IMPLEMENTATION OF INDUSTRY 4.0 IN THE DEVELOPMENT OF THE SPACE INDUSTRY

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1. INTRODUCTION

The deployment of Industry 4.0, which is defined by the integration of sophisticated technology and data-driven processes, has transformed several industries, allowing for higher productivity, efficiency, and flexibility. The space industry is one that has been heavily impacted by Industry 4.0. Driven by technical developments and the desire to explore beyond Earth's borders, the space industry has recognized the potential of Industry 4.0 to improve its operations and push the boundaries of space exploration even further.

Space exploration is an enthralling and necessary pursuit that feeds human curiosity while pushing the limits of knowledge and technical innovation. It provides a once-in-a-lifetime opportunity to explore the universe's mysteries, generating awe and amazement in individuals of all ages. Furthermore, there are various scientific discoveries and technological advances that emerge because of space travel. Fascinating statistics underscore its significance: Over 2,700 exoplanets have been confirmed by NASA's Kepler mission alone, opening new frontiers in the search for extra-terrestrial life, while the International Space Station has hosted more than 240 astronauts from 19 countries, fostering international collaboration and expanding our understanding of human adaptation to space.

1.1 Objective and Methodological Approach

The goal of this thesis is to investigate the application of Industry 4.0 in the development of the space industry. It seeks to examine how modern technology, automation, artificial intelligence, and data analytics can transform and drive innovation in the space sector. The study will look at the advantages, disadvantages, and prospective uses of Industry 4.0 in space missions, satellite manufacture, launch operations, and space exploration.

To accomplish this goal, a thorough assessment of existing literature and case studies will be done. Analysing academic papers, industry reports, and pertinent publications to get insights into the current situation of the space sector and the prospective influence of Industry 4.0 will be part of this. In addition, interviews will be performed with industry experts and professionals to gain first-hand knowledge and perspectives on the subject.

1.2 Scope

This thesis' scope includes the implementation of Industry 4.0 in many elements of the space industry. It will investigate how innovative technologies can be used in the design, development, and production of satellites to improve performance and lower costs. Furthermore, it will investigate the use of automation and robotics to improve efficiency and reliability in satellite testing, assembly, and integration operations.

The study will also look into the role of data analytics and artificial intelligence in space missions, such as optimizing launch routes, predicting space weather, and processing massive volumes of data from satellites and space probes. The possible applications of virtual and augmented reality in astronaut training and space exploration will also be investigated.

This research intends to provide light on the revolutionary potential of Industry 4.0 in extending the boundaries of space exploration by exploring the benefits, difficulties, and prospective uses of sophisticated technology and data-driven processes. The integration of sophisticated technology promises to change the space sector, from satellite manufacture to space missions and beyond but what are the consequences of such dynamic transformations.

2. INDUSTRY 4.0

The world as we know it today has been significantly shaped by the last three industrial revolutions. Each of these revolutions brought with it new technologies, manufacturing processes, and business models, fundamentally altering how people live, work, and communicate.

The brief analysis of the First Industrial Revolution (Wallace, 2022) noted that the first breakthrough lasted from the late 18th century to the mid-19th century and it was distinguished by the shift from manual labour to machine-based manufacturing based on water and steam power. This revolution had a significant impact on the textile industry, as well as iron and coal production. The steam engine, invented by James Watt in 1765, was a critical technological breakthrough that fuelled the revolution. The cotton gin, invented by Eli Whitney in 1794, and the spinning jenny, invented by James Hargreaves in 1764, both played important roles in the First Industrial Revolution. Because of these new technologies, mass production and efficiency increased, resulting in a significant increase in output.

The development of new industries such as the automobile, electricity, and oil characterized the Second Industrial Revolution (Engelmen, 2017), which began in the late nineteenth century and lasted until the early twentieth century. During this revolution, new technologies such as the internal combustion engine, the telephone, and the light bulb were introduced. The discovery of oil as a fuel source was also important in the Second Industrial Revolution because it enabled the production of gasoline and other petrochemicals. Consumer goods, such as automobiles and appliances, became more affordable and accessible to the public as they were mass produced.

The Third Industrial Revolution (Roberts, 2015), also known as the Digital Revolution, began in the late twentieth century and continues to the present day. The introduction of new technologies such as the personal computer, the internet, and mobile phones characterized this revolution. The ability to digitize information and instantly communicate it revolutionized the way people communicate and conduct business. New industries such as biotechnology and renewable energy were also developed during the Third Industrial Revolution. This revolution also gave rise to e-commerce, which allowed people to shop from anywhere in the world at any time. Social media platforms, which enable real-time communication with people all over the world, have also played an important role in the Third Industrial Revolution.

Each of the last three industrial revolutions has resulted in significant changes in the way people live, work, and communicate. The First Industrial Revolution saw the shift from manual to machine-based manufacturing, while the Second Industrial Revolution saw the introduction of new industries such as the automobile, electricity, and oil. The Third Industrial Revolution was marked by the introduction of new technologies such as the personal computer, the internet, and mobile phones, which transformed how people communicated and conducted business. The Fourth Industrial Revolution, which is characterized by the convergence of physical, digital, and biological technologies, is currently underway. This revolution is expected to transform industries such as healthcare, transportation, and manufacturing, as well as significantly alter people's working and living environments.

2.1 Fourth Industrial Revolution

Industry 4.0 as explained by by Ryalat (2023) is the name given to the idea of smart factories where machines are complemented by web connectivity and connected to a system that can visualize the entire production chain and make decisions on their own. The trend is toward automation and data sharing in manufacturing technologies including Cyber-Physical Systems (CPS), Internet of Things (IoT), Cloud Computing (CC) and cognitive computing. Industry 4.0 is a transformation that makes it possible to collect and analyse data in all machines, enabling faster, more flexible and more efficient processes for produce higher quality goods at reduced costs. This manufacturing revolution increase productivity, change the economy, foster industrial growth and will change the profile of the workforce, ultimately changing competitiveness of companies and regions.

Although implementing Industry 4.0 in a manufacturing operation may appear to be a hard process for some, there are four principles that should persuade leaders to start the transition. (Spencer, 2021)

1. Interoperability: the ability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of Things (IoT) or the Internet of people (IoP).

2. Information transparency: the transparency provided by information technology Industry 4.0 provides operators with a wealth of useful information necessary to make the right decisions. Interconnectivity allows operators collect vast amounts of data and information from all points in the manufacturing process, which aids functionality and identifies areas who can benefit from innovation and improvements.

3. Technical assistance: firstly, the capacity of the assistance systems to help humans by adding and displaying information in a way comprehensive tool to make informed decisions and solve urgent problems in a short time. Second, the ability of physical cybernetic systems to physically support humans by performing a variety of tasks who are unpleasant, too tiring, or unsafe for their peers of human work.

4. Decentralized decisions: The ability of cyber-physical systems to make decisions for themselves and carry out their tasks with the greatest possible autonomy. Only in the case of exceptions, interferences or conflicting objectives, delegates tasks at a higher level.

2.2 Key technologies

For the advancement of industry 4.0, there must be harmony between all the elements of the industry. Hence, there is a development in every key technology in this revolution. The industries of the future would be incomplete without one another.

2.2.1 Artificial intelligence

Artificial intelligence is a collection of technologies that enable automatic and complex problem solving while mimicking human reasoning. They accomplish this through advanced decision algorithms and learning systems. In other words, artificial intelligences use computers and machines to mimic the human mind's problem-solving and decision-making abilities.

Unlike machine learning or automatic learning, artificial intelligence is not only an algorithm that improves over time, but it is also capable of drawing new conclusions about a data set and thus creating a new algorithm that can adapt.

Today, artificial intelligences can create images of anything you ask them to do, as well as others capable of maintaining a fairly natural conversation, are revolutionizing the worlds of art and technology, respectively.

AI has numerous applications in industry, including real-time prediction and management of operations, maintenance, and remote assistance via expert remote guidance, avoiding unnecessary displacements, and even assisting carriers in predicting arrival times. An artificial intelligence could provide realistic training, real-time interaction, the possibility of repetitions, and risk simulation without danger in the field of training. It would enable marketing to visualize the product in its final environment without the need for a physical product.(Rojek et al., 2023)

According to IBM (2022), AI and machine learning allow manufacturing companies to take full advantage of the volume of information generated not just on the factory floor, but across their business units, and even from partners and third-party sources. AI and machine learning can create insights providing visibility, predictability and automation of operations and business processes. For instance: Industrial machines are prone to breaking down during the production process. Using data collected from these assets can help businesses perform predictive maintenance based on machine learning algorithms, resulting in more uptime and higher efficiency.

However, AIs have limitations and challenges, which are primarily related to privacy and data assurance. On the other hand, it is possible that the results are not entirely natural, as it is mathematics and programming that are at work which means that it could sometimes lead to errors that could occur because they are not perfect machines.

