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A COMPARATIVE ANALYSIS OF THE ROLE OF INDUSTRIAL AND HUMANOID ROBOTS AS DRIVERS OF EFFICIENCY AND FLEXIBILITY IN THE AUTOMOTIVE INDUSTRY

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RESEARCH ARTICLE

ABSTRACT: All industrial sectors are undergoing a transformation of production processes through the implementation of Industry 4.0 technologies. The automotive industry, as one of the most dynamic sectors, is also experiencing significant changes due to increasing demands for more efficient, flexible, and sustainable production. In this context, a key factor in enhancing the performance of production systems is the implementation of industrial and service robots, while more recently, greater attention is being given to the integration of humanoid robots. This paper aims to provide a comparative analysis of the role of industrial and humanoid robots as drivers of efficiency and flexibility in the automotive industry. The analysis is based on criteria such as speed, precision, adaptability, implementation costs, and human-robot collaboration capabilities. In addition to the theoretical overview, the paper includes case studies from real-world applications, highlighting the practical impact of these technologies. The findings suggest a complementary role of both robot types and emphasize the importance of their integrated use within modern production frameworks such as Industry 4.0 and smart factories.

KEY WORDS: *automotive industry, industrial robots, humanoid robots, efficiency, flexibility, automation, Industry 4.0*

KOMPARATIVNA ANALIZA ULOGE INDUSTRIJSKIH I HUMANOIDNIH ROBOTA KAO POKRETAČA UČINKOVITOSTI I FLEKSIBILNOSTI U AUTOMOBILSKOJ INDUSTRIJI

REZIME: Sve industrijske grane nalaze se u fazi transformacije proizvodnih procesa kroz implementaciju tehnologija karakterističnih za Industriju 4.0. Automobilska industrija, kao jedan od najdinamičnijih sektora, takođe prolazi kroz značajne promene usled sve većih zahteva za efikasnijom, fleksibilnijom i održivijom proizvodnjom. U tom kontekstu, ključni faktor unapređenja performansi proizvodnih sistema predstavlja implementacija industrijskih

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i servisnih robota, dok se u poslednje vreme sve više pažnje posvećuje i integraciji humanoidnih robota Ovaj rad ima za cilj da kroz komparativnu analizu ispita ulogu industrijskih i humanoidnih robota kao pokretača efikasnosti i fleksibilnosti u automobilskoj industriji. Analiza se zasniva na kriterijumima kao što su brzina, preciznost, adaptivnost, troškovi implementacije i mogućnost saradnje sa ljudskim radnicima. Pored teorijskog pregleda, rad obuhvata i prikaz studija slučaja iz prakse koje osvetljavaju stvarne primene i efekte ovih tehnologija. Rezultati istraživanja ukazuju na komplementarnu ulogu oba tipa robota i naglašavaju potrebu za njihovom integrisanom upotrebom u okviru savremenih proizvodnih koncepata kao što su Industrija 4.0 i pametna fabrika.

KLJUČNE REČI: *automobilska industrija, industrijski roboti, humanoidni roboti, efikasnost, fleksibilnost, automatizacija, Industrija 4.0*

A COMPARATIVE ANALYSIS OF THE ROLE OF INDUSTRIAL AND HUMANOID ROBOTS AS DRIVERS OF EFFICIENCY AND FLEXIBILITY IN THE AUTOMOTIVE INDUSTRY

