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Robotics in Supply Chain

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ABSTRACT

Robotics and automation have developed as key technologies for supply chain management as a result of the increased demand for quicker and more effective supply chains. They improve supply chain management by lowering long-haul expenses, boosting work and usage strength, reducing errors, declining repetitive stock checks, updating orchestrating, taking care of times, and assembling induction to the problematic and hazardous places. Autonomous robotics have the potential to improve operations, and they offer new opportunities to increase productivity, reduce risk, decrease cost, and improve data collection, particularly as customer expectations and volumes of packages, shipments, and orders reach unsustainable levels for traditional approaches. The recent developments in robotics and automation for supply chain are reviewed in this paper.

KEYWORDS: *robotics, space robotics, supply chain, supply chain management*

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INTRODUCTION

An essential part of the global economy, the supply chain sector is in charge of shipping, distributing, and delivering commodities to customers all over the world. Supply chains are increasingly under immense pressure to deliver goods faster and more efficiently than ever before. To meet these demands, companies are increasingly turning to emerging technologies such as robotics. New technologies are presenting promising opportunities for improvement across the supply chain. Robotics has become part of the solution for global supply chains. Autonomous robots are already bringing innovation to the supply chain and delivering significant value. Figure 1 illustrates robotics in supply chain [1].

Customers' rising expectations for quicker order fulfilment, fierce rivalry, and the emergence of newer business models have driven businesses to seek out cutting-edge technological solutions in order to serve their clientele. This causes a new generation of technological solutions to emerge, including mobile, intelligent, autonomous, and smart robots that can be valuable in supply chains and warehouses in particular. Businesses can improve throughput, lower errors, and cut labor costs by automating repetitive and manual processes [2].

Supply chain management (SCM) is a crucial component of modern corporate operations. The integration of robotics into supply chain management is becoming a necessity for businesses looking to thrive in a competitive field. Supply chain robotics helps warehouses increase efficiency, reduce costs, and improve safety in the workplace. Automation in supply chain management leads to higher efficiency, accuracy, lower costs, and improved safety. Figure 2 shows different components of SCM [2].

WHAT IS A ROBOT?

The word "robot" was coined by Czechriter Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots and later added the zeroth law [3]:

- Law 0: A robot may not injure humanity or through inaction, allow humanity to come to harm.
- Law 1: Robots must never harm human beings,

- Law 2: Robots must follow instructions from humans without violating rule 1,
- Law3: Robots must protect themselves without violating the other rules.

Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing. Figure 3 indicates that robotics is one of the branches of artificial intelligence.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [4]:

1. All robots have some form of mechanical construction designed to achieve a particular task;
2. They have electrical components which power and control the machinery;
3. All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc.
4. All robots contain some level of computer programming code.

Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy.

Robotics is an interdisciplinary field that involves the design, construction, operation, and use of robots. It is a branch of engineering and computer sciences that includes the design and use of machines that are capable of performing programmed tasks without human involvement. The field develops machines that can efficiently carry out various tasks, can automate tasks, and do various jobs that a human might not be able to do. Robots could someday be our drivers, companions, collaborators, teachers, specialists, and exploration pioneers [5].

SUPPLY CHAIN ROBOTS

Supply chain operations are active 24/7/365. Autonomous robots can be used to improve the speed and accuracy of routine operations, particularly in warehousing and manufacturing spaces; work side-by-side with humans for added efficiency; and reduce the risk of employee injury in dangerous environments. Figure 4 shows the key development in autonomous robots [6].

Some qualities that differentiate autonomous robots from their predecessors include [7]:

1. Are programmed to perform tasks with little to no human intervention or interaction.
2. Vary significantly in size, functionality, mobility, dexterity, intelligence, and cost.
3. Range in scope from robotic process automation to flying vehicles with artificial intelligence.
4. Recognize and learn from their surroundings and make decisions independently.
5. Are expected to show strong growth over the next five years, particularly within supply chain operations that include lower-value, potentially dangerous, or high-risk tasks.
6. Could allow people currently performing manufacturing, final assembly, and warehousing to shift to more strategic, less dangerous, and higher value work.
7. Could soon operate with more human-like abilities.