2.2.2 Nanotechnology

Nanotechnology is the manipulation of matter on a nanometric scale, that is, between 1 to 100 nanometres, to transform them and obtain new attributes, such as resistance, durability, driving, lightness, among others. A nanometre is one billionth of a of a meter (1 nm = 10^{-9} m). This technology is capable of precisely manipulating the atoms and molecules for the manufacture of micro-scale products.

This technology is already applied in textile, cosmetic and electronic production. But the nanotechnologies not only offer us the promise of great benefits only in the business, but also regarding human health (medicine) and other fields such as the environment and the space.

For example, in the field of electronics, nanotechnology would make it possible to improve the speed and efficiency of microchips, in addition to reducing their size. In addition, it would allow the development of flexible touch screens. With regard to energy, nanotechnology would allow the solar panels that double the amount of sunlight converted to energy, plus other efficiency improvements in wind power generation.

In short, nanotechnology will change things for the better that were previously unthinkable, so that will generate a revolution within industry 4.0, making processes more efficient and innovative. On the contrary, a very large investment will be needed on the part of companies and governments to develop these new applications.

2.2.3 Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) consists of internet-connected machinery and the advanced analytics platform that processes the data it produces. IIoT devices range from tiny environmental sensors to complex industrial robots. While the word industrial may be a reminder warehouses, shipyards, and factories, the IIoT has potential in various industries, including space.

“For any business that deals with the production or transportation of physical goods, IIoT can create breakthrough operational efficiencies and introduce completely new business models. IIoT technology could be applied in various stages of industries principally in production where machines can self-monitor and predict potential problems, which means less downtime and a higher overall efficiency.” (Munirathinam, 2020, p. 116)

Supply chains that manage inventory by sensors, IIoT technology could take it upon itself to order supplies just before they run out. This decreases the amount of waste produced while holding inventory needed in stock and this frees up employees to concentrate on other tasks.

This technology could simplify and provide a much secure method for environmental control. With sensor-controlled climate control, it will eliminate guesswork and frustration involved in manually changing a structures climate. In addition, the entry points can be monitored and respond quickly to potential threats will increase the security.

2.2.4 Robots

Robotization is not a concept of the distant future. Humans currently live with robots and our coexistence will only grow from now on. A simple smart watch that monitors your health is an example of our coexistence. The idea of robotization is to replace the work that is currently being done by humans. In general, the jobs of a routine, repetitive and codable nature are those that are subject to a greater robotization.

Collaborative robots called cobots are the first iteration before the complete robotization. They the newest type of robots designed to interact with people in a shared work environment. The robots that are intended to work hand-in-hand with humans. These machines focus on repetitive tasks, such as inspection and picking, to help workers focus more on tasks that require problem solving skills. Since they operate alongside people, they work at a more manageable speed and the cobots are also designed to stop immediately when a person contacts them.

An unpopular category of robotics is cloud robotics. Cloud robotics is the combination of robotics and cloud technologies such as cloud computing. In essence, robots are linked to the cloud, allowing them to access cloud services such as massive processing power or storage space. As a result, cloud robotics enables a robot to perform computationally less expensive tasks locally (for example, data collection from sensors) while offloading computationally or storage intensive tasks to the cloud.

2.3 Accelerated adaptation

Recently the world faced a global pandemic known as the Covid-19, it spread at such a rate that the governments across the globe had to impose strict lockdowns and other measures which include closing businesses, banning gathering and restricting travel.

Businesses closed, unemployment rose, and many people faced financial hardship as a result of the lockdowns, which had a significant impact on the global economy but there were some businesses that were thriving, how were those businesses able to do so?

During the pandemic, businesses benefited from various technologies that make up to industry 4.0. Some of these are the resilient supply chain, technologies that enable remote work, technologies that connect different parts of the production process, robotics and predictive analytics. Some examples are the use of robots such as drones and thermal cameras to control the use of masks and temperature body, also for cleaning hospitals and public transport or for the assistance of old people. 3D printing was also used to make material faster for the protection of health workers or even respirators. Big data was used to provide real-time solutions in both health and transportation. Similarly, intelligence artificial was used to predict covid cases and the resources needed to treat them, as well as mobility patterns, detection of foci, calculation of risk factors and it was even key to the creation of vaccines. Broadly speaking, these technologies bring numerous benefits to companies like improvement in efficiency, cost reduction and the continuation of the activity.

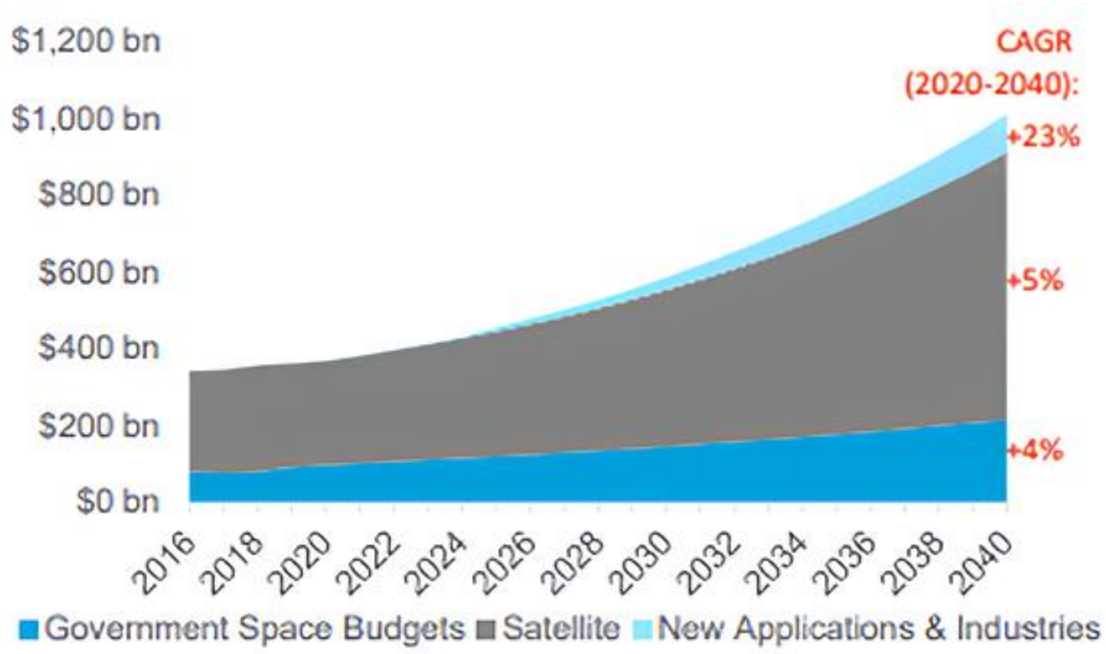
The pandemic has accelerated the process of implementing and developing new technologies in order to adapt to its new environment. There is some parallel between the situation that the pandemic has left the world in and the situation that outer space is in, in terms of isolation, limited resources, and restricted movement. Before delving into the implementation of Industry 4.0 in the space industry, it is critical to first understand the space industry.

3 SPACE INDUSTRY

The space industry appertains to the exploitation, exploration and commercialization of the space. This compromises of production, sale and distribution of goods and services related to the space development.

According to the extensive report by Citi (Mcbain et al., 2022, p. 22), “We estimate the space economy will be worth over $1 trillion in annual sales by 2040 from ~$370 billion in 2020, growing at a ~5% compound annual growth rate (CAGR). We forecast strong growth across the satellite industry, government space budgets, and a flurry of new applications and industries."

Figure 1:Forecast of the space economy.



Source: Citi Research, Satellite Industry Association (2016-20)

With the development of the space industry, there will be a noticeable shift from the satellite sector to different applications such as sustainability with space based solar solutions, space construction, space tourism, space logistics and consumer broadband.

Currently, the space industry across the globe has very few private companies led by billionaires and the industry is dominated by government agencies in wealthy nations. There is an increase in long term investors, beyond billionaires and government agencies. Despite its growth potential, the space economy is still in its early stages and faces significant challenges.

3.1 Limitations of the space industry

The high cost of space exploration and development is a major limitation of the space industry. A single space shuttle mission can cost between $500 million and $1 billion to develop and launch, according to a National Research Council report.(Council, 2008)

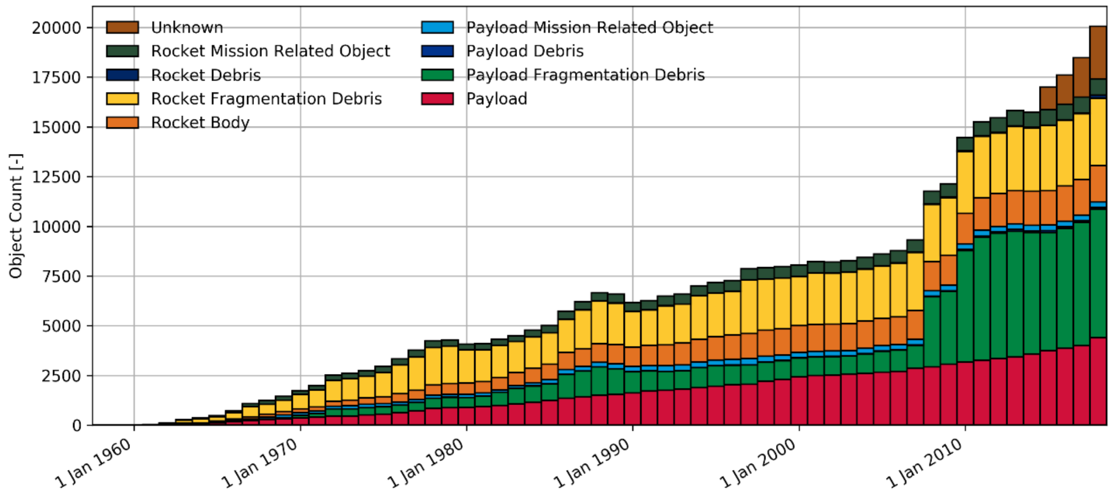
Another constraint of the space industry is limited access to space. Only a few countries currently have the capability of launching rockets and sending satellites into space. The number of countries and organizations that can participate in space exploration and development is thus limited.