Isak Karabegović

INTRODUCTION

The automotive industry is undergoing a profound transformation driven by escalating global competition, increasing consumer expectations, environmental regulations, and rapid technological advancements. To remain competitive, manufacturers must enhance production efficiency, flexibility, and sustainability while simultaneously reducing costs and accelerating product development cycles. These challenges have catalyzed the adoption of advanced digital technologies, particularly automation and robotics, within the framework of Industry 4.0 [1-3]. Automation has long been integral to industrial manufacturing; however, the advent of Industry 4.0 has redefined its scope, emphasizing the integration of cyber-physical systems, the Internet of Things (IoT), and artificial intelligence (AI) to create intelligent, interconnected, and adaptive production environments [4]. Robotics, as a cornerstone of this paradigm, has evolved beyond performing repetitive tasks to enabling dynamic interaction with complex environments through enhanced sensing, learning, and decision-making capabilities [5-7]. In contemporary manufacturing settings, two primary categories of robots are distinguished: industrial robots and humanoid robots. Industrial robots are engineered for high-speed, high-precision operations such as welding, painting, and assembly. They are characterized by their rigidity and are typically confined to structured environments. Conversely, humanoid robots are designed to emulate human form and behavior, facilitating their operation in unstructured settings and enabling collaboration with human workers. These robots possess advanced capabilities, including speech recognition, visual perception, and adaptive learning, making them suitable for tasks requiring flexibility and human-like interaction [8]. The integration of humanoid robots into manufacturing processes is gaining momentum, with companies like Tesla and BMW exploring their potential to perform complex tasks and collaborate with human workers on assembly lines [9,10]. Despite their promise, challenges such as high costs, technical limitations, and safety concerns persist, necessitating further research and development to fully realize their potential in industrial applications [11]. The objective of this study is to conduct a comparative analysis of the roles of industrial and humanoid robots as drivers of efficiency and flexibility in the automotive industry. By examining their respective capabilities, limitations, and applications, this research aims to provide insights into their optimal integration within modern manufacturing systems. The findings are intended to inform strategic decisions regarding automation investments and workforce development in the context of Industry 4.0.

1. THEORETICAL FRAMEWORK FOR THE IMPLEMENTATION OF INDUSTRIAL AND HUMANOID ROBOTS AIMED AT ENHANCING EFFICIENCY AND FLEXIBILITY IN PRODUCTION

Industrial robots are programmable, automated machines used in structured manufacturing environments to perform tasks such as welding, painting, assembly, and material handling. Their core features include high precision, repeatability, and the ability to function continuously, making them indispensable in mass production. The integration of industrial robots significantly increases production output and reduces operational costs by automating repetitive and physically demanding tasks. However, their implementation requires substantial capital investment, skilled personnel for programming and maintenance, and considerable system integration efforts. These limitations are particularly significant for small and medium-sized enterprises (SMEs), which may lack the necessary technical and financial resources [12]. Moreover, industrial robots are typically designed for rigid, predefined tasks, limiting their ability to respond dynamically to changes in production requirements. Humanoid robots are advanced robotic systems designed to resemble the human form and replicate human-like behavior, enabling them to operate in unstructured or semi-structured environments originally tailored for humans. Equipped with sensory systems, vision modules, voice recognition, and decision-making algorithms, humanoid robots can engage in complex tasks that require dexterity, cognitive processing, and human-robot interaction [10,13]. In the industrial domain, humanoid robots are being explored for applications that demand flexibility and close collaboration with human operators. For instance, Tesla's development of the Optimus humanoid robot aims to address challenges related to labor shortages and skill gaps in assembly operations [14]. While humanoid robots hold significant promise, their industrial adoption remains limited due to high developmental costs, unproven reliability in real-time industrial contexts, and concerns related to operational safety [13,15]. Efficiency in manufacturing is commonly defined as the optimal utilization of inputs (labor, machines, and materials) to maximize output, often quantified through metrics such as Overall Equipment Effectiveness (OEE). Flexibility refers to a system's ability to adapt swiftly to changes in production volume, product variety, or process configurations without incurring significant time or cost penalties. The integration of advanced robotics, including both industrial and humanoid robots, enhances manufacturing performance by contributing to these two strategic dimensions. Industrial robots provide efficiency through speed and consistency, while humanoid robots offer potential for flexibility by performing variable tasks and adapting to dynamic environments [12,14,16]. Several studies have explored the impact of industrial robots on productivity, product quality, and operational cost-efficiency. Smith et al. [12] conducted an empirical analysis showing that increased use of industrial robots positively correlates with improved labor productivity and a reduced environmental impact in manufacturing systems. Recent research on humanoid robots, though still in its early stages, highlights their potential to address workforce shortages and mitigate the effects of aging labor populations in developed economies, particularly through case studies involving advanced systems such as Tesla's Optimus robot [14]. Ficht and Behnke provide a technological review of bipedal humanoid robots, emphasizing their evolving mechanical and sensory capabilities [13,17]. These studies underline the complementary strengths of both robot types, indicating the need for hybrid models of human-robot collaboration within the Industry 4.0 paradigm.