TYPES OF SUPPLY CHAIN ROBOTS

Traditionally, autonomous robots have been deployed for executing routine and repetitive tasks, requiring complex programming for setup and implementation while lacking the agility to easily adjust operations. The following types of robots are used in supply chain [8]:

1. *Collaborative Robots*: Cobots are a subcategory of robots designed to work collaboratively and safely alongside humans. Cobots can take many forms. They can assist with tasks such as transport, assembly, lifting, or precision work, complementing human efforts rather than replacing them. The collaboration between robots and humans enhances overall productivity, reducing the physical strain on workers and allowing them to focus on more complex tasks. These versatile, semi-independent robots were created to aid human employees in carrying out various tasks in a warehouse environment. A portion of the cobots patrol the stockroom floor in search of human pickers and serve as adaptable storage containers for orders that have been picked
2. *Autonomous Mobile Robots*: For a robot or mobile manipulator to be considered autonomous, it must be equipped with advanced navigation systems and sensors that allow them to move autonomously in dynamic environments and without the need for direct human supervision. In today's fast-paced warehouse environments,

autonomous mobile robots (AMRs) are not just becoming key players, but are actively transforming operations. These robots can be set up and learn their surroundings in short amounts of time. They drive efficiency and flexibility, fundamentally changing how goods are moved, picked, and delivered within warehouses. While traditional automated systems follow fixed, pre-programmed routes, AMRs are designed to make independent decisions on the go. Using sensors and advanced algorithms, AMRs can safely navigate through crowded and dynamic environments like busy warehouses, where the constant movement of goods and workers occurs. By leveraging LiDAR (Light Detection and Ranging), AMRs can navigate complex environments, avoid obstacles, and dynamically adjust their paths, ensuring smooth and efficient movement across a warehouse. Figure 5 shows some examples of mobile robots [9].

3. *Pick-Assist Robot:* A "pick" refers to the act of retrieving a specific item from its storage location to fulfill an order. Traditionally, workers in distribution centers hand-pick and return inventory. A PA-AMR is a specialized form of autonomous mobile robot (AMR) designed to work alongside human workers in the picking process, typically found in warehouses and fulfillment centers. The combination of autonomy and precision ensures faster order fulfillment, fewer errors, and improved operational flow in dynamic warehouse environments. Automated robots equipped with cameras can recognize objects and materials and expedite picking. Figure 6 shows pick-assist robots [7].
4. *Automated Guide Vehicle*: Automated guided vehicle (AGV) is a type of robot that operates based on pre-programmed instructions or follows fixed, predefined paths.

These robots are designed to perform specific, repetitive tasks with minimal human intervention. AGVs are autonomous transportation systems that move goods inside of warehouses and manufacturing facilities. Typically, they are used to transport goods from one place to another, like from a storage area to a loading dock. AGVs replace physically demanding forklifts and pick trucks and help with material, supply, and stock movement. Figure 7 shows examples of automated guided vehicles [2].

5. *Aerial Robots*: Drone aircraft (or aerial robots) can be programmed to perform tasks with little to no human intervention or interaction. They can vary significantly in size, functionality, mobility, dexterity, artificial intelligence, and cost, from robotic process automation to flying vehicles with powerful image and data capturing capabilities. It is only a matter of time before aerial robots will transport our friends or family to our doors.

These robots fulfill many functions in supply chain, such as delivery robots, warehouse robots, inventory robots, and humanoid robots. The robots are helping distribution centers meet demands in a fast-paced world. Deciding on the appropriate type of robot will depend on the specific needs of the application. It is important to take into account some key factors to ensure the project's success: payload capacity, operating environment, navigation and safety, and integration with existing systems [10].

