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Industry 4.0 or the Fourth Industrial Revolution (4IR)

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ABSTRACT

"Fourth Industrial Revolution", "4IR", or "Industry 4.0" is a neologism describing rapid technological advancement in the 21st century. It follows the Third Industrial Revolution (the "Information Age"). The phase of industrial change is the combination of technologies like artificial intelligence (AI), advanced robotics, and gene editing that blurs the lines between the physical, digital, and biological worlds. There is a global shift from how the global production and supply network operates through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large- scale machine-to-machine communication (M2M), and the Internet of Things (IoT). This has led to increased automation, improved communication and self-monitoring, cum the use of smart machines which could analyze and diagnose issues without the need for human intervention. This is known to represent a social, political, and economic shift from the digital age of the late 1990s and early 2000s to an era of embedded connectivity distinguished by the ubiquity of technology in society (i. e. a metaverse) that changes the ways humans experience and know the world around them. The Fourth Industrial Revolution is said to mark the beginning of an "imagination age", where creativity and imagination are the primary drivers of economic value. This paper looks into the pros and cons of Industry 4.0 and considers the prospects it holds for the future for humans.

KEYWORDS: *Industry 4.0, creativity and imagination age, Internet of Things (IoT), machine-to-machine communication (M2M), artificial intelligence (AI), Big Data, robotics, Industrial IoT (IIoT), automation, cloud computing*

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INTRODUCTION

Industry 4.0 is defined as the integration of intelligent digital technologies into manufacturing and industrial processes. This encompasses a set of technologies that include Industrial IoT networks, AI, Big Data, robotics, and automation. Industry 4.0 allows for smart manufacturing and the creation of intelligent factories, as shown in Figure 1. It helps to enhance productivity, efficiency, flexibility and enabling more intelligent decision-making and customization in manufacturing and supply chain operations [1, 2], in conjunction with cloud computing. We have seen in the past the evolution of the production process, from the first industrial revolution, that of the steam machines to the last 3.0 called the Information and Communication Technology (ICT). Currently, we are in 4.0 era. The term Industry 4.0 originated from a project in the high-tech strategy of German government, which promotes the computerization of manufacturing. Industry 4.0 is where manufacturing systems and its products are not simply connected, drawing physical information into the digital domain, but also communicate, analyze, and use that information to add intelligent action back into the physical world [3].

HISTORY

The phrase Fourth Industrial Revolution was first introduced by a team of scientists developing a high-tech strategy for the German government. Klaus Schwab, executive chairman of the World Economic Forum (WEF), introduced the phrase to a wider

audience in 2015 article published by Foreign Affairs [4]. "Mastering the Fourth Industrial Revolution" was the 2016 theme of the World Economic Forum Annual Meeting, in Devos-Klosters, Switzerland [5]. Schwab was of the expectations that the era will be marked by breakthroughs in emerging technologies such as robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, the Internet of Things, the Industrial Internet of Things, decentralized consensus, fifth-generation wireless technologies, 3D printing, and fully autonomous vehicles [6].

THE FIRST INDUSTRIAL REVOLUTION

The First Industrial Revolution was marked by a transition from hand production methods to machines through the use of steam power and water power. The implementation of new technologies took a long time, so the period which this refers to was between 1760 and 1820, or 1840 in Europe and the United States. Its effects had consequences on textile manufacturing, which was first to adopt such changes, as well as iron industry, agriculture, and mining although it also had societal effects with an ever stronger middle class [7].

THE SECOND INDUSTRIAL REVOLUTION

The Second Industrial Revolution, also known as the Technological Revolution, was the period between 1871 – 1914 that resulted from installations of extensive railroad and telegraph networks, which allowed for faster transfer of people and ideas, as well as electricity. Increasing electrification allowed for factories to develop the modern production line [8].

THE THIRD INDUSTRIAL REVOLUTION

The Third Industrial Revolution, also known as the Digital Revolution began in the late 20th century. It was characterized by the shift to an economy centered on information technology, marked by the advent of personal computers, the internet, and the widespread digitalization of communication and industrial processes. The book titled "The Third Industrial Revolution," by Jeremy Rifkin published in 2011, focused on the intersection of digital communications technology and renewable energy [9], which was made into a 2017 documentary by VICE Media [10], as shown in Figure 2.