2. COMPARATIVE ANALYSIS OF THE IMPLEMENTATION OF INDUSTRIAL AND HUMANOID ROBOTS IN THE AUTOMOTIVE INDUSTRY

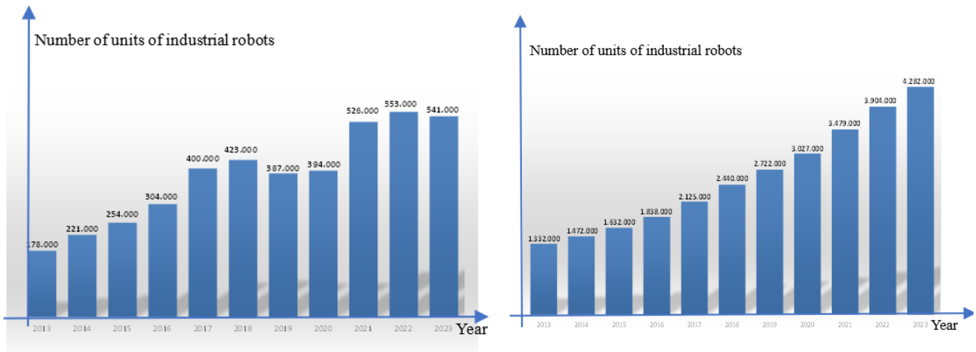
This research employs a comparative analysis as its methodological framework to examine the role of industrial and humanoid robots in optimizing production processes within the automotive industry. This method enables a systematic comparison of the performance of both robot types based on predefined criteria, facilitating the identification of their advantages, limitations, and integration potential in modern manufacturing systems [18,19].
The comparative analysis is based on secondary data collected from the following sources:

- *Industry reports*, which offer detailed insights into the implementation of industrial and humanoid robots in real-world production environments, providing a practical understanding of their applications;
- *Case studies*, which describe the integration of these robots in automotive production, particularly in areas such as welding, assembly, painting, and logistics;
- *Peer-reviewed scientific articles* indexed in the Web of Science (WoS) and Scopus databases, focusing on topics such as productivity, flexibility, and safety in robotic manufacturing contexts.

The integration of these sources enables a comprehensive understanding of current developments and trends in robotic applications. However, it should be noted that the study relies exclusively on secondary data, which may limit access to the most recent or highly specific industry practices. Moreover, the rapid pace of technological advancement may cause some data to become outdated quickly, thereby requiring contextual interpretation of the results [20].

2.1. Implementation of Industrial Robots

Industrial robotics has experienced significant growth over the past decade, driven by the emergence of Industry 4.0 technologies, rising demand for automation, and the need for enhanced production efficiency and precision. Industrial robots have become indispensable in modern production systems across various sectors, particularly in automotive manufacturing (International Federation of Robotics, 2023). Global implementation trends of first- and second-generation industrial robots were analyzed using statistical data from the International Federation of Robotics (IFR), the United Nations Economic Commission for Europe (UNECE), and the Organisation for Economic Co-operation and Development (OECD). Figure 1 presents annual and cumulative installations of industrial robots worldwide for the period 2013–2023 [21–25].



a – Annual implementation *b – Cumulative implementation*

Figure 1. Diagram of annual and cumulative implementation of industrial robots worldwide for the period 2013–2023

An analysis of the diagrams presented in Figure 1 indicates that the growth trend in the implementation of industrial robots has accelerated due to the increasing demand for production automation, labor cost reduction, and the need for greater precision and efficiency. Over the past decade, the annual growth rate of installed robots has averaged between 10%

and 15%, with a record number of new installations in recent years. In fact, the annual number of installed industrial robots has reached approximately 541,000 units (Figure 1-a), while the total number of implemented robots in 2023 reached around 4.3 million units [25].

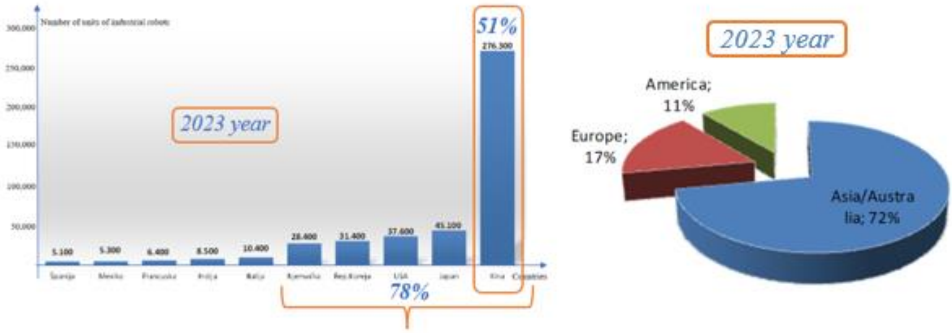


Figure 2. Diagram of the top ten countries in the world by industrial robot implementation in 2023 and the percentage distribution by continent in 2023