“Space exploration and development are inherently dangerous endeavours. There is always the possibility of equipment failure, accidents, and human life loss. The Challenger and Columbia space shuttle disasters, for example, resulted in the deaths of 14 astronauts.” (“The Space Shuttle Disasters and Quality Management - QMS,” 2018)

Space resources are limited, and the cost of transporting resources from Earth to space is prohibitively expensive. This restricts the ability to build permanent human settlements or conduct long-term space missions.(Green & Kleinhenz, 2019)

The space industry produces a lot of debris, such as discarded rocket stages and defunct satellites. This debris endangers operational spacecraft and contributes to the accumulation of space debris, which can have a domino effect on the space environment.

Figure 2: Count evolution by object type including debris.



Source: European Space Agency (2022)

According to the European Space Agency (2022): More than 560 in-orbit fragmentation events have been recorded since 1961. Only 7 events were associated with collisions and most of the current events were explosions of spacecraft and upper stages. The main cause of in orbit explosions is related to residual fuel that remains in tanks or fuel lines, or other remaining energy sources, that remain on board once a rocket stage or satellite has been discarded in Earth orbit. Over time, the harsh space environment can reduce the mechanical integrity of external and internal parts, leading to leaks and/or mixing of fuel components, which could trigger self-ignition. The resulting explosion can destroy the object and spread its mass across numerous fragments with a wide spectrum of masses and imparted velocities. It is however expected that in the future collisions will become the dominant source of space debris.

Space exploration and development can have a negative impact on the environment. Spacecraft launch and operation can result in greenhouse gas emissions and other pollutants that contribute to climate change according to the Aeronautics & Administration (2019).

Finally, the space industry is constrained by the technology available for space exploration and development. The ability to explore deep space or establish permanent human settlements on other planets is currently limited by current technology. Industry 4.0 technologies may be able to address these issues and accelerate the deep space exploration.

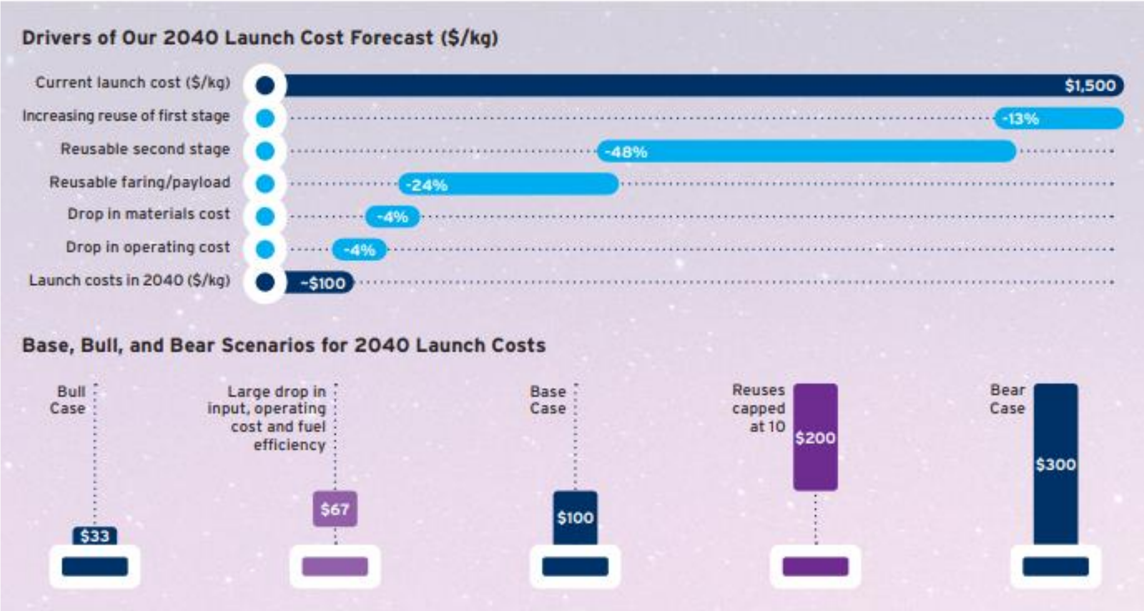
3.2 Key enablers

In the past, launching rockets has been a costly process, frequently costing in the hundreds of millions of dollars per launch. Yet, there have been several advances in recent years that indicate launch prices may drop dramatically soon, opening the door for a booming space industry. The cost of sending payloads into space is one of the essential elements in making space exploration and usage economically viable.

Using reusable rocket technology is an important enabler. The first stage of SpaceX's Falcon 9 rockets, for instance, can now be landed and reused, significantly lowering the cost of each launch. With its New Shepard and New Glenn rockets, Blue Origin, a company founded by Amazon CEO Jeff Bezos, is also advancing reusable rocket technology.

Enhancing the performance of rocket engines is another technique to reduce launch costs. The amount of fuel required to reach orbit is decreased by the design of more recent engines, such SpaceX's Raptor engine and Blue Origin's BE-4 engine, which are more powerful and efficient.

Figure 3: 2040 Launch cost forecasts in different scenarios



Source: Citi Research, Satellite Industry Association (2016-20)

According to the figure 2 shown above, regardless of the scenarios the launch costs will be dropped. In a bull case the cost will drop to $33 per kilo meanwhile in a bear case the price would reach $300 which is still at $1200 decrease from its current price of $1500.

Costs are also falling as a result of heightened competition in the commercial launch sector. With competitive pricing, more businesses are entering the market to provide launch services. This has caused a movement away from launches supported by the government and toward launches by the private sector.

Robotic and electronic system developments will make it possible to explore and carry out tasks that are either too unsafe or impossible for people to do. This covers tasks related to investigation, assembly, building, maintenance, and servicing. Robots have been employed in space for decades (such as the Rosetta space mission and Mars Exploration Rovers), but when combined with increasingly sophisticated autonomous and intelligent systems, they enable greater exploration and lower cost and risk.(Matthew Hutson, 2017)

3.3 Trends in the space sector

The space sector is currently one of the most rapidly evolving fields, with exciting developments taking place all over the world. Advances in satellite technology, the rise of private space companies, and increased demand for Earth observation data are a few of the most significant. The space sector is constantly evolving, from increased private investment and innovation to increased international collaboration. Furthermore, there is an increase in interest in space exploration, particularly among national space agencies, as well as potential new markets in space tourism and asteroid mining. These trends are significantly influencing the industry's direction.

One of the most significant trends in the space sector is the increase in private investment and innovation according to Klebnikov (2019), private companies such as SpaceX, Blue Origin, and Virgin Galactic are pushing the boundaries of space exploration. These companies, which have received significant investment from both private and public sources, are working on projects such as reusable rockets, space tourism, and satellite internet, among others. According to Forbes, private investment in the space industry has increased in recent years, with funding for space startups alone reaching $5.8 billion in 2020.

As reported on Space.com (Cross, 2019): another significant trend in the space sector is increased international cooperation. Countries are collaborating on space projects more than ever before, with joint efforts such as the International Space Station (ISS) demonstrating the benefits of international cooperation. The International Space Station (ISS) is a joint project of the United States, Russia, Japan, Europe, and Canada that has been continuously inhabited by astronauts since 2000. International collaboration, which allows countries to share knowledge, resources, and costs, is regarded as critical to the future of space exploration. According to a Space.com report, the trend toward increased international cooperation in space is expected to continue, with new partnerships and collaborations being formed on a regular basis.

According to the program overview (Nasa, 2020) the exploration of the Moon and Mars is another important trend in the space industry. NASA intends to return astronauts to the Moon by 2024 as part of its Artemis program, which aims to establish a long-term human presence on the Moon and eventually send humans to Mars. Meanwhile, SpaceX has ambitious plans to send humans to Mars in the near future, with the ultimate goal of establishing a self-sustaining city on Mars. These missions will necessitate significant technological advancements and the collaboration of multiple countries and private companies. NASA has already begun testing new Artemis technologies, such as the Space Launch System rocket and the Orion spacecraft.