CHARACTERISTICS

The Fourth Industrial Revolution is geared towards automation and data exchange in manufacturing technologies and processes which include cyber-physical systems (CPS), Internet of Things (IoT) [11], cloud computing [12, 13], cognitive computing, and artificial intelligence [13, 14], as shown in Figures 3, and 4. Machines improve human efficiency in performing repetitive functions, and the combination of machine learning and computing power allows machine to carry out increasingly complex tasks [15].

The Fourth Industrial Revolution has been defined as technological developments in cyber-physical systems such as high capacity connectivity; new human-machine interaction modes such as touch interfaces and virtual reality systems; and improvements in transferring digital instructions to the physical world including robotics and 3D printing (additive manufacturing); "Big Data" and cloud computing; improvements to and uptake of Off-Grid/Stand-Alone Renewable Energy Systems: solar, wind, wave, hydroelectric and the electric batteries (lithium-ion renewable energy storage systems (ESS) and EV). There is also emphasis on decentralized decisions i. e. the ability of cyber-physical systems to make decisions on their own and to perform their tasks as autonomously as possible. However, it is only in the case of exceptions, interferences, or conflicting goals, are tasks delegated to higher level [16].

DISTINCTIVENESS

Proponents of the Fourth Industrial Revolution suggest it is a distinct revolution and not a prolongation of the Third Industrial Revolution due to the following characteristics:

- Velocity – Exponential speed at which incumbent industries are affected and displaced [17].
- Scope and systems impact – The large amount of sectors and firms that are affected [17].
- Paradigm shift in technology policy – New policies designed for this new way of doing are present for example in Singapore's formal recognition of industry 4.0 in its innovative policies.

COMPONENTS

The application of the Fourth Industrial Revolution operates through [18, 19]:

- Mobile devices
- Location detection technologies (electronic identification)
- Advanced human-machine interfaces
- Authentication and fraud detection
- Smart sensors
- Big analytics and advanced processes
- Multilevel customer interaction and customer profiling
- Augmented reality/wearables
- On-demand availability of computer system resources
- Data visualization.

The Fourth Industrial Revolution trends towards "Smart Factories," which are production environment where facilities and logistics systems are organized with minimal human intervention. The technical foundations on which smart factories are based are cyber-physical systems that communicate with each other using the Internet of Things and Services, which has to do with the exchange of data between the product and the production line. Within modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual of the physical world and make decentralized decisions [20].

ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) has a wide range of applications across all sectors of the economy, as shown in Figure 5. In the 2010s it gained prominence in deep learning with its impact in the 2020s with the rise of generative AI – the period often referred to as the "AI boom" [21]. Models like GPT-4o can engage in verbal and textual discussions and analyze images (where GPT-4o means Generative Pre-trained Transformer 4 omni) [22].

ROBOTICS

Humanoid robotics traditionally lacked usefulness due to imprecise control and coordination, and they cannot understand their environment and how physics works. However, the modern humanoid robots are typically based on machine learning (ML), in particular reinforced learning. Humanoid robots are now more flexible, easier to train and versatile [23], as shown in Figures 6, 7, and 8.

PREDICTIVE MAINTENANCE

As a result of the use of advanced technologies and IoT sensors, Industry 4.0 facilitates predictive maintenance. Predictive maintenance, which can identify potential maintenance issues in real time, allows machine owners to perform cost-effective maintenance before the machinery fails or gets damaged [24].

3D PRINTING

The Fourth Industrial Revolution is said to have extensive dependency on 3D printing technology, also known as additive manufacturing. A few of the advantages of 3D printing are [25]:

- It can print many geometric structures
- It simplify the product design process
- It is relatively environmentally friendly
- In low-volume production, it can decrease lead times and total production costs
- It can increase flexibility
- Reduction in warehousing costs
- Helps the company towards the adoption of a mass customization business strategy
- Useful for printing spare parts and installing it locally, hence reducing supplier dependence and reducing the supply lead time.