By analyzing the diagram in Figure 2 (left), we conclude that China, as the leading manufacturer and consumer of industrial robots, accounted for over 51% of the total global implementation of industrial robots in 2023, with approximately 276,300 units installed in that year. In addition to China, the top five countries in terms of robot implementation include Japan, the United States, the Republic of Korea, and Germany. Together, these five countries were responsible for approximately 79% of the total global industrial robot installations in 2023. Besides these five, the top ten countries also include Italy, India, France, Mexico, and Spain, as illustrated in Figure 2.

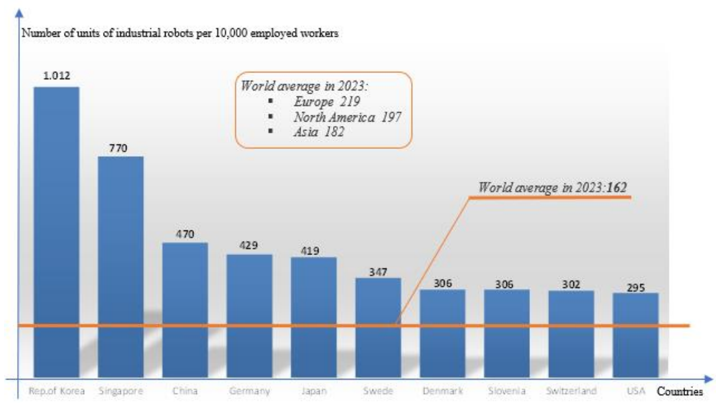


Figure 3. Implementation of industrial robots in the top ten countries worldwide per 10,000 employees in the industrial sector in 2023

The diagram on the right side of Figure 2 shows the distribution of robot implementation by continent, expressed as a percentage. It reveals that Asia/Australia leads with about 72% of global installations, followed by Europe with 17%, and the Americas with 11% in 2023. These data indicate a continuous global increase in the implementation of industrial robots, with a strong emphasis on the Asian market, which dominates global demand. A more accurate representation of robot implementation is obtained by analyzing the number of robots installed per 10,000 employees in the manufacturing industry. Figure 3 presents the implementation of industrial robots per 10,000 manufacturing employees in the top ten countries worldwide in 2023 [25].The implementation of industrial robots varies significantly among the world's leading countries, and the latest data for 2023 reveal substantial differences in the level of robotization. At the top of the list is South Korea, with an impressive 1,012 industrial robots per 10,000 manufacturing employees. This figure reflects a strong technological orientation and continuous investment in automation, particularly in sectors such as the automotive and electronics industries. Singapore follows with 770 robots per 10,000 workers, also indicating a high level of robotization, largely driven by high-tech manufacturing and precision industries. China, which has undergone significant industrial robotization over the past decade, reports 470 units per 10,000 employees, demonstrating its strategic commitment to industrial modernization. Germany, known for its strong industrial base, records 429 robots per 10,000 workers, while Japan, a pioneer in robotics, has 419 units. Sweden (347), Denmark (306), Slovenia (302), Switzerland (295), and the United States (295) are also among the global leaders in this domain. The global average stands at 162 robots per 10,000 employees, meaning that most leading countries significantly exceed this benchmark. On a continental level, Europe averages 219 robots, North America 197, and Asia 182, indicating that developed countries and regions with high-tech industries hold a significant advantage over the rest of the world. These statistics highlight the critical role of industrial robots in modernizing production processes and increasing productivity, particularly in technologically advanced nations. A high concentration of robots enables the automation of repetitive and demanding tasks, contributing to greater efficiency and global competitiveness.

