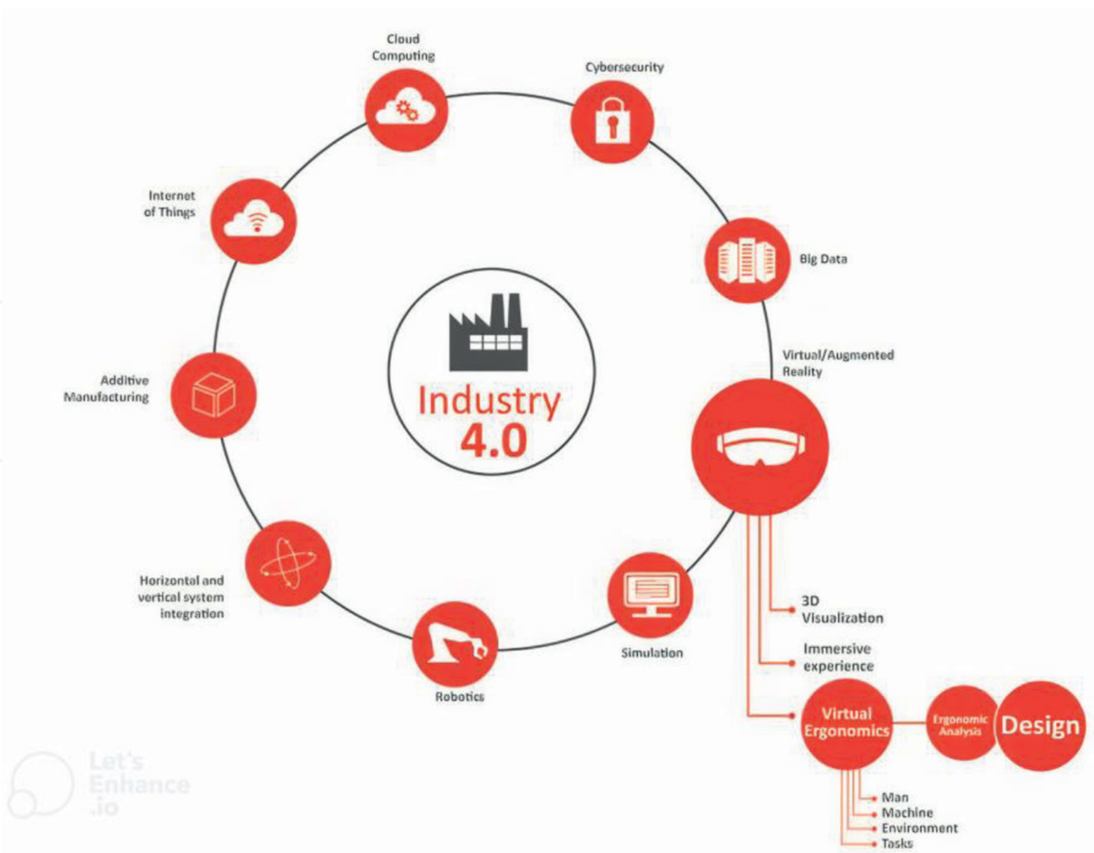


**Figure 5.**
*New approach for design with virtual ergonomics [57].*

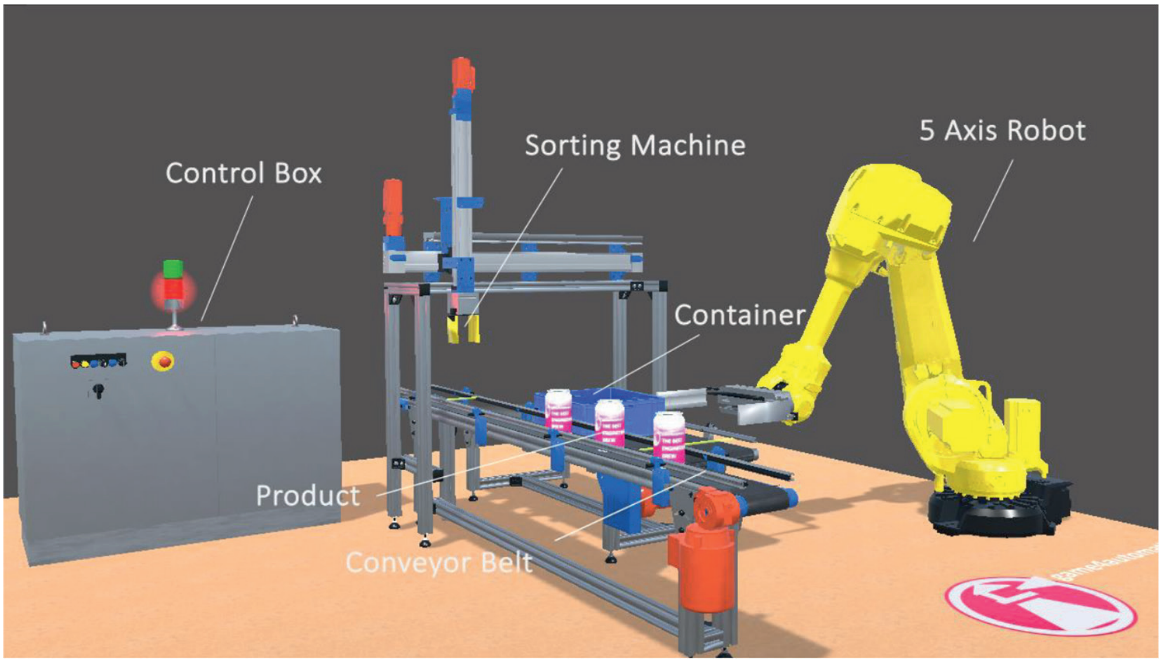


**Figure 6.**
*Virtual work environment.*

On the other hand, AR uses virtual replicas of real-world characters to enhance real-world events and experiences. Working with real-time interaction, integrating and re-collocating real and virtual objects, and combining real and virtual objects in the workspace are its three main components [59] (**Figure 6**).

Because of the created generated computer views, pictures, sound effects, and other useful data, which is integrated within the actual working environment and presented on a display, an *augmented operator* is dependent on augmented reality technology, which could be seen as the other side of the coin [60].

The cognitive load in situations involving technical reporting is reduced by augmented reality. Because AR is one of the nine enabling technologies (**Figure 7**), using it to create technical documentation for factory equipment or products that is appropriate for Industry 4.0 [61].