Japan is the world's leading manufacturer of industrial robots, accounting for approximately 47% of global production. Other significant producers include China, Germany, and South Korea. These countries have established robust robotics industries, contributing substantially to the global supply of industrial robots. The US accounted for approximately 7% of the global industrial robotics market in 2023 by many estimates.

Amazon is one of the top leading companies when it comes to recognizing the advantages of robots and to the adoption of supply chain robotics. Amazon currently enlists the help of more than 100,000 robots to fulfill customer orders. FedEx, following the footsteps of Amazon, introduced its first robot that drew a digital three-dimensional map of the vast 630,000-square-foot freight depot, making it easier for workers to navigate and take irregular items across the depot. The venerable British automaker Rolls Royce collaborated with Intel to develop a clever AI system that may speed up and improve commercial shipping.

APPLICATIONS OF ROBOTICS IN SUPPLY CHAIN

Warehouses, manufacturers, packagers, and other companies are getting their money's worth for robotics. Common areas of applications of robotics in supply chain include the following [2]:

- *Automation:* Robots can be used to automate the supply chain. Business owners and supply-chain professionals are understanding more and more the power of automation. Automation helps to do tasks that are often done by people through the use of self-operating physical machines, computer software, and other technology. Automating the supply chain is a key objective for most logistics companies. Autonomous mobile robotics are helping to automate supply chain tasks from assembly line tending to stock distribution and

sorting to transporting goods from storage. The stable and continuous supply of a production line is one of the tasks that an autonomous mobile robot can automate. In this way, the production flow is not interrupted at any time. There are tasks that humans perform best and there are tasks that can be automated. Figure 8 shows supply chain automation [9].

- *Automated Storage:* Automated storage systems are used to store and retrieve goods from warehouses. It is a collection of computer-controlled systems that help computerize stock management and store/recover goods upon request. They operate as cranes, move along set rails, can surely traverse across item pathways and vertical levels, remove, and store objects. It is used to speed up order fulfillment and project management of supplies in a stockroom environment. Figure 9 illustrates the storage system [2].
- *Chatbots:* Chatbots can be used to enhance user experience. NLP is what enables robots to comprehend customer issues or feedback when they are discussed with them by customers. Chatbots offer round-the-clock customer service, responding to common requests concerning purchase status, shipment details, refunds, and product inquiries. This lessens the workload for human workers and guarantees that clients get help when they need it. The use of chatbots improves transparency and lowers consumer concern by retrieving and providing precise order status updates. Chatbots can assist customers in placing orders by assisting them in making product selections, adding goods to their shopping carts, and completing transactions. Chatbots can also help with order modifications, such as changing delivery addresses or removing an item.
- *Warehouse Management:* One of the most integral parts of the supply chain process is a company's warehousing system. The journey from manual labor to mechanization in warehouses has been significant. The role of robotics and automation has become central to warehouse digital transformation. Robots that can lift, move and pack products are a vital part of supply chains, warehouses especially. In warehouses, robots are responsible for a range of tasks, including sorting, picking, and transporting goods. By ensuring that goods are stored, picked, and delivered in a timely and effective manner, warehouse management plays a crucial function in the supply chain. However, warehouse management, which includes many responsibilities including inventory control, material handling, and order fulfilment, maybe a challenging and labor-intensive procedure. The decision to implement automation in warehousing should be driven by strategic considerations that align with your business goals and operational needs. Robotics and automation are reshaping warehouse operations by improving scalability, operational efficiency, and accuracy. Automation and robotics in warehousing offer several key benefits that collectively contribute to more efficient, effective, and sustainable operations. Figure 10 shows robots used in warehousing [11].
- *Robotics-as-a-Service* (RaaS): RaaS allows warehouses to deploy robotic solutions without the hefty initial investment, offering maintenance, updates, and scalability under a service subscription model. This model is increasingly popular as it allows for technological adaptability without the financial burden of outright purchases. Although the Robotics-as-a-service (RaaS) model can mitigate some of the financial burden, the transition to a highly automated warehouse still requires substantial investments in technology, infrastructure, and software.