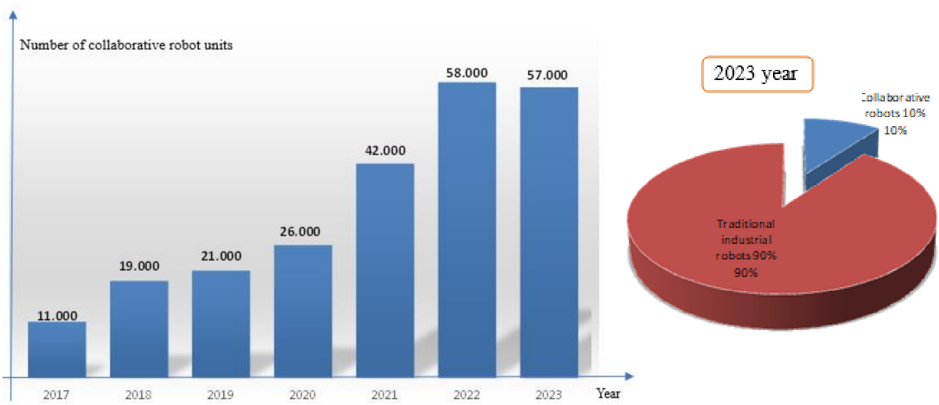


Figure 4. Implementation of collaborative robots in the world in the period 2017-2023 and percentage application in 2023 [23-26]

Collaborative robots (cobots) have become a key component of modern industrial automation between 2017 and 2023 [23-26]. Unlike traditional industrial robots, cobots are designed to operate safely alongside humans, making them ideal for tasks that require human-machine collaboration. According to the provided data, the global implementation of cobots has shown consistent growth over this period. In 2017, approximately 11,000 cobot units were installed, increasing to 19,000 in 2018. During 2019 and 2020, moderate growth was observed with 21,000 and 26,000 units respectively. A significant increase occurred in 2021, when installations reached 42,000 units. The peak was recorded in 2022, with 58,000 units, followed by a slight decline to 57,000 units in 2023.This growth has been driven by the demand for more flexible production solutions, expansion of manufacturing capacities, and labor cost reduction in developed and industrially oriented countries. The popularity of cobots stems from their versatility, safety, and ability to quickly adapt to various production processes. They are particularly useful in small and medium-sized enterprises, where production lines often change. However, despite the growth, cobots still represented only 10% of all industrial robots in 2023, while traditional industrial robots accounted for 90%. This indicates that although interest in cobots is rising, traditional robots continue to form the backbone of automated production systems. Cobots are most commonly used in the electronics and automotive industries (30%), followed by consumer goods (20%), and logistics and warehousing (15%). In the food and pharmaceutical sectors, they represent around 10%, while the remaining 25% is distributed across other industrial sectors. China, the United States, and Germany are leading in cobot implementation, thanks to their strong industrial bases and policies promoting digitalization of manufacturing. Europe shows stable growth, particularly in the automotive and electronics sectors. Given the increasing focus on safety, adaptability, and production efficiency, the cobot market is expected to continue growing in the coming years, although traditional robots will likely remain dominant in industrial facilities for some time. Industrial robots play a crucial role in transforming the automotive industry by enabling greater efficiency, precision, and flexibility in production processes. From the first robotic arms introduced on assembly lines in the 1960s to today's sophisticated automated systems, robots have become an integral part of manufacturing plants. Their application spans a wide range of tasks—from welding and painting to assembly and quality control. The integration of robots results in faster production, reduced human error, and improved worker safety, but it also requires adjustments in organizational structures and continuous employee training. With the emergence of advanced technologies such as collaborative robots (cobots) and artificial intelligence, the automotive industry is increasingly moving toward so-called smart factories within the framework of Industry 4.0. The implementation of industrial robots in the automotive industry over the past decade is illustrated in Figure 5 [21-25].

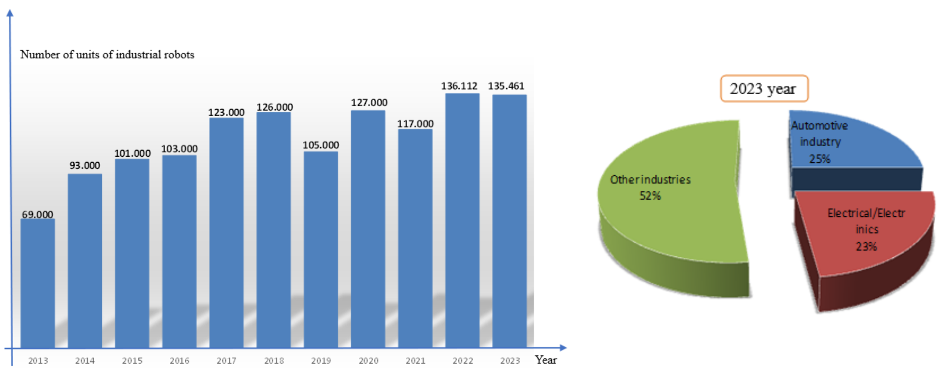


Figure 5. Implementation of industrial robots in the automotive industry in the period 2013-2023. year