Finally, in the space sector, the use of artificial intelligence (AI) and machine learning is becoming increasingly important. AI is being used to improve satellite imagery, forecast space weather, and develop autonomous spacecraft systems. NASA is a pioneer in AI research in the space sector, with projects like the Autonomous Sciencecraft Experiment (ASE) investigating the use of AI in space exploration.(Hille, 2022)

It has become evident that space organisations are beginning to implement the technologies of industry 4.0 in various ways. Given the benefits that Industry 4.0 technologies can bring to space exploration and research, this is not surprising. For example, the use of artificial intelligence and machine learning algorithms can assist space organizations in more efficiently processing and analysing large amounts of data, allowing for better decision-making and faster discoveries. The incorporation of Industry 4.0 technologies into space exploration and research has the potential to revolutionize the field and result in significant advances. As a result, how space organizations continue to adopt and adapt these technologies in the coming years will be interesting to watch.

4. DIGITALISATION OF THE SPACE INDUSTRY

The use of Industry 4.0 technologies to improve and optimize various aspects of space-related activities, such as satellite design and manufacturing, launch operations, and mission control, is referred to as the digitalization of the space industry. The ability to gather, process, and analyse massive amounts of data in real time is one of the primary advantages of digitalization in the space industry.

Furthermore, digitalization has the potential to improve collaboration and communication among various teams and organizations involved in space-related activities. This can result in more rapid innovation and more effective problem-solving.

4.1 Artificially Intelligent Space industry

AI is transforming the space industry in a variety of ways, from satellite data analysis to mission planning, robotics to autonomy. The space industry has always been a forerunner in the use of cutting-edge technologies, and artificial intelligence is the latest addition to that list. AI implementation in the space industry has resulted in significant process improvements, cost savings, and enhanced capabilities.

4.1.1 AI in mission planning

Artificial intelligence (AI) is being used in mission planning to optimize spacecraft trajectories and reduce mission costs. AI algorithms can calculate the best trajectory for a spacecraft based on factors like gravitational forces, fuel consumption, and mission objectives. This can result in significant cost savings by reducing the amount of fuel required for a mission and shortening the duration of the mission.

NASA's Deep Space Network (DSN), for example, employs AI algorithms to optimize communication between Earth and spacecraft. The DSN employs a combination of artificial intelligence and machine learning to predict the best times to communicate with spacecraft based on their position and signal strength. The DSN has been able to reduce the amount of time required for communication, lowering costs and increasing the amount of data that can be transmitted as a result (Johnston & Wyatt, 2017).

4.1.2 AI in satellite data analysis

One of the most important applications of AI in the space industry is satellite data analysis. Satellites collect massive amounts of data, such as images of the Earth, climate data, and communication data. For human analysts, the sheer volume of data generated can be overwhelming. AI can be used to automate satellite data analysis, such as detecting changes in the environment, tracking weather patterns, and detecting anomalies in communication data.

4.1.3 AI in robotics and autonomy

AI is also influencing how robots are used in space missions. Robots are widely used in space exploration for tasks such as structure assembly, spacecraft repair, and sample collection. AI can be used to enhance these robots' autonomy, allowing them to operate more efficiently and effectively in space.

NASA's Mars rovers are outfitted with artificial intelligence algorithms that allow them to operate autonomously. The rovers can make decisions based on the data they collect, such as which rocks to analyse and which samples to collect, thanks to the AI algorithms. This increases the rovers' efficiency by reducing the need for human intervention.

4.1.4 AI in space mining

Space mining is another area where AI is expected to have a significant impact. Mining asteroids and other celestial bodies for resources like metals, water, and helium-3 has the potential to transform the space industry and allow for long-term space exploration.

Mining in space, on the other hand, is a complex and difficult task that necessitates sophisticated technologies and strategies.

Artificial intelligence (AI) can be used to improve the efficiency and safety of space mining operations. For example, based on their composition and proximity to Earth, AI algorithms can be used to identify the most promising asteroids for mining. Mining robots and equipment can also be controlled using AI, allowing them to operate autonomously and adapt to changing conditions.

4.1.5 AI in space debris management

Space debris is becoming a major issue, with thousands of pieces of debris orbiting the Earth and endangering satellites and spacecraft. Artificial intelligence (AI) can be used to track and manage space debris, lowering the risk of collisions and ensuring the safety of space assets. AI algorithms can be used to predict the trajectory of space debris, allowing operators to avoid collisions. AI can also be used to create more efficient and effective space debris removal strategies, such as the use of robotic arms and nets to capture and remove debris.

4.1.6 AI in space manufacturing

Artificial intelligence is expected to have a significant impact on space manufacturing. By allowing astronauts to produce tools, spare parts, and even habitats in space, manufacturing in space has the potential to reduce the cost and complexity of space missions. AI can be used to optimize the manufacturing process, allowing astronauts to produce high-quality products with minimal resources. AI algorithms, for example, can be used to design and optimize 3D-printed parts, reducing the time and resources required to produce them.

4.2 Nanotech applications in the space industry

Nanotechnology has created a new frontier in space exploration. Nanotechnology, which involves manipulating matter at the atomic or molecular level, has a wide range of potential applications in the space industry. In the space industry, nanotechnology has been used in a variety of ways, including the development of nanomaterials, sensors, and devices. This essay will discuss how nanotechnology is being used in the space industry and how it has improved the processes.

4.2.1 Nanomaterials in space

Nanomaterials have unique properties that make them appealing for use in space. Carbon nanotubes, for example, are a type of nanomaterial that is strong, lightweight, and has a high thermal conductivity. These characteristics make them suitable for space applications, such as lightweight and strong space structures like telescopes and satellites. Carbon nanotubes are also being used to create lightweight, flexible solar cells that can power space missions. Other types of nanomaterials, such as nanocomposites, are being developed to create lightweight, strong materials for spacecraft construction.

4.2.2 Nanotechnology in Sensors and Devices

Nanotechnology has also been used in the development of sensors and space-related devices. NASA, for example, has developed a nano sensor capable of detecting and measuring the amount of hydrogen in space. This technology is significant because hydrogen can be used as rocket fuel, and measuring hydrogen in space can aid in the development of more efficient rocket engines. Other nanotechnology-based sensors being developed include biosensors for monitoring astronaut health and gas sensors for detecting hazardous gases in spacecraft.

4.3 IIoT in Space

Industrial Internet of Things is being integrated in the space sector which includes satellites, rockets, and space exploration vehicles, to improve their operational efficiency and safety.

4.3.1 Launch systems using IIoT

Rocket and other space vehicle launches are high-risk operations that require precision and dependability. The IIoT has been used to improve the safety and efficiency of launch systems. Sensors can monitor the health of launch systems, such as fuel levels, temperature, and pressure, and send the information to ground control. This information can be used to identify potential problems before they become critical, lowering the risk of launch failures.

Nanotechnology has provided solutions to some of space propulsion's challenges, such as reducing spacecraft weight and increasing fuel efficiency. Nanocatalysts, for example, have been developed by researchers to improve the efficiency of rocket engines, allowing them to burn fuel more efficiently and produce more thrust. Furthermore, nanotechnology has been used to create lightweight materials that can reduce the weight of spacecraft, making them more fuel-efficient and easier to launch into space.

4.3.2 Space Exploration Vehicles using IIoT

Other planets and moons in our solar system are explored using space exploration vehicles such as rovers and landers. To reach their destinations safely, these vehicles require precise control and navigation. The IIoT has been used to improve the navigation and control systems of space exploration vehicles. Sensors on these vehicles can collect and transmit data on their position, velocity, and orientation to ground control. This information can be used to adjust the vehicle's trajectory and ensure it arrives safely at its destination.

4.4 Robotization of the space industry

Over the years, the use of robots in the space industry has steadily increased. Robots have played an important role in space exploration, allowing space missions to operate more efficiently and at a lower cost.

4.4.1 Exploration by robots

As stated in the 2020 mission perseverance report (NASA, 2020), since the 1960s, robots have played an important role in space exploration. They have allowed scientists to explore planets and moons that would be too dangerous or too far away for humans to visit. The Mars rover is one of the most successful space exploration robots. Spirit, Opportunity, and Curiosity are among the Mars rovers launched by NASA. These rovers have collected data and samples from the Martian surface, revealing important information about the planet's geology, atmosphere, and potential for life. The Perseverance rover, which will be launched in 2020, is the most recent and technologically advanced Mars rover to date. It is outfitted with a variety of scientific instruments, including a helicopter drone that can explore areas that the rover cannot reach.

4.4.2 Satellite deployment by robots

Satellites are also deployed and maintained using robots. The process of deploying a satellite into orbit can be risky and costly, necessitating the coordination of a large team of engineers and technicians. This process as mentioned by (Grumman Company, 2020) has been automated by robots, lowering the cost and risk of satellite deployment. Northrop Grumman's MEV-1 (Mission Extension Vehicle) is one example. The MEV-1 is a satellite servicing robot capable of docking with orbiting satellites and providing propulsion, power, and other services.

