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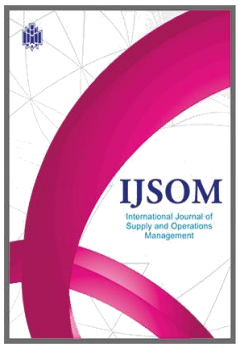

Industry 4.0 Adoption in Transportation: Does Industry 4.0 Adoption Enhance Sustainability? A Systematic Literature Review

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Abstract

The study aims to examine the adoption of Industry 4.0 technologies in the transportation industry and their impact on enhancing sustainability. A systematic literature review was conducted to identify the application and impact of Industry 4.0 in the transportation industry within the context of sustainability. The results showed that Industry 4.0 technologies have significantly contributed to sustainability in the transportation sector. Blockchain technology. Internet of Things (IoT). Artificial intelligence (AI), big data analytics (BDA), Radio Frequency Identification (RFID), Global Positioning System (GPS), and the use of robotics and sensors are found to be the most prominent technologies used in the transportation industry. The results also indicated some key challenges which include higher investment costs, cyber security threats, technological integration, and insufficient qualified and skilled human resources. The study provides valuable insight to businesses and policymakers. Industry 4.0 technologies have the crucial potential to resolve transportation and logistics disruptions and improve sustainable performance. Future studies could investigate to fully understand the long-term effects of Industry 4.0 on sustainability in the transportation sector and the potential for new technologies to further improve transportation systems and explore the barriers to adopting Industry 4.0 technologies in different contexts.

Keywords: Transportation; Industry 4.0; IoT; Blockchain; Sustainability; Impact; Technology.

1. Introduction

Globally, the organizations are transforming into digital form known as Industry 4.0 (Sony & Naik, 2019). Industry 4.0 is transforming the global supply chain industry by integrating advanced technologies such as artificial intelligence, the Internet of Things, blockchain, data analytics, robotics, etc. This integration is leading to significant changes in the way industries work across the world. These technologies have an extensive influence on day-to-day business activities including transportation sector (Bagloee et al., 2016). The transportation industry plays a vital role in the movement of goods and people across borders, connecting different regions of the world. The integration of transportation and Industry 4.0 can revolutionize the transportation industry by optimizing routes, reducing energy consumption, and enhancing safety and reliability. Furthermore, the Industry 4.0 enabled sustainable transportation system benefits a lot because of its data-driven proactive planning, real-time decision-making, and autonomous operations (Sun et al., 2021).
However, the global focus on sustainability is driving industries to operate in a greener manner (Khan et al., 2023). Companies are more concerned and focused on making their supply chain greener (Diabat & Govindan, 2011). By

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adopting Industry 4.0 technologies in transportation, the industry can transform and improve efficiency, safety, and sustainability. However, the way, sustainability is impacting Industry 4.0 and its contribution to sustainable economic, environmental, and social development is gaining prominence and much more attention (Ghobakhloo, 2020).

Developing countries like India, , Bangladesh, and Pakistan are still at an early stage of adopting Industry 4.0 in the transportation industry. The reason could be it is very difficult to change the perception of users towards the effective implementation of new technologies (Khan, et al., 2022). Thus, these countries are facing various challenges and barriers in adopting these technologies. Despite this, the government of Pakistan has established the National Logistics Cell (NLC), a leading digital platform that uses advanced technologies such as the Internet of Things, big data analytics, and Blockchain, to improve transparency, traceability, and efficiency in the transportation sector.

Many technologies come under the umbrella of Industry 4.0 and because of that organizations are facing problems identifying which they should use (Khan et al., 2017). Also, the rise in the concept of sustainability is another concern of organizations (Belhadi et al., 2019; Oudani et al., 2023). However, not all companies are ready to adopt these technologies, and some are still struggling to find the talent or knowledge required to adopt them effectively. Organizations are facing difficulty in hiring qualified people in their workforce (Dalmarco et al., 2019). Particularly, in the transportation industry the adoption of these technologies is not much appreciable, and organizations are facing problems regarding implementing them to achieve sustainability (El Hamdi et al., 2019).

Through this research paper, we bridge the gap between the difficulties faced by organizations in achieving sustainable transportation and for that which technologies they should opt for. We discussed the technologies being used in the transportation industry and how they are impacting their sustainability. Also, we provided some recommendations to make their transportation industry better and more sustainable. Therefore, this paper aims to discuss the recently implemented IR 4.0 technologies and their adoption in the transportation industry and how it is impacting sustainability. Finally, we discussed the benefits associated and key challenges that occur in adopting and achieving sustainable transportation through Industry 4.0. Therefore, this research paper reviews the literature from 2011-2023 using a systematic literature review approach to address the following research questions:

RQ1: What are the potential impacts of Industry 4.0 adoption on sustainability in the transportation industry?
RQ2: How can the transportation industry benefit from the increased automation of Industry 4.0?
RQ3: What impact does the adoption of Industry 4.0 have on the sustainability of the transportation industry?