It is well known that, since the early stages of their application, the majority of industrial robot implementations have occurred in the automotive and electrical/electronics industries—a trend that has continued to this day. This is supported by the fact that, in 2023, 25% of all industrial robot installations (135,461 units) were in the automotive industry, while the electrical/electronics industry accounted for 23% (125,804 units). The remaining 52% (279,735 units) were installed across all other industries, with a total of 541,000 industrial robots implemented globally in 2023. Figure X illustrates the growth trend in industrial robot implementation within the automotive industry over the period from 2013 to 2023. A steady increase in installations is evident, with a notable acceleration after 2018, reflecting the ongoing digitalization and automation of production processes. The highest number of installations was recorded in 2021 and 2022, which can be linked to the growing need for production flexibility following disruptions caused by the pandemic. This trend also mirrors the broader transition toward the Industry 4.0 paradigm, where industrial robots play a key role. The data clearly indicate that the automotive industry remains one of the primary drivers of the global robotics market

2.2. Implementation of Service and Humanoid Robots

In addition to the development of second-generation industrial robots and their implementation across all manufacturing processes, advancements and research in robotics technology have also contributed to the emergence of service robots for professional use. These robots are utilized within industrial environments, with the most widespread application currently seen in service robots for transport and logistics. They are deployed for tasks such as finished product inspection, monitoring, and oversight of manufacturing processes [27,28]. The global trend of service robot adoption for professional services is illustrated in Figure 6, showing the top seven application areas in 2023 [29].

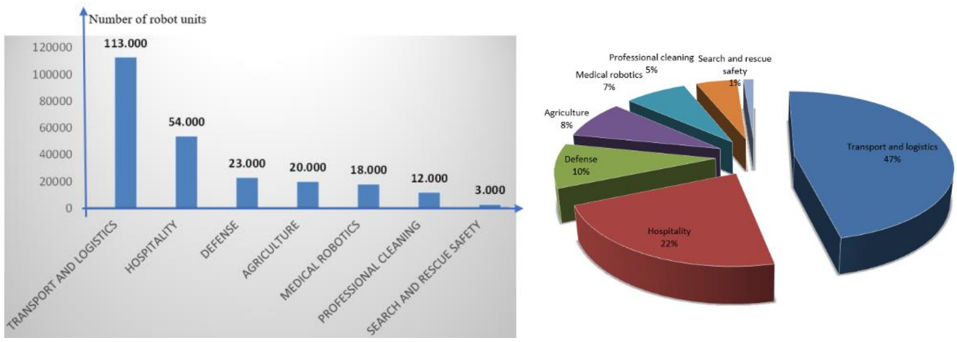


Figure 6. Implementation of service robots for professional service in seven top applications in 2023 in the world

Based on the diagram shown in Figure 5, we can conclude that the largest number of service robots is used in the transport and logistics sector, with as many as 113,000 units, accounting for nearly half of the total deployment. This high number is primarily driven by the growing need for automation in warehousing, distribution, and delivery, which enhances efficiency and reduces operational costs. The hospitality sector ranks second with 54,000 units. In this domain, robots are used for serving, food preparation, and delivery within hotels and restaurants. The automation of these tasks improves service quality and reduces waiting times. Defense follows with 23,000 units, where robots are primarily utilized for reconnaissance, surveillance, and various military operations, thereby enhancing safety and reducing risks to human lives. Agriculture ranks fourth, with 20,000 units deployed to assist with harvesting, irrigation, and crop maintenance. The automation of agricultural processes contributes to increased productivity and reduced labor dependence. Medical robots account for 7% of total usage, with 18,000 units employed in operating room assistance, rehabilitation, and patient care. The professional cleaning sector follows with 12,000 units (5%), while security, search, and rescue applications are the least represented, with 3,000 units (1%), primarily due to specific operational requirements and high implementation costs. The pie chart provides an overview of the proportional distribution of service robots across sectors. It is evident that transport and logistics dominate with 47%, followed by hospitality at 22%. Defense (10%), agriculture (8%), medical robotics (7%), professional cleaning (5%), and security (1%) represent smaller portions of the total implementation. The 2023 deployment of service robots clearly shows dominance in sectors where automation is crucial for efficiency and productivity. Transport, logistics, and hospitality lead due to their demand for speed and process optimization, while less represented sectors such as security and cleaning reflect specific challenges in robot integration. The implementation of service robots for transport and logistics is becoming an increasingly important component of modern production systems in the automotive industry . These autonomous systems—such as Autonomous Mobile Robots (AMRs) and Automated Guided Vehicles (AGVs)—enable more efficient management of internal logistics, reducing delivery times for parts and optimizing the flow of materials between production zones [30]. Their deployment minimizes human intervention in repetitive and physically demanding tasks, enhances workplace safety, and allows greater adaptability in response to changes in production processes. Service robots are easily integrated into existing systems, utilizing sensor-based navigation, camera vision, and software solutions for real-time task tracking and coordination. Given the growing market demand for flexible and adaptable manufacturing, logistics robots are becoming a key component in the development of smart factories. The automotive industry, as one of the most technologically advanced sectors, is increasingly exploring the implementation of humanoid robots in its production and logistics processes [31,32].