3D printing is one of the leading emerging technologies of Industry 4.0. The use and implementation of additive manufacturing, in combination with other technologies, is producing an evolution in the industry towards an intelligent production where machines (autonomous, automatic and intelligent), systems and networks are able to exchange information and respond to the systems of production management. In addition, as a technology capable of turning a 3D design into a product without intervention, 3D printing has a fundamental role. Furthermore, with 3D printers, the need for expensive tools and fixtures is eliminated, reducing post-processing, material waste and human intervention. These are the characteristics that define the industry of the future. With the Gartner curve – as shown in Figure 9, 3D printing has come to maturity very quickly. This curve represents the maturity, adoption and commercial application of a specific technology. At the highest peak is medical implant 3D printing, point of sale 3D printing and in supply chains. There is also 3D printing in classrooms within the education sector and bioprinting for research in the field of medicine [26].

SMART SENSORS

Sensors and instrumentation drive the central forces of innovation, not only for Industry 4.0 but also for other "smart" megatrends, such as smart production, smart mobility, smart homes, smart cities, and smart factories [27].

Smart sensors are devices that generate data and allow further functionality from self-monitoring and self-configuration to condition monitoring of complex processes. With the capability of wireless communication, they reduce installation effort to a great extent and help realize a dense array of sensors [28].

In agriculture and food industries, smart sensors in these two fields are still in the testing stage with respect to collecting, interpreting and communicating the information available in the plots with regards to leaf area, vegetation index, chlorophyll, hygrometry, temperature, water potential and radiation [29, 30].

TRANSITION TO THE KNOWLEDGE ECONOMY

Knowledge economy is an economic system in which production and services are largely based on knowledge-intensive activities that contribute to an

accelerated pace of technology and scientific advance, as well as rapid obsolescence [31-33]. Industry 4.0 aids transitions into knowledge economy by increasing reliance on intellectual capabilities than on physical inputs or natural resources.

CHALLENGES TO INDUSTRY 4.0

Some of the challenges to the implementation of Industry 4.0 are [34]:

1. **Economic vis-a-vis:**
   - High economic cost
   - Business model adaptation
   - Unclear economic benefits/excessive investment
   - Driving significant economic changes through automation and technological advancements, leading to both job displacement and the creation of new roles, necessitating widespread workforce reskilling and systemic adaptation [35].
2. **Social: under which are:**
   - Privacy concerns
   - Surveillance and distrust
   - General reluctance to change by stakeholders
   - Threat of redundancy of the corporate IT department
   - Loss of many jobs to automatic processes and IT controlled processes, especially for blue-collar workers [34, 36].
   - Increased risk of gender inequalities in professions with job roles most susceptible to replacement with AI [37, 38].
3. **Political:**
   - Lack of regulation, standards and forms of certifications
   - Unclear legal issues and data security [34].
4. **Organizational:**
   - IT security issues
   - Reliability and stability needed for critical machine-to-machine communication (M2M), including very short and stable latency times
   - Need to maintain the integrity of production processes
   - Need to avoid any IT snags, as those would cause expensive production outages
   - Need to protect industrial know-how (contained also in the control files for the industrial automation gear)
   - Lack of adequate skill-sets to expedite the transition towards Industry 4.0 [39, 40]
   - Low top management commitment
   - Insufficient qualification of employees [34].

COUNTRY APPLICATIONS

Industry 4.0 is being adopted by some countries now of which are: United States of America, United Kingdom, Malaysia, Uganda, South Korea, Australia, South Africa, Germany, Estonia, India, Indonesia, just to mention a few.

INDUSTRY APPLICATIONS

It is said that the aerospace industry is characterized as "too low volume for extensive automation". However, Industry 4.0 principles have been investigated by several aerospace companies, and technologies have been developed to improve productivity where the upfront cost of automation cannot be justified. An example of this is the aerospace parts manufacturer Meggitt PLC's M4 project [41]. Bosch in 2017 launched the Connectory, a Chicago, Illinois based innovation incubator that specializes in IoT, including Industry 4.0.

Industry 4.0 inspired Innovation 4.0, a move toward digitalization for academia and research and development [42]. In 2017, the 81 million pounds Materials Innovation Factory (MIF) at the University of Liverpool opened a center for computer aided materials science [43], where robotics formulation [44], data capture and modeling are being integrated into development practices [42].

INDUSTRY 5.0

Industry 5.0 is been proposed as a strategy to create a paradigm shift for an industrial landscape in which the primary focus should no longer be on increasing efficiency but on promoting the well-being of society and sustainability of the economy and industrial production [45-47].