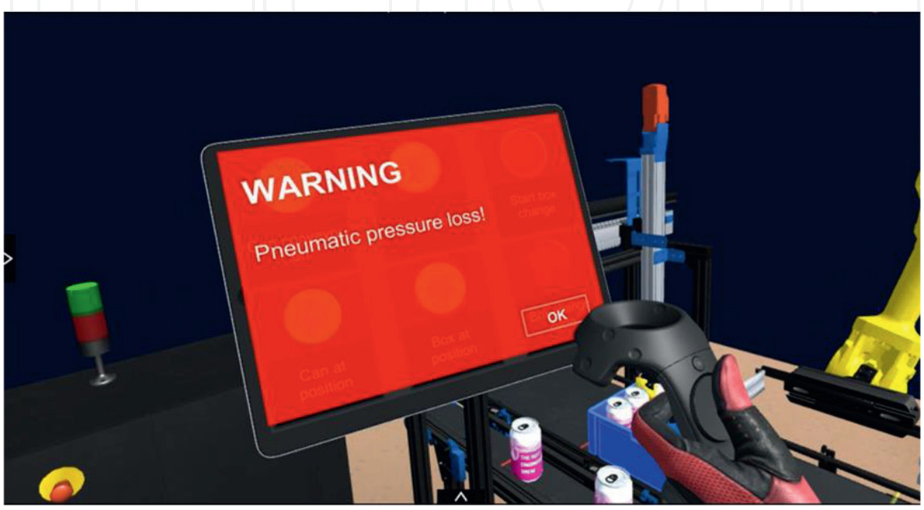


**Figure 7.**
*Cognitive load.*

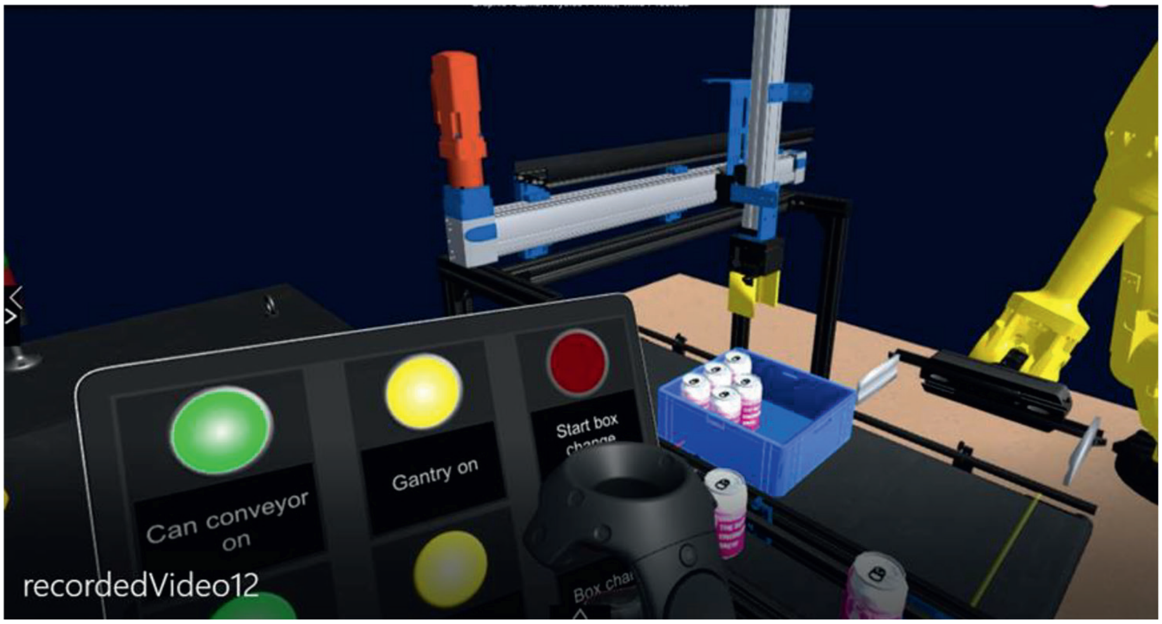


**Figure 8.**
*Production in AR.*

Because of its advanced manufacturing, AR can create a new appearance of reality. Users can feel as though they are actually inside it thanks to this. The way technical information is presented to its users is said to be significantly altered by cutting-edge computer graphics interfaces like virtual and augmented reality. Currently, voice and body movement recognition, onboard 3D real world synchronization, and high-resolution head-mounted displays (HMD) are being used widely and becoming less expensive [60].

Through the concept of "diagnostic intelligence," which is carried out by real-time sensors, AR can be used in any factory to maintain machines and equipment. Using this concept, performance-related data for an entire machine or a specific component can be collected while it is in use. Factory managers can monitor the production lines using the AR to identify, analyze, and correct problems. This improves the effectiveness of production processes [58] (**Figure 8**).

The assembly and maintenance work are required because of AR technology [62]. In describing the task the operator must complete and how the task must be completed, graphics and other visual objects have proven to be exceptionally effective [61]. Operators can benefit from AR's visual characters in two specific tasks:

- Identifying elements, for instance, using bold, clear colors and text labels in ARMAR inside a military vehicle.

- Executing the process, for instance, by using an animated 3D model of an object, such as bolts, and an operation description, such as a text referring to unscrew the bolt in an automotive task [63].