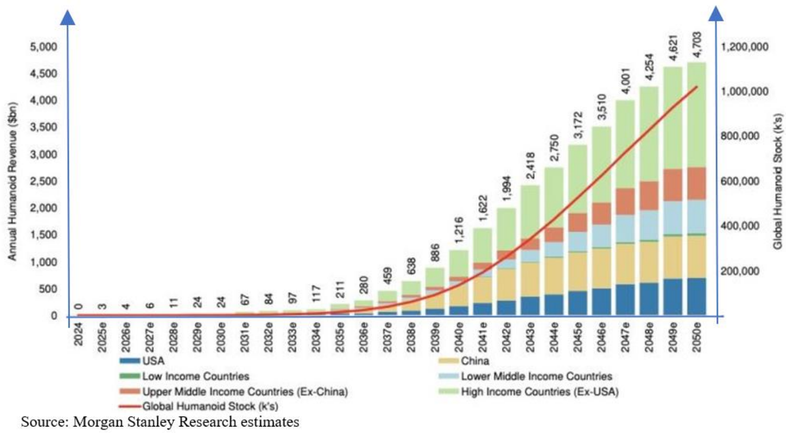


Figure 7. Forecast of global revenue and stock of humanoid robots through 2050

Unlike traditional industrial robots, humanoid robots are designed to mimic human form, movement, and behavior, allowing for easier integration into existing workflows without major modifications to the work environment. Their application is especially valuable for tasks that require high adaptability, fine motor skills, or human-robot collaboration. In final vehicle assembly, humanoid robots can assist in handling irregular components, tightening screws, or conducting visual quality inspections . Additionally, they are increasingly used for intra-plant logistics tasks, such as transporting parts and tools between workstations. The best illustration of humanoid robot implementation in automotive manufacturing is shown in the diagram in Figure 7, which presents projections for the global deployment of such robots up to the year 2050 [33]. Figure 7 presents a projection of annual revenue from humanoid robots (in billions of USD) and global stock of humanoid robots (in thousands of units) for the period from 2020 to 2040, according to estimates by Morgan Stanley Research. The data reveal a significant increase in both revenue and the number of robots, with the most rapid growth expected after 2028. The largest contribution to this growth is anticipated to come from high-income countries (excluding the U.S.), China, and the United States, while low-income countries are projected to experience slower growth. The red line on the graph represents the global number of humanoid robots, which is projected to surpass one million units by 2050. The introduction of these robots has the potential to significantly reduce the physical workload of human workers and enhance overall production efficiency. However, several challenges remain — including high costs, the need for precise workplace mapping, and ethical and safety concerns associated with human–robot interaction. Despite these challenges, leading companies such as BMW, Tesla, and Hyundai are already testing humanoid robots under real production conditions, demonstrating the growing potential of this technology within the automotive industry. Similarly, car manufacturers are exploring the use of humanoid robots in in-plant logistics [34-36]. These robots can take over tasks such as transporting parts and materials between different production stations, thereby reducing the need for human intervention and increasing operational efficiency. Nevertheless, the implementation of humanoid robots continues to face obstacles, such as high costs, technical limitations, and the necessity for additional workforce training. Although humanoid robots are still in the developmental phase, they hold the potential to revolutionize manufacturing environments that demand flexibility. Tesla's Optimus humanoid robot, currently under development, has demonstrated the ability to perform tasks requiring fine motor skills and complex information processing, such as folding laundry. However, the high costs of development and integration still present barriers to broader adoption. In modern manufacturing systems, flexibility is essential—production lines must quickly adapt to new models and variations. Industrial robots perform optimally in structured environments but often require reprogramming for every task change. Humanoid robots, designed to operate in human environments, offer greater adaptability and the ability to interact with human workers. The advantages and disadvantages of implementing industrial and humanoid robots in the automotive industry are summarized in Table 1 [37,38].