4.4.3 Maintenance by robots

In addition, robots are used to maintain and repair satellites in orbit. These robots can replace solar panels, repairing faulty hardware, and refuelling satellites. NASA's Robotic Refuelling Mission (RRM) is an example of such a robot. The RRM is a satellite servicing testbed that has been used to demonstrate the viability of robotic satellite refuelling (Robotic Refueling Mission 3 | NASA’s Exploration & In-Space Services, 2019).

4.4.4 Manufacturing by robots

Robots are also used in the space where there is no gravity, it is possible to create materials with unique properties that are not possible on Earth. Robots are being developed to build structures and materials in space, lowering the cost and time required to transport materials from Earth. The European Space Agency's MELT project is one example of a space manufacturing robot. The robot is intended to fabricate metal structures using a technique known as metal additive manufacturing (ESA - MELT 3D Printer, 2018).

4.4.5 Mining by robots

Space mining is another area where robots are being used. Mining resources like water, platinum, and other metals on the moon and asteroids is an exciting prospect for the space industry. Mining robots are being developed to reduce the cost and risk of sending humans to mine these resources. The European Space Agency's PROSPECT project is one example of a space mining robot. The robot is intended to collect samples from the moon's and asteroids' surfaces and analyse them for potential mining opportunities (ESA - Exploration of the Moon - About PROSPECT, 2019).

4.5 Process improvement

While AI implementation is expected to result in further process improvements, cost savings, and enhanced capabilities. AI algorithms are expected to play a critical role in the next generation of space exploration missions aimed at establishing a long-term human presence on the moon.

In many ways, nanotechnology has improved processes in the space industry. For example, the use of nanomaterials in spacecraft construction has made spacecraft lighter and stronger, potentially lowering the cost of launching them into space. Nano sensors have also improved processes in the space industry by providing more accurate and efficient monitoring of spacecraft and equipment. This can help to prevent failures and extend the lifespan of spacecraft.

The implementation of IIoT in the space industry has provided several benefits. IIoT allows space operators to remotely monitor and control their systems, reducing the need for physical maintenance and repair. This has reduced downtime and service interruptions, improving space operations efficiency. IIoT sensors can also gather data on system performance, which can be used to improve processes and cut waste.

The space industry is a high-risk environment that necessitates accuracy and dependability. The IIoT has increased safety by allowing space operators to remotely monitor and control their systems, reducing the risk of human error. In addition, IIoT sensors can collect data on system health, which can be used to identify potential issues before they become critical, lowering the risk of accidents and failures.

The IIoT has increased the reliability of space systems by allowing space operators to remotely monitor and control their systems. Data collected by IIoT sensors on system health can be used to predict and prevent system failures. This has reduced the likelihood of costly downtime and service interruptions, thereby improving the dependability of space operations.

Despite that, the future of AI in the space industry appears bright. What are the benefits to the society and economy from the next generation of technologies being integrated into space missions and programs that leads to such enthusiasm?

4. BENEFITS TO THE ECONOMY

The implementation of industry 4.0 in the space industry is ought to bring major benefits which would reshape the economy in a manner that will catapult the GDP with noticeable changes in the employment and income.

4.1 Economy

Several studies have been conducted to estimate the benefits of Industry 4.0 to the economy and the world. This includes studies aimed at estimating the benefits of specific technologies as well as studies aimed at quantifying the overall benefit of Industry 4.0.

Table 1:Estimates of the economic impact of robotics, automation, and digitalisation

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
Accenture (2017). Industrial Digitalisation Review Benefits Analysis (Made Smarter Review (2017	UK	Manufacturing	Industry 4.0	Value at stake estimated to be approximately £455 billion over the next decade
		Construction		Value at stake estimated to be approximately £89 billion over the next decade
		Food and drink		Value at stake estimated to be approximately £56 billion over the next decade
		Pharmaceuticals		Value at stake estimated to be approximately £22 billion over the next decade
		Aerospace		Value at stake estimated to be approximately £18 billion over the next decade
Made Smarter Review (2017). Working group report on jobs and the economy	UK	Total economy	Industry 4.0	Net gain of 175,000 jobs.
Made Smarter Review (2017). Sustainability working group report	UK	Total economy	Industry 4.0	Reduction in CO2 emissions by 4.5 percent.
Made Smarter Review: Industrial Digitalisation 2017	UK	Total economy	Industry 4.0	Improve industrial productivity by more than 25% by 2025.
BCG (2017). Is UK Industry ready for the Fourth Industrial Revolution	UK	Manufacturing	Industry 4.0	Industrial efficiency gains of 25% and increased manufacturing sector growth rates of 1.5-3 percent, delivering growth of around 0.5% of GDP annually.
BCG (n.d.), The Benefits of Industry 4.0.	UK	Automotive	Industry 4.0	10-20% productivity increase, measured by conversion costs
		Food and beverage		10-20% productivity increase, measured by conversion costs
		Components		20-30% productivity increase, measured by conversion costs
		Machinery		10-20% productivity increase, measured by conversion costs
		Other manufacturing		20-30% productivity increase, measured by conversion costs

Accenture (2015). The Growth GameChanger: How the Industrial Internet of Things can drive progress and prosperit	World	Total economy	Industrial Internet of Things	Add $10.6 trillion to the world economy by 2030, given current investment levels. The estimate could rise to up to $14.2 trillion with greater investment and the enactment of key measures to absorb IIoT technologies.
KPMG (2016). The Digitalisation of the UK Automotive Industry	UK	Automotive	Industry 4.0	Fully embracing digitalisation could yield gains of £6.9 billion every year by 2035 for the automotive sector, and a benefit to the total economy of around £74 billion cumulatively by 2035.
Barclays (n.d.). Future-proofing UK manufacturing	UK	Manufacturing	Automation / robotic equipment	Estimated the value added to the UK by the manufacturing sector of a moderate increase in investment in automation of £1.24 billion to be £60.5 billion over the next decade (direct effects), and a further £2.5 billion a year by 2020 and £3.9 billion a year by 2025 (indirect effects).
McKinsey (2013). Disruptive technologies: Advances that will transform life, business, and the global economy	World	Total economy	Internet of Things	Potential direct economic impact of $2.7 to $6.2 trillion per annum in 2025
			Advanced Robotics	Potential direct economic impact of $1.7 to $4.5 trillion per annum in 2025.
			3D Printing	Potential direct economic impact of $0.2 to $0.6 trillion per annum in 2025
McKinsey (2018). Disruptive force in the industrial sectors	Global	Total economy	Artificial Intelligence	Market size for AI estimated to grow at an annual rate of 50% - 60% from $2 billion in 2016 to $130 billion in 2025.
			Connected devices	Connected devices estimated to growth at an annual rate of 15% - 20% from 18 billion units in 2016 to 75 billion units in 2025.
			Cybersecurity	Market size for cybersecurity estimated to grow at an annual rate of 5% - 10% from $96 billion in 2016 to $210 billion in 2025
Special Interest Group Robotics and Autonomous Systems (2014). RAS 2020 Robotics and Autonomous Systems	UK	Non-military	Robotics and Autonomous Systems	Estimated market for non-military Robotics and Autonomous Systems (RAS) products and technologies of £70 billion by 2020-2025, impacting 15% of GVA (£218 billion) on the UK economy, and a potential to raise manufacturing sector productivity by up to 22%, generating a long-term employment increase of up to 7%, if current RAS technology was optimised.
Lockheed Martin (n.d.). 3D Printing 101	Firm level	Satellite production	3D Printing	Utilising 3D titanium printing in satellite production can reduce cycle time by 43% and yield a cost reduction of 48% compared to traditional satellite production.
PWC (2017). Sizing the prize – What's the real value of AI for your business and how can you capitalise?	World	Total economy	Artificial intelligence	Contribution of up to £15.7 trillion in 2030 ($6.6 trillion from increased productivity and $9.1 trillion from consumption side-effects)

Brynjolfsson, Hitt and Kim (2011). Strength in Numbers: How Does DataDriven Decisionmaking Affect Firm Performance?	US	Firm level	Data-driven decision making	Firms that adopt data-driven decision making have 5% - 6% higher output and productivity than expected, given their investments in other information and communication technology.
Barua, Mani and Mukherjee (2013). Measuring the Business Impacts of Effective Data	Fortune 1000 firms	Firm level	Data-driven decision making	A 10% increase in the usability of data - presenting data more concisely and consistently across company platforms (e.g. laptops) - is associated with a 14% increase in labour productivity on average
Citigroup-Oxford (2015). TECHNOLOGY AT WORK: The Future of Innovation and Employment	Firm level	Mining	Autonomous drill rigs	Shifting to autonomous drill rigs can increase productivity by 30% - 60%.
Meech, J. (2012). Simulation of Autonomous Mine Haulage Trucks	Firm level	Mining	Autonomous mine haulage trucks	Shifting to autonomous mine haulage trucks is associated with a 15-20% increase in output, a 10-15% decrease in fuel consumption, and an 8% reduction in maintenance costs.
Dave Clark, Senior Vice President of Worldwide Operations and Customer Service at Amazon. Cited by: CitigroupOxford (2017). TECHNOLOGY AT WORK v3.0: Automating e-Commerce from Click to Pick to Door	Firm level	e-Commerce	Autonomous warehouse robots	Automated picking and packing processes, utilising Kiva robots, reduce operating expenses of Amazon’s fulfilment centres by ~20%
Evans and Anninziata (2012). Industrial Internet: Pushing the Boundaries of Minds and Machines	US	Total economy	Industrial Internet	If the industrial internet could achieve a productivity growth differential similar to the internet revolution (3.1%), it could generate average income gains of $20,000 by 2030, approximately 40% of current US GDP per capita. A more conservative productivity growth of 2.6% would still deliver average income gains equivalent to 25% of US GDP per capita.
	Global	Health care		Deployment of the industrial internet can drive health-care costs down by roughly 25% - equivalent to approximately $100 billion in savings per year