BENEFITS

The supply chain has seen a considerable increase in efficiency, productivity, and cost savings through the use of robotics and automation, AI, and ML. Robots could provide a competitive advantage for companies. Supply chain robotics allows human workers to pass on tasks that they cannot, should not, or do not want to do. Autonomous robots primarily drive supply chain innovation and value by reducing direct and indirect operating costs and increasing revenue potential. They can help perform lower value, mundane tasks so humans can work collaboratively to focus on more strategic efforts that cannot be automated. Other benefits include the following [12,13]:

- *Efficiency:* Supply chain efficiency refers to a wide range of performance indicators such as overall costs, inventory level, and customer satisfaction. Human workers have downtime; they take breaks, sick days, vacations, etc., and work less efficiently than their robotic counterparts. The supply chain's efficiency, productivity, and cost savings have significantly increased with the usage of robotics and automation, AI, and ML. Robotics significantly streamline processes such as picking, packing, and shipping, which drastically reduces cycle times and labor costs. Robots can operate continuously without the need for breaks, reducing downtime, and increasing

productivity. Additionally, automation minimizes human errors in order fulfillment, further enhancing operational efficiency.

- *Flexibility:* Robots offer unprecedented flexibility in performing a variety of tasks, from transporting goods to warehousing and order picking. Robotic systems can be programmed and reprogrammed to perform different tasks and handle various products, making them ideal for warehouses that handle a diverse range of items. This flexibility allows warehouse operations to adapt quickly to changes in product lines or seasonal fluctuations without significant disruptions or additional costs.
- *Scalability:* As businesses grow, robotics systems can be scaled up easily. Whether expanding warehouse operations or increasing production capacity, robots provide the flexibility needed to meet rising demands.
- *Sustainability:* Automation can lead to more sustainable operations by optimizing energy use and reducing waste through improved accuracy and efficiency. For example, robots can optimize picking paths and reduce unnecessary travel within a warehouse, thereby lowering energy consumption. Additionally, fewer errors mean less waste from damaged or incorrectly shipped products.
- *Employee Satisfaction:* Using autonomous robots to perform repetitive, mundane manual tasks can also improve employee satisfaction as they shift to more strategic and mentally stimulating work.
- *Cost Reduction:* While the initial investment in robotics can be substantial, the long-term savings are considerable. Reduced labor costs, fewer errors, and lower overhead contribute to a higher return on investment.
- *Enhanced Accuracy:* Robots are precise and consistent, which minimizes errors in order fulfillment and reduces waste. This level of accuracy improves customer satisfaction and loyalty, as orders are fulfilled correctly and on time.
- *Safety Improvement:* Rather than replacing human workers, automated robots have so far played an invaluable role in keeping them safe. Robots can perform lower-value, more dangerous tasks so human workers are able to enjoy improved workplace safety. This not only protects employees but also lowers costs associated with accidents and insurance.

CHALLENGES

Although there are many benefits to using robotics and automation in the supply chain sector, there are also difficulties in putting them into practice. Increasing demand, growing expenses, and the need for increased efficiency and speed are just a few of the challenges the supply chain sector must overcome. The cost of implementing robotics technologies, which can be substantial, is one of the biggest obstacles. Other challenges include the following [12,13]:

- *Integration Complexity:* Integrating new robotic systems with existing warehouse management systems and infrastructure can be highly complex and technically challenging. It often requires significant modifications to existing processes and can be costly and time-consuming.
- *High Costs:* The cost of robots, along with the necessary systems to support them, can be prohibitive for many businesses, especially small to medium-sized enterprises. Regular maintenance and updates are necessary to ensure operational efficiency, which can also involve additional costs and specialized technical support. Many businesses find the investment to be justified due to the possible long-term cost savings and the boosted effectiveness and productivity.
- *Regulation:* Implementing robotics in warehousing must comply with existing safety and workplace regulations, which can vary widely by region and industry. Ensuring that robotic systems are safe for human interaction and do not violate any labor laws is crucial.
- *Human Labor:* A common concern surrounding the rise of robotics is the potential for job displacement. Concerns over the displacement of human labor and potential job losses have been highlighted by the use of robotics, automation, AI, and ML in the supply chain. While it is very unlikely that we should worry about sentient robots taking over the world, the risk of them taking people's jobs deserves further scrutiny. However, proponents contend that these technologies can actually generate new employment prospects in fields like robot programming and maintenance. In most cases, robots free human employees from mundane, repetitive tasks and empower them to concentrate on core business objectives instead.
- *Labor Shortages:* Labor shortages are another significant challenge. Finding and retaining qualified workers for physically demanding warehouse jobs can be daunting. The talent

shortage is well documented, but investments in robotics and automation are proven to attract new recruits to supply chain. The supply chain talent pool has not kept pace with changes, resulting in a shortage of skilled professionals. Scholarship was created to not only inspire fresh and new ideas within the industry, but to find talent as well.

- *Resistance to Change:* Supply chain managers must prepare for resistance from labor unions and those who fear losing their jobs to a new wave of technology. Businesses must explain to anxious workers and consumers that robots can actually create jobs. Such opposition marks the beginning of a new chapter in labor relations, in which automation can be viewed as either a job killer. Workers around the world are under assault from the threat of automation by greedy companies only interested in making money and eliminating workers who helped them build their success and companies.
- *Raw Materials:* The rising costs of raw materials are posing significant challenges for the robotics industry, where metals such as aluminum, copper, and rare earth elements are essential in the production of components like motors, sensors, and batteries. With global demand for these materials skyrocketing, driven by industries such as electric vehicles, renewable energy, and consumer electronics, supply shortages have led to price hikes.

CONCLUSION

Through improvements in sensors, dexterity, artificial intelligence, and trainability, robots are becoming faster and more sophisticated, and they now include safety provisions that allow them to work collaboratively with humans. The benefits are expanding for the supply chain of the future as autonomous robots become capable of working around the clock with more consistent levels of quality and productivity, performing tasks that humans cannot, should not, or do not want to do.

Autonomous robots are helping define the supply chain of the future by helping companies decrease long-term costs; provide labor and utilization stability; increase worker productivity; reduce error rate; reduce frequency of inventory checks; optimize picking, sorting, and storing times; and increase access to difficult or dangerous locations. They are expected to see strong growth in the coming years, particularly within supply chain operations that include lower-value, potentially dangerous or high-risk tasks. They will be more ubiquitous in the supply chain of the future as advancements make them operate with more human-like abilities [6]. More information on robotics in the supply chain industry can be found in the books in [14-17] and the following related journals:

- Robotica
- Robotics
- Robitics and Autonomous
- *Robotics and Computer-Integrated Manufacturing,*
- *Advanced Robotics*
- *Autonomous Robots*
- *Automation in Construction*
- *Journal of Robotics*
- *Journal of Robotic Systems*
- *Journal of Robotic Surgery*
- *Journal of Robotics and Mechatronics*
- *Journal of Intelligent & Robotic Systems*
- *Journal of Mechanisms and Robotics-Transactions of the ASME*
- *Journal of Automation, Mobile Robotics and Intelligent Systems*
- *Journal of Future Robot Life*
- *IEEE Robotics and Automation Letters*
- *IEEE Transactions on Robotics*
- *International Journal of Medical Robotics and Computer Assisted Surgery*
- *International Journal of Robotics Research*
- *International Journal of Social Robotics*
- *International Journal of Humanoid Robotics*
- *International Journal of Advanced Robotic Systems*
- *Science Robotics*
- *Soft Robotics*