Additionally, based on research questions we formulated these research objectives:

1.1 Research Objectives:

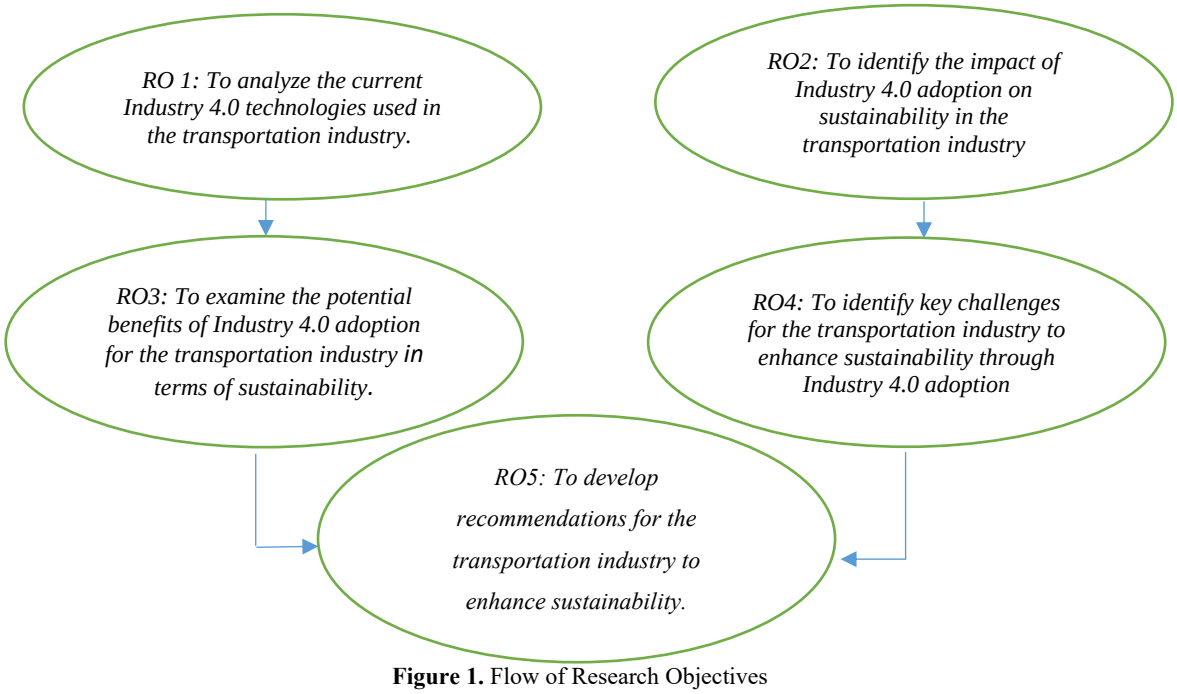

Figure 1. Flow of Research Objectives

The rest of the paper is designed as: section 2 discusses the methodology and inclusion/exclusion criteria. Section 3 includes a discussion based on the application of Industry 4.0 adoption in transportation to enhance sustainability. Further, we discussed the implications and potential benefits of the application of Industry 4.0 in the transportation industry to enhance sustainability. Lastly, we discussed the key challenges in the adoption of Industry 4.0 in the transportation industry to enhance sustainability. This paper proceeds in discussing the objective wise discussion in the rest section. In section 4 we address the practical implications and future research directions. The last section of the paper presented the conclusions.

2. Research Methodology

2.1. Initial Selection Criteria of Selected Articles

The databases of Scopus, Web of Science, google scholar, science Direct, Taylor & Francis, Emerald, Elsevier and Springer were used for the initial search. The custom search option was 2011-2023 as Industry 4.0 was introduced in 2011. We used keywords like "Industry 4.0," "sustainability," "transportation," and "logistics". Also, each technology was separately searched with keywords like "blockchain," "artificial intelligence," "IoT," "Big Data," "cloud computing," "logistics 4.0," "RFID," and "GPS" respectively. Only the published peer-reviewed scientific and impact factor journals along with conference proceedings are selected. Further, we adopted Bolean search method (AND/OR) and extended our search by using terms AND and OR as logical operators. The above mentioned keywords were selected to search the databases mentioned earlier to fetch relevant studies.