CONCLUSION

Industry 4.0 is a transformative shift in manufacturing which is driven by advanced technologies like IoT, AI, and robotics, enabling highly automated, data-driven, and customized production processes, leading to increased efficiency, flexibility, and productivity with both challenges to workforce adaptation and skills development that requires strategic implementation to fully realize its potential and opportunities for economic growth. Robots and machines are already part of our everyday life, which is a new reality that must be accepted by everyone, coupled with its numerous benefits among which are: availability of goods, affordability of goods, increased jobs, and improved medical care.

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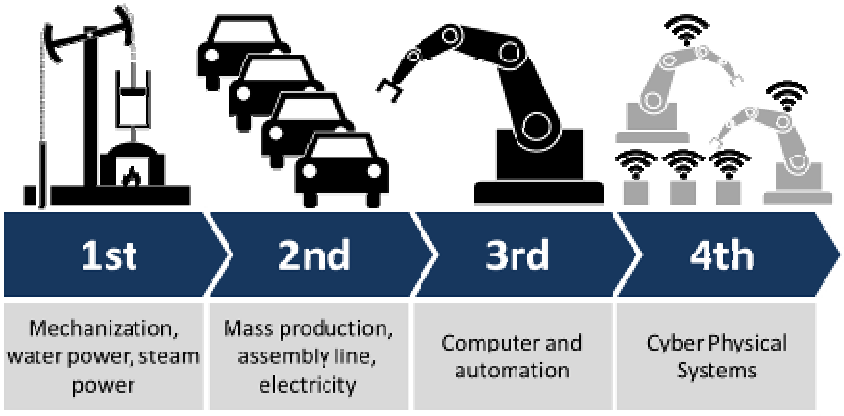


Figure 1. Industry 4.0.png

Source:https://www.google.com/search?sca_esv=e6182da575e8b716&sxsrf=AHTn8zqQcCRyBV1eDnz5R6eUEQebkg6FPw:1739570205927&q=images+on+industry+4,0+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBjLjqIC1CYKD9DDQAQS3Z5NmlRTZM9mMZwadeXOSzfMOuJ9MVOHDHVayNtOyOCEREm3RXZuZWpCKSNf1HgZ9GY_3s6mbwIMPgr4rsBKOtXrDRbh7ZTQllzMsxzAahWmrrBeh2A4_7NFFlJVSECdlabxCH&sa=X&ved=2ahUKEwjMq76BlMSLAxVuSkEAHUJZCN8QtKgLegQIERAB&biw=1036&bih=539&dpr=1#vhid=SLV6jurA-AMh-M&vssid=mosaic

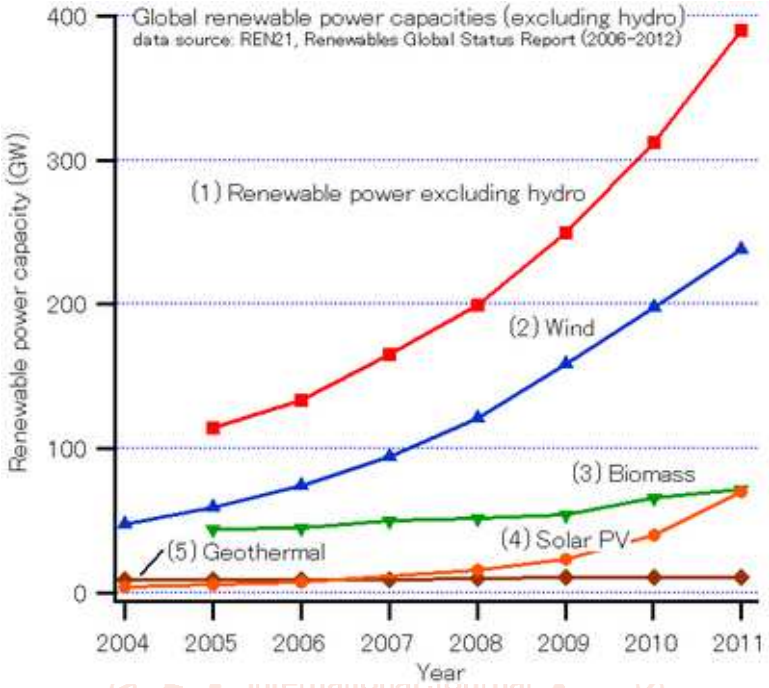
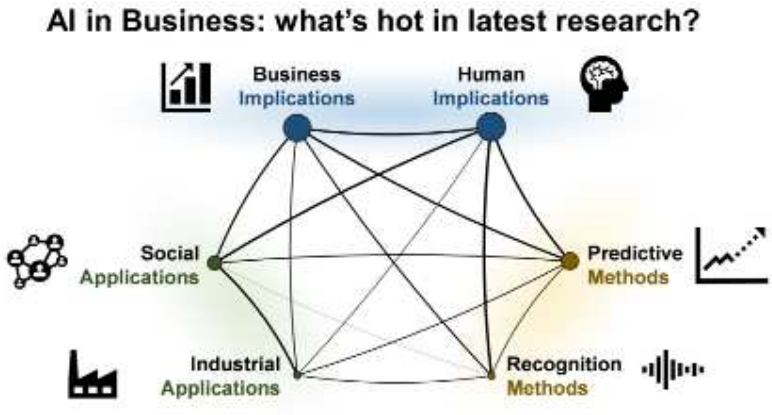