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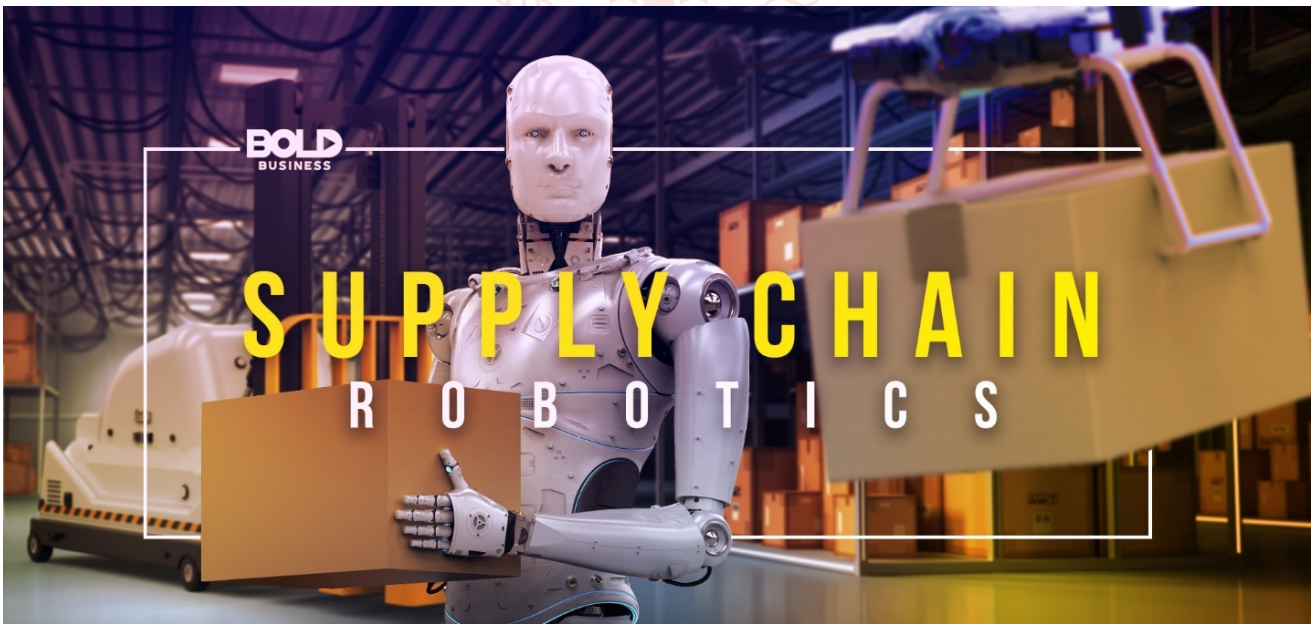

Figure 1 Illustration of robotics in supply chain [1].