2.2. Content Screening and Complementary Search

For content screening, a clear and broad definition of transportation management, logistics management, sustainability, Industry 4.0 technologies, and independent technologies like AI, IoT, cloud computing, blockchain, RFID, Big data, and GPS technologies were selected to identify and include the relevant articles. For inclusion criteria, we go through the keywords, title, abstract, and findings of the articles. Moreover, the main body of the articles was also studied during inclusion. Articles that reported the use of industry 4.0 technologies in transportation and logistics management, also including the aspect of sustainability were selected. On the other hand, articles that did not correctly define the use of technologies in transportation and logistics and mentioned the use of industry 4.0 technologies in other fields besides transportation and logistics management were excluded. Through this criterion, we successfully obtained 65 articles for final review. The finalized articles are shown in below tables.

3. Discussion

3.1 RO1: The Current Industry 4.0 Technologies Used in The Transportation Industry

Technologies not only provide new ways of observing, monitoring, and managing transportation systems but also can change the attributes of the transportation system (Ran et al., 2012). In the transportation industry, the adoption of Industry 4.0 technologies has the potential to revolutionize operations and improve efficiency. Due to this, there is a drastic change in the way organizations operate (Sony & Naik, 2019). To go hand in hand with other organizations and industries, the transportation industry also uses technologies to stay competitive. Various advanced technologies are being utilized to transform traditional transportation practices. The Industry 4.0 concept with the integration of a set of technologies is still an evolving idea (Dalmarco et al., 2019). However, the above-mentioned technologies of Industry 4.0 are artificial intelligence, big data analytics, blockchain, cloud computing, the Internet of Things, RFID, GPS, and sensors. The use of these technologies has a great impact on the transportation industry. By leveraging these Industry 4.0 technologies, the transportation industry can achieve significant advancements such as operational efficiency, sustainability, safety, and customer experience. The integration and effective utilization of these technologies continue to drive innovation and transformation in the transportation sector, shaping the future of mobility and logistics. According to (Ran et al., 2012). The technologies can majorly change the characteristics of the current transportation system with increased connectivity, automation, and optimization toward a much more user-oriented, system-optimal, safe, and sustainable system.