Figure 2. Renewable energy industry

Source:https://www.google.com/search?sca_esv=e6182da575e8b716&sxsrf=AHTn8zqQcCRyBV1eDnz5R6eUEQebkg6FPw:1739570205927&q=images+on+industry+4,0+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBjLjqIC1CYKD9DDQAQS3Z5NmlRTZM9mMZwadeXOSzfMOuJ9MVOHDHVayNtOyOCEREm3RXZuZWpCKSNf1HgZ9GY_3s6mbwIMPgr4rsBKOtXrDRbh7ZTQllzMsxzAahWmrrBeh2A4_7NFFlJVSECdlabxCH&sa=X&ved=2ahUKEwjMq76BlMSLAxVuSkEAHUJZCN8QtKgLegQIERAB&biw=1036&bih=539&dpr=1#vhid=vFhIKVnOsQ0dsM&vssid=mosaic

Figure 3. Artificial intelligence

Source:https://www.google.com/search?sca_esv=f52b6fd816e23425&sxsrf=AHTn8zpKVb8D4kGF1Pw1KTkLjeTewIJVBg:1739647467124&q=artificial+intelligence+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBnsX62dbVmWR6QCQ5QEtPRrGFxp3K3tehynY_7YR4ChVqTPcqms9fJ2kFLDSo6rRGuGOaiT61qM4m_k9vEqzaRdQ_eO7Jw17czliUyMx9rCl6BE_3TIHAfi80UGrmj199NrrkW2XNFureHY8F40IhMN20h&sa=X&ved=2ahUKEwjVxL_qs8aLAxVAVKQEHYvvNWQQtKgLegQIDxAB&biw=1036&bih=539&dpr=1#vhid=jKyagRUld9l10M&vssid=mosaic



Network visualization of the AI in Business topic model. Nodes' size is proportional to the relative presence of the topic in current literature while the width of each edge shows the level of inter-topic distance. Adapted from: A. Sestino, A. De Mauro (2021), "Leveraging Artificial Intelligence in Business: Implications, Applications and Methods", Technology Analysis & Strategic Management, DOI: 10.1080/09537325.2021.1883583

Figure 4. Artificial intelligence of things

Source:https://www.google.com/search?sca_esv=f52b6fd816e23425&sxsrf=AHTn8zpKVb8D4kGF1Pw1KTkLjeTewIJVBg:1739647467124&q=artificial+intelligence+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBnsX62dbVmWR6QCQ5QEtPRrGFxp3K3tehynY_7YR4ChVqTPcqms9fJ2kFLDSo6rRGuGOaiT61qM4m_k9vEqzaRdQ_eO7Jw17czliUyMx9rCl6B-E_3TIHAfi80UGrmj199Nrrkw2XNFureHY8F40IhMN20h&sa=X&ved=2ahUKEwjVxL_qs8aLAxVAVKQEHYvvNWQQtKgLegQIDxAB&biw=1036&bih=539&dpr=1#vhid=qZf0brkYYkaHpM&vssid=mosaic