Table 1. Comparative analysis of advantages and limitations of industrial vs. humanoid robots across key production stages in the automotive industry

Production Stage	**Industrial Robots**	**Humanoid Robots**
Pressing	High speed and precision; low flexibility to design changes.	Not suitable due to limited strength and speed.
Body Assembly	Efficient in welding and standard tasks; require reprogramming.	Adaptable to model variations; not yet widely applied.
Painting	Consistent and fast; suitable for hazardous environments.	Rarely used; require protection of sensitive components.
Final Assembly	Effective for simple tasks; limited in complex scenarios.	Capable of complex, adaptive tasks in collaboration with humans.

Table 1 presents a comparison of the advantages and disadvantages of industrial and humanoid robots across various stages of automotive manufacturing. Industrial robots have proven to be highly efficient in stages such as stamping, welding, and painting, due to their high speed, precision, and resistance to harsh working conditions. However, they lack flexibility and adaptability to design changes. In contrast, although humanoid robots are not yet widely deployed, they demonstrate promising potential in final assembly tasks, where interaction with human workers and the ability to perform more complex and unstructured operations are essential. In stages that require strength and speed, such as stamping, humanoid robots are not yet competitive. While industrial robots continue to dominate most stages of production, humanoid robots offer significant advantages in areas requiring higher levels of flexibility and cognitive adaptability. Humanoid robots are capable of working side by side with human workers and can take over physically demanding or repetitive tasks, thereby improving ergonomics and workplace safety. The best examples of humanoid robot implementation can be found in leading automotive companies. BMW has initiated trials of humanoid robots at its Spartanburg plant. The Figure 02 robot has successfully performed tasks such as inserting components into fixtures, demonstrating the potential of humanoid robots in assembly stages. Tesla is developing the Optimus robot, aimed at automating repetitive and hazardous tasks within its facilities. Although still under development, this robot represents a significant step toward humanoid workforce automation. Toyota continues to rely on industrial robots as a core component of its lean manufacturing philosophy, employing them in welding, painting, and assembly processes to ensure high efficiency and product quality. While industrial robots remain dominant in high-volume, repetitive processes such as pressing and welding, humanoid robots show promise in flexible, human-centric tasks—especially in final assembly operations. Their ability to work alongside humans can improve ergonomics, safety, and operational flexibility in dynamic production systems [26,38].

CONCLUSION

The comparative analysis of industrial and humanoid robots in the automotive industry highlights their complementary yet distinct roles in modern manufacturing. Industrial robots, with their proven precision, speed, and reliability, remain the foundation of high-volume production, particularly in structured environments like welding, painting, and assembly. Countries such as China, South Korea, and Germany lead in robot deployment, underscoring the link between automation and competitiveness. However, as demand grows for greater flexibility and adaptability, the limitations of traditional robots become evident. In this context, humanoid robots introduce a new paradigm. Though still in developmental stages, they offer promise in tasks requiring dexterity, variability, and human-like interaction, especially in final assembly and internal logistics. Service robots like AMRs and AGVs also contribute by optimizing intralogistics and supporting modular production. Yet, humanoid systems face technological and economic challenges, including high costs, fragility, and complex safety and integration issues. Automotive leaders such as Tesla, BMW, and Hyundai are testing humanoid robots to evaluate their viability in real manufacturing contexts. These pilot projects signal a shift toward more adaptive automation strategies. When comparing robot types across performance, adaptability, and cost, industrial robots dominate structured tasks, while humanoids show potential in dynamic, collaborative settings. As a transitional solution, collaborative robots (cobots) are emerging, blending human capabilities with robotic precision. Ultimately, these technologies are not rivals but complementary assets in smart manufacturing. Their future roles will depend on technical advancements, economic viability, workforce readiness, and ethical considerations. Continued research and interdisciplinary collaboration will be vital in ensuring that automation evolves toward a more resilient, efficient, and human-centered industrial model.

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