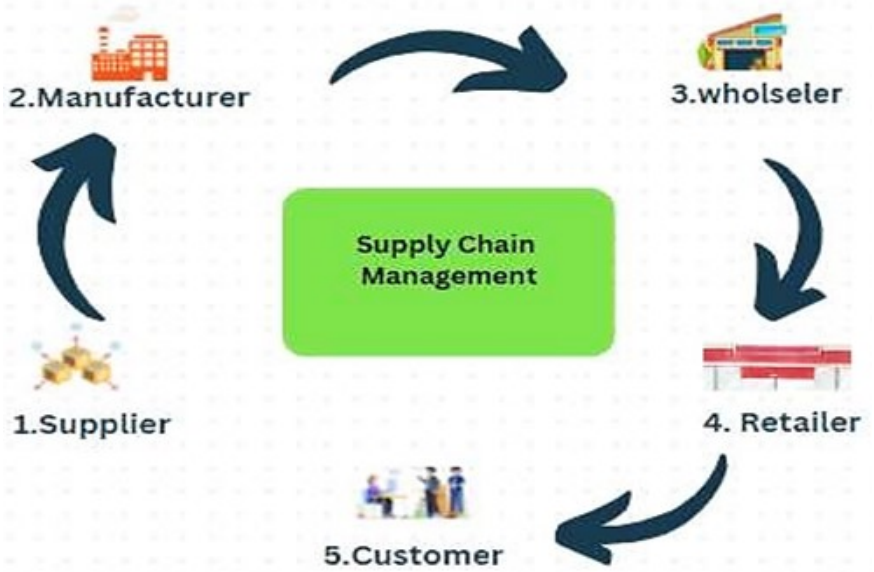

Figure 2 Different components of SCM [2].

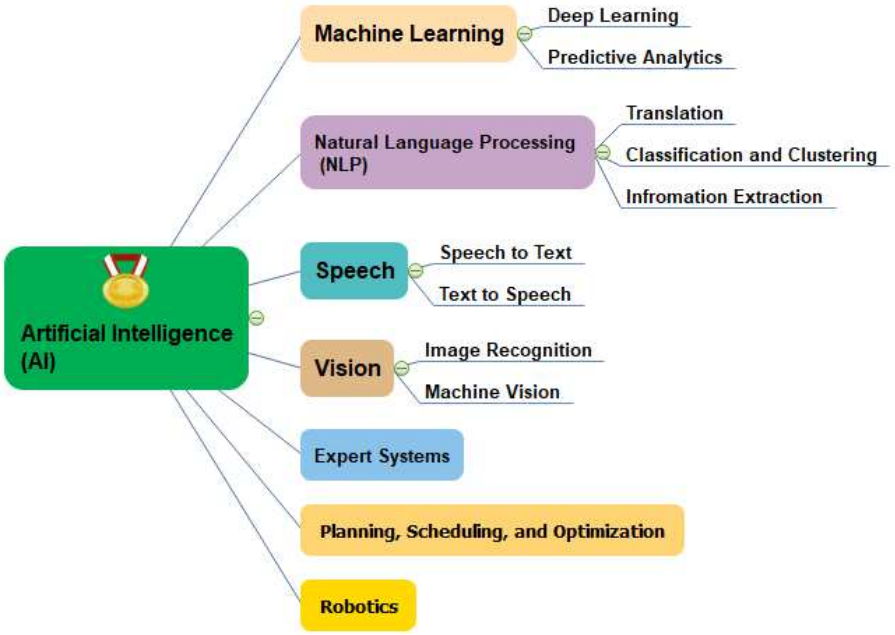

Figure 3 Robotics is one of the branches of artificial intelligence.

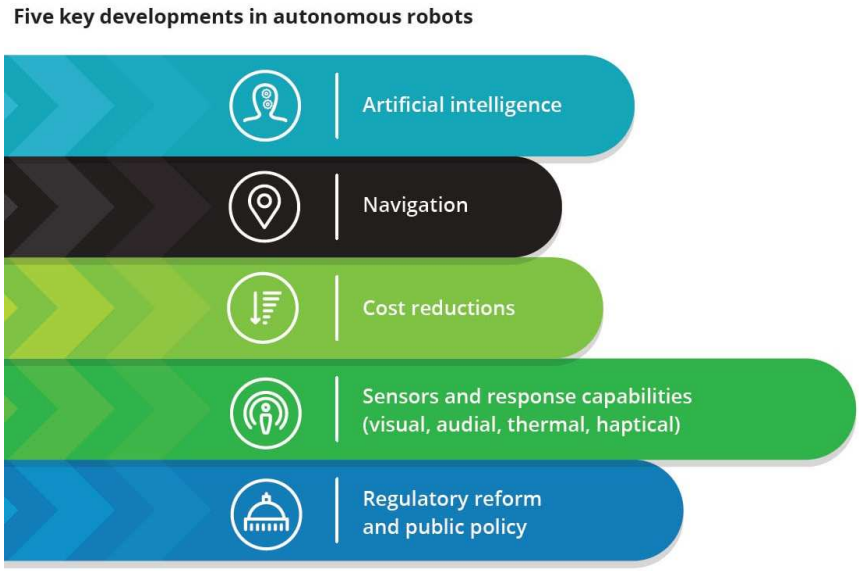

Figure 4 Key developments in autonomous robots [6].