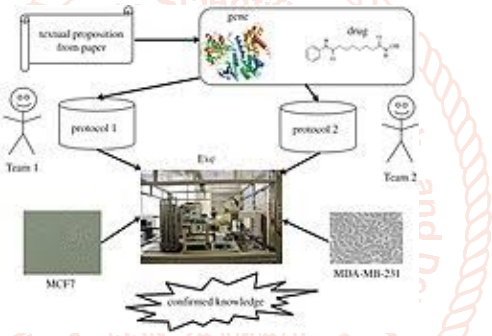


Figure 5. Applications of artificial intelligence

Source:https://www.google.com/search?sca_esv=f52b6fd816e23425&sxsrf=AHTn8zpKVb8D4kGF1Pw1KTkLjeTewIJVBg:1739647467124&q=artificial+intelligence+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBnsX62dbVmWR6QCQ5QEtPRrGFxp3K3tehynY_7YR4ChVqTPcqms9fJ2kFLDSo6rRGuGOaiT61qM4m_k9vEqzaRdQ_eO7Jw17czliUyMx9rCl6BE_3TIHAfi80UGrmj199Nrrkw2XNFureHY8F40IhMN20h&sa=X&ved=2ahUKEwjVxL_qs8aLAxVAVKQEHYvvNWQQtKgLegQIDxAB&biw=1036&bih=539&dpr=1#vhid=Vw4ZAEfkSF1AtM&vssid=mosaic

Figure 6. Automation

Source:https://www.google.com/search?q=robotics+in+industry+4.0+by+wikipedia&sca_esv=f52b6fd816e23425&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrXBg5z9VnVHUf8rMi8ypsB4dOFdg%3A1739648673138&ei=oe6wZ7aJCIGshbIPmSBsA4&ved=0ahUKEwj23cipuMaLAxUBVkEAHRtyAOYQ4dUDCBE&oq=robotics+in+industry+4.0+by+wikipedia&gs_lp=EgNpbWciJXJvYm90aWNzIGluIGluZHVzdHJ5IDQuMCBieSB3aWtpcGVkaWFIt5EBUNYGWMFhcAF4AJABAJgBgKgAZEeqgEIMC4xLjE0LjG4AQzIAQD4AQGYAgKgAuEBwgIEECMYJ5gDAIgGAZIHBTEuMC4xoAedBw&sclient=img#vhid=rWugJGOrYJ0PeM&vssid=mosaic

Figure 7. Robotics

Source:https://www.google.com/search?q=robotics+in+industry+4.0+by+wikipedia&sca_esv=f52b6fd816e23425&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrXBg5z9VnVHUf8rMi8ypsB4dOFdg%3A1739648673138&ei=oe6wZ7aJCIGshbIPmSBsA4&ved=0ahUKEwj23cipuMaLAxUBVkEAHRtyAOYQ4dUDCBE&oq=robotics+in+industry+4.0+by+wikipedia&gs_lp=EgNpbWciJXJvYm90aWNzIGluIGluZHVzdHJ5IDQuMCBieSB3aWtpcGVkaWFIt5EBUNYGWMFhcAF4AJABAJgBgKgAZEeqgEIMC4xLjE0LjG4AQzIAQD4AQGYAgKgAuEBwgIEECMYJ5gDAIgGAZIHBTEuMC4xoAedBw&sclient=img#vhid=eqzD04GDxvn_BM&vssid=mosaic

Figure 8. Humanoid robot

Source:https://www.google.com/search?q=humanoids+in+industry+4.0+by+wikipedia&sca_esv=f52b6fd816e23425&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrfTaBLZLgHQN7a1T8VRFbvSYwTMA%3A1739648708852&ei=xO6wZ6LWM4fMhbIPrKViA4&ved=0ahUKEwiiyMy6uMaLAxUHZkEAHXpZBeEQ4dUDCBE&oq=humanoids+in+industry+4.0+by+wikipedia&gs_lp=EgNpbWciJmh1bWFub2lkcyBpbiBpbmR1c3RyeSA0LjAgYnkgd2lraXBlZGlhSKV5UMkLWK5LcAF4AJABAJgB1gOgAcMkqgEIMi0xMy4yLjK4AQzIAQD4AQGYAgCgAgCYAwCIBgGSBwCgB4UG&sclient=img#vhid=MSI19QyIB1EODM&vssid=mosaic

Figure 9. Gartner Curve

Source:https://www.google.com/search?q=gartner+curve+by+wikipedia&oq=gartner+curve+by+wikipedia&aqs=chrome..69i57.49999j0j15&sourceid=chrome&ie=UTF-8#vhid=7wsE0QxXdiCQrM&vssid=1