## 4. Conclusion

Organizational arrangements and human performance efficiency studies were conducted on physical ergonomics up until the third industrial revolution. There was a slight shift towards cognitive ergonomics after the third industrial revolution, but the research on skills and abilities required were not extensively studied. With the introduction of the new Industry 4.0 era, physical tasks, activities, and responsibilities of human in the manufacturing environment are minimized, or even disappeared. However, cognitive skills gained importance in this new age due to the new technologies. Development, operation, and maintenance of such cutting-edge technologies requires certain skills and abilities. Thus, it is inevitable to update the role and responsibilities of people in a manufacturing environment. As a result, ergonomic viewpoints have progressed from concentrating solely on adjusting the human to the other components of the work system physically and organizationally to upgrading cognitive abilities to process more information.

Therefore, it is unnecessary for humans to constantly worry that machines will take their jobs and replace them, as this will only cause conflicts between the two. Collaboration must be at the forefront of new technological advancement for businesses and employees to profit from the advantages of both people and machines. Because of Operator 4.0's flexibility, work environments in the future will be flexible and adaptable, which implies that the workplace will change for the better in terms of safety and productivity as new technologies are adopted.

As a result, I4.0 has given a lot of attention to cognitive ergonomics, which focuses on mental processes, such as perception, memory, information processing, reasoning, and reactions. The new I4.0 paradigm has gained a lot of attention, but it also has raised some concerns about its developments, effects on operators, and underlying concepts. The current study offered a summary of the pertinent literature, presented the I4.0's most recent applications, and discussed how this idea—when combined with cognitive ergonomics—can benefit both academics and industry professionals in the future.

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