Figure 5 Examples of mobile robots [9].

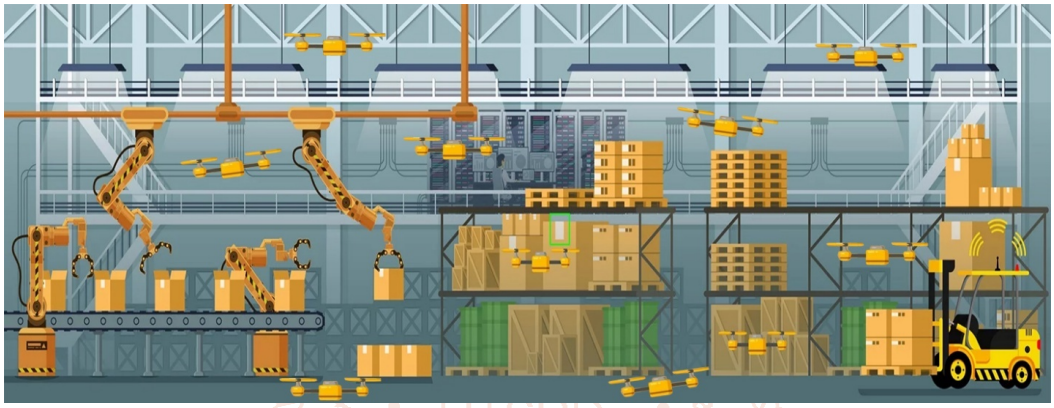

Figure 6 Pick-assist robots [7].

Figure 7 Automated guided vehicles [2].

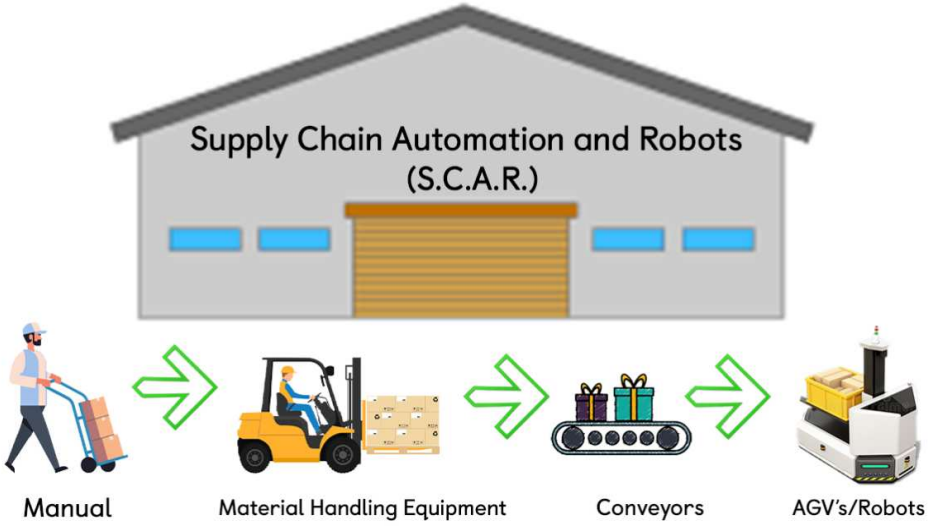

Figure 8 Supply chain automation [9].

Figure 9 Automated storage system [2].

Figure 10 Robots used in warehousing [12].