		Commercial aviation		Cost reductions of 1% from better flight planning and operational changes, brought about by the industrial internet, could save the global commercial airline business nearly $2 billion in fuel costs per year, or approximately $30 billion over 15 years. A 1% reduction in capital expenditures, brought about by the industrial internet, could result in cost savings of $1.3 billion per year, or approximately $29 billion over 15 years. A 1% improvement in maintenance efficiency due to the industrial internet could reduce commercial jet engine maintenance costs by $250 million.
		Rail transportation		A 1% reduction in rail operations systems inefficiencies, brought about by the industrial internet, would save about $1.8 billion per or, or approximately $27 billion over 15 years.
		Power production		Improvements in country-level average gas generation efficiency of 1%, due to the industrial internet, would reduce fuel spending by more than $3 billion in 2015 and $4.4 billion in 2020, or approximately $66 billion over a 15 year period.
		Oil & Gas Development and Delivery		An additional 1% reduction in capital expenditure, due to the industrial internet, would translate into savings of $6 billion per year or $90 billion over 15 years
Vodafone (2017). IoT Barometer 2017/18	World	Firm level	Internet of Things	Among industrial adopters, the Internet of Things increased revenue by 19% on average and cut costs by 16% on average.

Source: London Economics (2019)

The value at stake for the UK manufacturing industry and aerospace over the next decade is predicted to be £455 billion and £18 billion, respectively, according to the Made Smarter Review (Made Smarter Review, 2017). Furthermore, the analysis indicates that the overall UK economy might benefit from a net increase of 175,000 employment and a 4.5 percent reduction in CO_2 emissions as a result of Industry 4.0. Furthermore, according to the research, industrial digitalization might boost industrial productivity by more than 25% by 2025.

BCG's report (Boston Consulting Group, 2017) suggests that Industry 4.0 could lead to industrial efficiency gains of 25% and increased manufacturing sector growth rates of 1.5-3 percent, delivering growth of around 0.5% of GDP annually in the UK. In terms of sectoral coverage, BCG's report indicates that the automotive, food and beverage, components, machinery, and other manufacturing sectors could experience productivity increases ranging from 10-30%, measured by conversion costs, through Industry 4.0 adoption.

According to KPMG's (KPMG UK, 2016) research on the digitalization of the UK automotive industry, fully adopting digitalization could result in annual gains of £6.9 billion for the automotive sector and a cumulative benefit to the economy of roughly £74 billion by 2035.

According to Barclays (Barclays, 2016), the value added to the UK by the manufacturing sector of a moderate increase in automation investment would be £1.24 billion, resulting in a total benefit of £60.5 billion over the next decade (direct effects), and an additional £2.5 billion a year by 2020 and £3.9 billion a year by 2025 (indirect effects).

The Internet of Things has the potential to have a direct economic impact of $2.7 to $6.2 trillion per year in 2025, while the market for artificial intelligence is expected to increase from $2 billion in 2016 to $130 billion in 2025. Connected devices are predicted to increase at a 15% - 20% yearly rate from 18 billion units in 2016 to 75 billion units in 2025.

Data-driven decision making has been proven to raise output and productivity by 5% - 6% beyond projected levels at the company level, while a 10% increase in data usability can lead to a 14% gain in labour productivity. In the mining business, the deployment of autonomous drill rigs can enhance productivity by 30% to 60%.

If the Industrial Internet achieves a productivity growth differential comparable to the Internet revolution, it has the potential to provide average income gains of $20,000 by 2030 and reduce healthcare expenses by around 25%, equating to nearly $100 billion in annual savings.

The Industrial Internet can also save money in the commercial aircraft, rail transportation, power generation, and oil and gas development and delivery industries by enhancing flight planning, decreasing operating inefficiencies, increasing maintenance efficiency, and lowering fuel costs.

Overall, disruptive technologies are projected to have a substantial impact on the economy and enterprises, with the ability to boost productivity and create new growth prospects.

4.2 Employment

Industry 4.0 implementation in the space industry is likely to have a significant impact on jobs. The increasing use of automation, data exchange, and artificial intelligence in manufacturing and space industry may increase efficiency and reduce costs, but they may also result in job displacement as some tasks previously performed by humans are automated.

Automation is one of the primary ways that Industry 4.0 technologies are expected to impact jobs in the space industry. In some cases, the use of robotics and autonomous systems in space exploration, manufacturing, and maintenance tasks may reduce the need for human labour and astronauts. Tasks like satellite assembly, testing, and launch operations, for example, could potentially be automated, reducing the need for human labour and increasing efficiency (Sorells, 2018).

However, in the space industry, automation is unlikely to completely replace human labour. Highly skilled workers will still be required to design, build, and maintain these systems, as well as to perform tasks that cannot be easily automated. Furthermore, the adoption of Industry 4.0 technologies is expected to generate new job opportunities in fields such as data analysis, software engineering, and robotics. It may lead to increased demand for space-related products and services which in turn would create new job opportunities in fields like satellite communications, earth observation, and space tourism.

The use of advanced materials and additive manufacturing technologies is another way that Industry 4.0 is expected to impact jobs in the space industry. These technologies may enable the development of lighter, stronger, and more complex spacecraft and space systems. While this may reduce the need for some traditional manufacturing jobs, it may also open up new opportunities for workers skilled in materials science and 3D printing.

Space missions are turning out to be less risky from a launch perspective, the environment in outer space still remains unsafe for humans. Robots can be used for spacecraft and space station maintenance and repairs, reducing the need for spacewalks and exposure to the hazardous space environment. 3D printing technology can be used in space to produce spare parts, tools, and equipment, reducing the need for resupply missions, and lowering the risks associated with transportation and logistics. Hence, it would not be necessary to transport labours in numerous amounts for construction, maintenance, and demolition purposes.

According to (Made Smarter Review, 2017), the positive impact of IDTs (Industrial Digital Technologies) on the UK economy over the next decade could be as high as £455 billion for UK manufacturing, increasing manufacturing sector growth between 1.5 and 3 percent per annum. The effect: a conservative estimated net gain of 175,000 jobs throughout the economy and a reduction in CO2 emissions by 4.5 percent.6 Overall, from the data and evidence collated, we are confident that IDTs can improve industrial productivity by more than 25 percent.

The implementation of Industry 4.0 in the space industry is likely to have an impact on jobs in both positive and negative ways. There is the potential to result in a net gain of jobs in the space industry. Workers will need to develop the skills needed to adapt to the changing landscape of the space industry.

4.3 Income

Industry 4.0 technology integration is set to revolutionize the space industry. The profit margins will grow substantially primarily due to the increasing revenue and the decreasing costs. This increase in profit margin could translate to increased salary or bonuses for employees.

The use of IoT, AI, and robotics in space exploration and research will boost the industry's productivity and efficiency, which in turn will reduce the need for human intervention, saving space agencies money. AI and robotics in the manufacturing process will reduce production time and cost. The reduction in manufacturing costs will also result in lower prices for consumers, which will increase demand for space equipment and services. Manufacturing will become more efficient and error-free, resulting in a higher-quality product. The revenue generated by the space industry will rise as a result.

For an extended period in the future, there may be a shortage of highly skilled labour. This is likely due to a variety of factors, including population aging, changes in the education system, and technological advancements. As a result, major corporations will struggle to find enough skilled workers to meet their needs. They will offer lucrative incentives such as signing bonuses, high salaries, and other perks to attract the few available skilled workers.

Furthermore, as competition for skilled labour grows, businesses will need to offer even more competitive compensation packages to attract and retain employees. This will most likely be paid for by eliminating low-skilled labour and reallocating budget to attract and retain skilled workers. It is crucial that workers develop their skills to the dynamic environment to prevent losing their jobs.

4.4 Sustainability

The introduction of Industry 4.0 is projected to have a substantial impact on the space industry's sustainability.

Reduced environmental effect of space exploration is one of the most significant ways that sector 4.0 can improve the sustainability of the space sector. The space industry has a substantial environmental impact, especially in terms of greenhouse gas emissions from rocket launches. According to Space X launch report assessment(*Space Launch Report: SpaceX Falcon 9 v1.2 Data Sheet*, 2018), a single rocket launch can emit 116 tonnes of carbon dioxide in 165 seconds. However, by optimizing launch trajectories, lowering fuel consumption, and boosting rocket engine performance, Industry 4.0 technologies can assist reduce the carbon footprint of space exploration.

AI can be used to optimize launch trajectories, reducing the quantity of fuel required for a mission. AI algorithms can assist cut fuel usage and thus carbon emissions by estimating the most efficient course for a flight. Furthermore, Industry 4.0 technologies, such as 3D printing and sophisticated materials, can be leveraged to construct more efficient rocket engines, reducing the environmental impact of space travel even further.

Another way sector 4.0 might increase space sector sustainability is by enabling more effective recycling and reuse of space debris. The amount of space debris in orbit around the Earth is a major source of concern for the space industry, as it threatens present and future spacecraft. It is conceivable to develop more efficient means of tracking, catching, and repurposing space debris by utilizing Industry 4.0 technology such as robotics and

AI. Robots equipped with AI algorithms, for example, can be used to identify and gather trash, which can then be reused or recycled in future missions.

Furthermore, Industry 4.0 can assist improve the space industry's sustainability by enabling more efficient use of resources in space. The development of space-based industry, mining, and agriculture could minimize dependency on Earth's resources while also assisting in the long-term development of space. It is possible to maximize resource usage in space by applying AI and other Industry 4.0 technologies, decreasing waste, and enhancing efficiency.

Industry 4.0 can help support the sustainable development of space by minimizing the environmental impact of space exploration, enabling more effective recycling and reuse of space debris, boosting resource usage in space, and enabling more sustainable space tourism.

5. ETHICS

As the space industry evolves and becomes more advanced, ethical issues arise that must be addressed.

Automation and job displacement are two major ethical issues associated with the implementation of Industry 4.0 in the space industry. As more manufacturing and production processes become automated, many jobs are at risk of becoming obsolete, resulting in widespread job loss and economic disruption. This can have serious social and economic ramifications, especially for low-skilled workers who may lack the necessary skills to transition into new jobs. As a result, it is critical that governments and businesses address these concerns by investing in education and training programs that assist workers in developing the skills required to adapt to new technologies and industries.

Artificial intelligence (AI) is a critical component of Industry 4.0, with the potential to completely transform manufacturing and production processes. However, there is concern that AI systems may become biased(Stahl, 2021), resulting in discrimination and inequality. This is especially true in hiring and recruitment, where AI systems may be programmed with biased algorithms that favour certain groups over others. To address this issue, AI systems must be created in a transparent and ethical manner, with a focus on fairness and inclusivity.

Cybersecurity is a major ethical issue. As more devices connect to the internet, there is a risk that they will be hacked or compromised, resulting in data breaches and other cyberattacks. Companies must therefore take steps to ensure the security of their systems and devices, as well as the implementation of robust cybersecurity measures to protect against cyber threats.(Avdibasic et al., 2022)

The exploitation and ownership of resources is another ethical issue associated with the space industry. As space exploration and exploitation progress, there is concern that companies and governments will compete for resources such as rare metals and minerals, resulting in conflicts and resource exploitation. There is also the issue of who owns the resources found in space. As a result, it is critical that international regulations and agreements are developed to ensure that space resources are used responsibly.

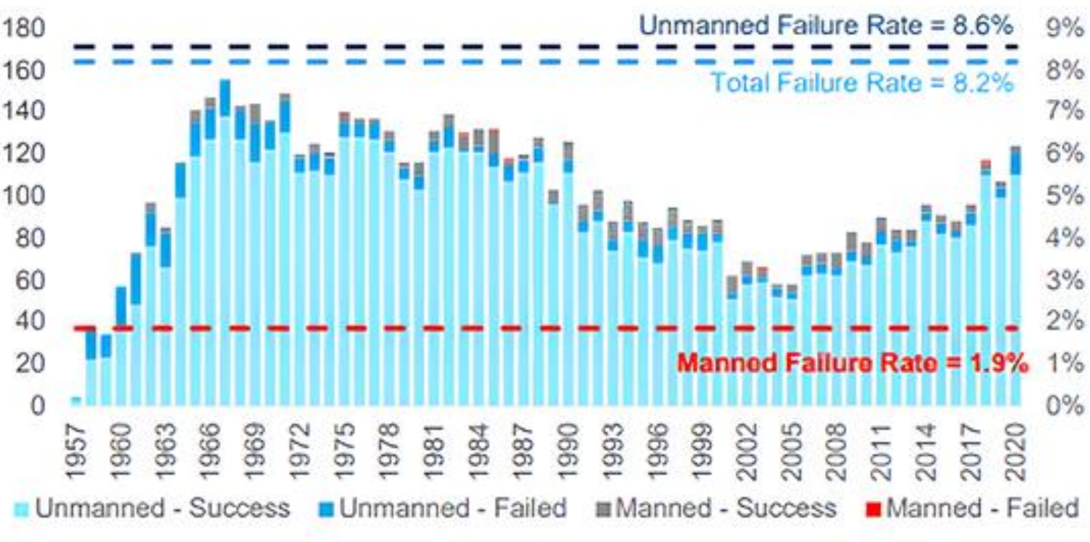
7. CHALLENGES FACED

The space industry faces several challenges that stagnate its growth and demotivate private investors who will lead the growing industry.

Due to the history of space program delays, the capital expenditures required for these projects might be substantial, with a comparatively long payback period. As a result, wealthy people, private equity firms, and government entities have frequently played an important role in funding the commercial space industry.

From the first satellite launch in 1957 to 2020, the total launch failure rate is expected to be 8%, with a decline to 6% in the last 20 years. The failure rate for manned launches, on the other hand, is substantially lower - less than 2%, or one out of every 50 launches. For space passenger journeys, this is still far too high (commercial aircraft engines fail once every million flights). Furthermore, space mishaps are frequently significantly more severe and result in fatalities. Given the difficulties involved, longevity does not guarantee that an accident will not occur.

Figure 4: Unmanned and Manned Space Launches: Successes vs. Failures



Source: Citi Research, Space Launch Report (1957-2020)

Space-related abilities and expertise are exceedingly specialized and complicated. Furthermore, astronauts must undergo considerable training, which normally lasts between five and eight years for a 10- to 14-day mission and involves G-force training and 12-meter dives. Furthermore, astronauts' bodies and minds are subjected to considerable stress during training, lift-off/re-entry, and ongoing space exposure. Space radiation can induce cancer, impair the central nervous system, disrupt cognitive function, diminish motor function, and create behavioural problems. Long durations of isolation and confinement in a confining and potentially hostile living environment may have a psychological and physical impact on health and sleep. All these dangers can endanger both the astronaut and the crew.

The United Nations Outer Space Treaty of 1967 (United Nations. Office for Outer Space Affairs. & United Nations. General Assembly., 2002) was the cornerstone for international space law, although it is now out of date and contains minimal mention of commercial space activities, such as private firms conducting mining operations in space. The United Nations is tasked with reviewing present and potential dangers to space activities, as well as making recommendations on possible norms, regulations, and principles of responsible behaviour, as well as drafting a treaty to prevent a space arms race.

Regardless of the setbacks, the space industry offers numerous opportunities, including the potential for ground-breaking scientific discoveries, the development of new technologies, the expansion of human knowledge and exploration, and the growth of commercial space activities such as satellite communications and space tourism. With the ongoing improvement of space technology and increased collaboration between the public and private sectors, the space industry has many exciting potential for innovation and growth.

8. OPPORTUNITIES FOR THE SPACE SECTOR WITH INDUSTRY 4.0

As a high-tech industry, the space industry stands to benefit greatly from the deployment of Industry 4.0. This will totally change the industry and put years of effort ahead of it.

The value chain in the space industry includes several stages, including research and development, design, manufacturing, testing, and launch. To ensure the mission's success, each stage of the value chain demands high precision and accuracy. The typical value chain in the space industry entails numerous entities collaborating to finish a project. However, as Industry 4.0 is implemented, the value chain is becoming increasingly integrated, with several steps being completed by a single entity.

The application of Industry 4.0 is changing space research and development. Researchers are using big data analytics to analyse massive volumes of data in order to uncover trends and make predictions. This data can be utilized to optimize spacecraft design and lessen the likelihood of failure. Researchers are also using artificial intelligence to simulate and evaluate spaceship concepts before they are manufactured. This eliminates the need for physical testing, saving time and money.

The utilization of 3D printing is transforming the design phase of the space industry's value chain. Designers can use 3D printing to make prototypes fast and affordably, decreasing the time and expense of the design process. Furthermore, 3D printing enables the construction of complicated geometries that would be impossible to create using standard manufacturing methods. Designers can now construct more efficient spaceship designs, decreasing weight and improving payload capacity.

The use of robotics in manufacturing is changing the way spacecraft are built. Robots can accomplish jobs with high precision and accuracy, lowering the possibility of human error. Furthermore, robots may work around the clock, increasing productivity and lowering costs. The usage of the internet of things also allows for real-time monitoring of production processes, allowing for the detection of any flaws before they become major concerns.

Testing is an important stage in the space industry's value chain, and the deployment of Industry 4.0 is changing the way testing is done. Virtual testing and simulation are replacing physical testing, saving time and resources. Furthermore, the usage of big data analytics enables engineers to evaluate test data to detect problems and make improvements.

The usage of Industry 4.0 technology is also revolutionizing the launch phase of the space industry's value chain. Using big data analytics, launch providers may optimize launch trajectories, decreasing fuel consumption and enhancing efficiency. Furthermore, the use of robotics enables the automation of launch processes, lowering the danger of human error.

The introduction of Industry 4.0 is altering the space industry's value chain. Artificial intelligence, big data, the internet of things, robotics, and 3D printing are being used to streamline processes, increase efficiency, reduce costs, and improve quality. The space industry is a high-tech industry, and the adoption of Industry 4.0 allows it to preserve its position as a technological and innovative leader.

The availability of process and production data, it is possible to better integrate processes within the organization, from R&D, purchasing, production and logistics. and marketing.

Intelligent delivery and logistics systems, flow monitoring and management of raw materials and products allow optimization of logistics and production processes and increase the quality of the planning. In turn, the availability of digital data and the "visibility" of the production allows for easier sharing of information between the organization and its contractors and suppliers, on the one hand, as well as with customers and companies in the distribution network, on the other.

The deployment of sector 4.0 technologies is transforming the value chain of the space sector, opening up significant potential for improvements in space research and commercialization. The incorporation of sector 4.0 technology in the space sector is an exciting time for space enthusiasts and stakeholders, as it has the potential to unleash the next generation of space exploration and innovation.

9. NEW BUSINESS ENTRY

When discussing scientifically advanced and historically significant NASA missions (Nasa, 2020), it is a common misperception that giant corporations with practically infinite resources were the only ones capable of carrying them out to work on them. This is simply not true. Small enterprises contribute significantly to mission-critical system research, development, production, and testing.

Small enterprises built some of the most essential scientific devices designed to survey and navigate diverse sections of the Martian planet, from Perseverance's robotic arm to Ingenuity's small but strong propellors.

Table 2:Supporting Small Businesses

Supporting small businesses	
A+J Product Solutions	Wire support bracksts, sealing flange (program and machine)
Aerodyne Industries, LLC	ATOM small business teammate
AeroVironment Inc.	Prototypes of the helicopter propulsion and structural systems, including landing legs, motors, blades, and control mechanisms
Analytical Mechanics Associates	Analyzed vehicle environments during the high speed entry at Mars
Applied Sciences Laboratory, Inc.	Thermal modeling and analyses
Aremco Products, Inc.	Ceramabond for model construction, materials
ATA Engineering, Inc.	Analysis and testing support for the powered descent vehicle, rover, robotic arm, remote sensing mast, mobility system, skycrane, and sample caching system
Black Rock Technology Group, LLC	Membrane box, materials
California Fine Wire Company	Wiring materials
Edmund Optics Worldwide	Infrared (IR) bandpass filters
Galbraith Laboratories, Inc.	Mars Entry, Descent, and Landing Instrumentation 2 (MEDLI2) thermal protection system (TPS) material char analysis
Hadland Technologies Inc.	Computerized tomography (CT) scanning for MEDLI2 heat flux sensors

Hardware, Inc	Membrane box, materials
Lascar Electronics Inc	Calibration services
Masten Space Systems	Testing of JPL lander vision system used on the perserverance lander
Medtherm Corporation	Heat flux transducer Gardon gage sensor and recalibration support of Gardon gage
Motiv Space Systems	Rover's Robotic Arm, the Mastcam-Z Zoom and Focus Mechanism, the robot arm's 6-DOF Force Torque Sensor and the Mastcam-Z Filter Wheel
Pelican Wire Co., Inc.	Calibration services and certificate of conformance
Photon Systems, Inc.	Deep UV laser
Precision Control Systems, Inc	Lamp support tube and retainer, materials
Sierra Lobo, Inc.	EECAM (Enhanced Engineering Cameras), EDLCAM (Entry Descent Landing Camera), MOXIE (Mars In-Situ Resource Utilization Experiment), SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals), and MGSE (Mechanical Ground Support Equipment)

Source: MARS 2020 Mission Perseverance Rover (2020)

AeroVironment Inc. is well-known for developing unmanned aircraft systems, charging systems for electric vehicles, and other technology. They might use the prototypes they created for helicopter propulsion and structural systems, such as landing legs, motors, blades, and control mechanisms, to develop new unmanned aerial vehicles or to improve existing helicopter designs.

Medtherm Corporation's heat flux transducer and Gardon gage sensor could be used in aerospace applications to measure temperatures and pressures in high-temperature environments. These types of sensors are important for understanding the behaviour of materials and components under extreme conditions, which is crucial for developing new aerospace technologies.

Motiv Space Systems specializes in the development of robotic space exploration systems. The Rover's Robotic Arm, the Mastcam-Z Zoom and Focus Mechanism, the 6-DOF Force Torque Sensor on the robot arm, and the Mastcam-Z Filter Wheel are all components that could be utilised to construct new robotic systems for space exploration missions. These technologies are useful for jobs that are too risky or difficult for humans to conduct directly, like as investigating the surface of Mars or other planets.

Overall, these companies' goods have the potential to aid in the development of new aerospace technologies, improve existing designs, and offer new capabilities for space exploration missions. This is only possible because of the advancement in Industry 4.0 technologies that allows even small enterprises to participate in the space industry which has an extremely high cost of entry.

10. CONCLUSION

Implementing industry 4.0 in the development of the space sector brings both potential benefits and obstacles. The incorporation of modern technologies such as artificial intelligence, nanotechnology, the industrial Internet of Things (IIoT), and robotics has the potential to transform several elements of the space sector.

Through automation, connection, and data-driven processes, the Fourth Industrial Revolution, represented by Industry 4.0, has changed manufacturing and other industries. With its specific requirements and constraints, the space sector can tremendously benefit from the adoption of these technologies.

In the space sector, artificial intelligence has emerged as a critical enabler. It has the potential to improve mission planning, satellite data processing, robotics and autonomy, space mining, debris management, and space manufacturing. AI algorithms are capable of processing massive volumes of data in real time, making real-time choices, and improving the efficiency and effectiveness of space missions.

In the space industry, nanotechnology has interesting uses. Nanomaterials have the potential to improve the performance of satellites, sensors, and electronics. They can enable lightweight and durable materials, advanced sensors, and tiny components, boosting space systems' capabilities.

The Industrial Internet of Things (IIoT) enables connectivity and data exchange among diverse space industrial components. It can improve decision-making by optimizing launch systems, monitoring space exploration vehicles, and enabling real-time data processing.

Space research, satellite placement, maintenance, manufacturing, and mining could all be transformed by robotics. Robots can function in harsh settings, execute repetitive jobs with pinpoint accuracy, and mitigate the risks associated with human presence in space.

The application of Industry 4.0 in the space industry has various economic benefits. It has the potential to generate economic growth, create new job opportunities, raise income levels, and contribute to sustainability initiatives. Integration of sophisticated technology can result in cost savings, increased productivity, and the development of new space products and services.

However, implementing Industry 4.0 in the space industry poses obstacles. Among the primary problems that must be addressed are technical complications, legislative frameworks, security concerns, and the necessity for qualified human resources. Ethical concerns around the use of AI, data protection, and the responsible use of space resources must also be carefully explored.

Certain constraints that emerged throughout the course of this research must be acknowledged. To begin with, the space sector is highly specialized and complex, necessitating competence in multiple areas. As a result, the research may encounter difficulties in getting precise technical knowledge and accessing proprietary data.

The deployment of industry 4.0 in the space sector is a continuous process, with new technologies and techniques emerging on a regular basis. As a result, the research may not include all of the most recent advancements in this fast-expanding field. Efforts will be made, however, to guarantee that the information gathered is current and relevant to the situation of the space sector.

The research was largely concentrated on the possible benefits and obstacles of implementing Industry 4.0 in the space industry. While this thesis strives to provide a comprehensive study, due to time and resource limits, it may not cover every element of the issue in depth.

Despite these limitations, the prospects presented by Industry 4.0 for the space sector are enormous. It has the potential to open the door to new business models, collaborations, and creative space businesses. Start-ups and new entrants can take advantage of the benefits of sector 4.0 to create revolutionary solutions that will contribute to the growth and advancement of the space sector.

In conclusion, the application of Industry 4.0 to the advancement of the space sector shows considerable promise. Advanced technology integration has the potential to transform space exploration, satellite manufacture, launch operations, and other facets of the space sector. Addressing problems such as technical complexities, regulatory frameworks, and ethical issues, on the other hand, is critical for the successful deployment of Industry 4.0 in the space sector.

As we observe the convergence of technology and space, the industry's future is hanging on a thin rope. Will the space sector completely embrace sector 4.0's potential and break new ground? Or will the difficulties and constraints stymie its progress? Only time will tell the course the space sector will take in this digital revolution era.

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