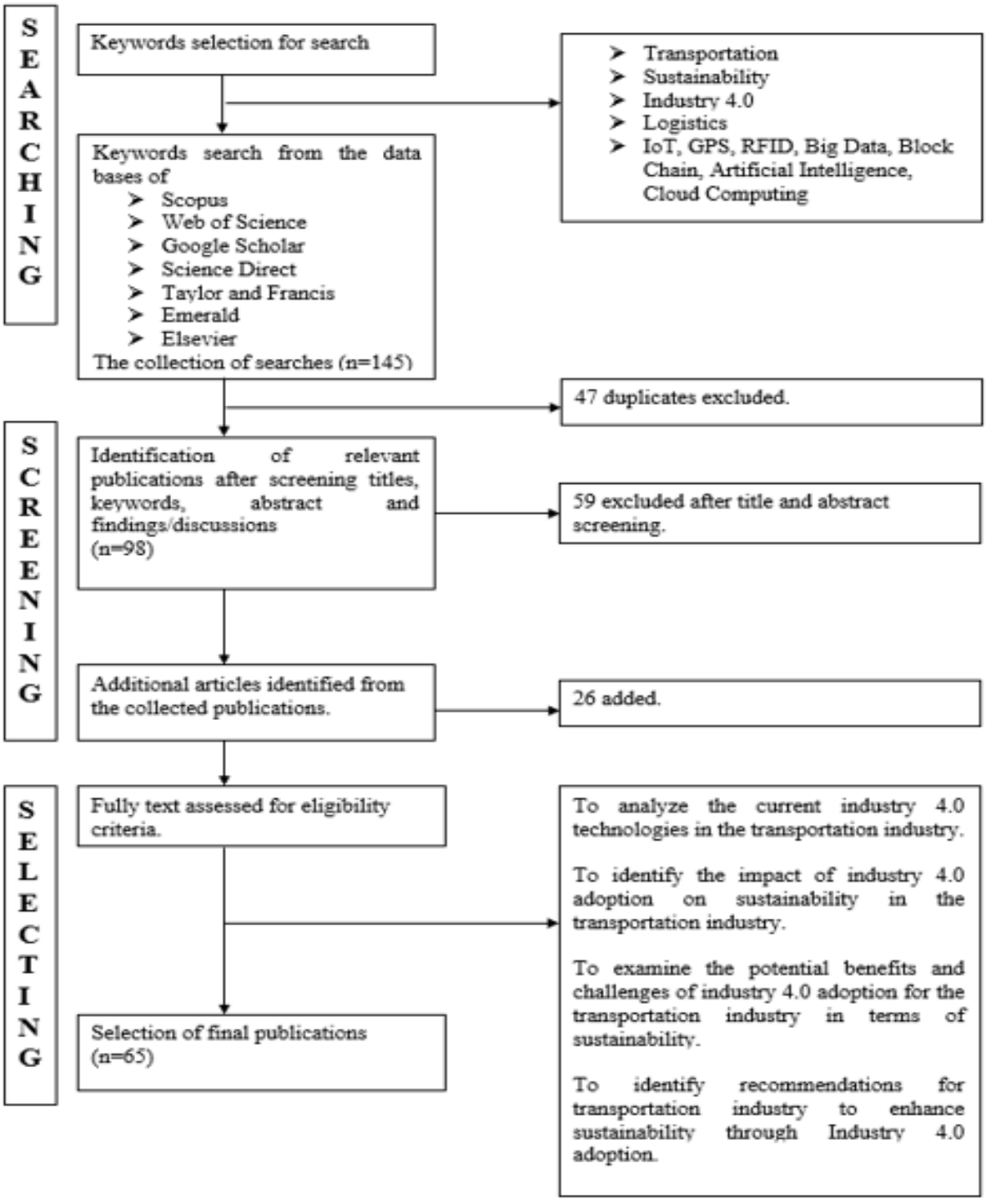

Figure 2. Screening anf Selection Criteria

Table 1. Recent IR 4.0 technologies used in Transporation

Authors	Technology	Impact/Finding
Ran et al. (2012)	Intelligent Transportation system technologies (ITS) such as wireless communication, connected vehicle, smart vehicle cloud computing	These ITS technologies can change the way of the existing transportation system with increased connectivity, automation, and optimization which make it more user-oriented, system-optimal, safe, and sustainable system.
Imran et al. (2018)	Big data, smart factories, cyber-physical systems (CPS), (IoT), and interoperability	Industry 4.0 has major importance in overcoming the various challenges of the textile and logistics industry of Pakistan.
Sharma et al. (2020)	RFID	The transportation industry can highly benefit from RFID systems.
Fitri et al.(2022)	Big Data, IoT, Cloud computing, AI, Blockchain	The GCC countries are at a very early stage in the adoption of Industry 4.0 in their logistics and transportation.
Maxim Mnyakin (2023)	AI, IoT, and cloud computing	The benefits of these technologies and also concludes that the incorporation of these technologies can result in an improvement in the overall efficiency of transportation systems.
Vaidya, et al. (2018)	Big data, cloud computing, IoT, and Autonomous Robots	Nine pillars of Industry 4.0 are explained with the examples to understand the application of Industry 4.0 as well as used to identify the challenges and issues with the implementation of Industry 4.0.
Khan & Manzoor (2021)	Blockchain, IoT, AI, BDA, Cloud Computing, 5G and smartphone applications, robotics and drones	These are key technologies used in the supply chain and they also discuss their impact on the supply chain as well as key barriers.
Hamdi, & Abouabdellah (2022)	AI, CPS, Cloud computing, big data, and IoT	The link between Industry 4.0 and Logistics 4.0. Also, they discuss the role of technologies and their contributions to adopting them in the logistics process.
Sony & Naik (2019)	CPS, IoT, and cloud computing	They identify six key components and their interrelationships.
Shoukat & Xiaoqiang (2022)	N/A	From the data of the largest logistics service providers in Pakistan, it is concluded that intermodal transportation is 82.6% more economical and 78% greener compared with road freight transportation.
Yi-Hu et al. (2015)	GPS	They identified seven key factors which are executive support, funding and budget, experience, and ability of consultants, project team composition, user recognition, timely and correct information, and degree of completeness of transmission equipment
Abdirad, & Krishnan (2020)	Industry 4.0	The findings reveal interesting findings, which are helpful for the academic and industry both, especially for top managers.
Machała, et al. (2022)	Virtual Reality (VR), Augmented Reality (AR).	AR/VR technologies and IT systems can transform traditional companies into innovative companies to compete in the global market.
Montemayor, & Chanda (2023)	Industry 4.0	All automotive companies are shifting to electric vehicles but the efforts currently in operation are not at scale.
Akkerman, et al. (2022)	Industry 4.0	Only small adaptations have been done but there is growing interest for Industry 4.0 concepts in cross-docking.

Shi, et al. (2011)	RFID	The container transportation industry is still in the basic stages of its RFID applications.
Lookman, et al. (2023)	Industry 4.0	The innovative capability radically affected the trucking company's competitive advantage, but industry 4.0 does not moderate this impact.
Özdağoğlu & Bahar (2022)	Industry 4.0	The potentials of smart or digital supply chain and discusses how companies handle their logistics operations during the COVID-19 period.

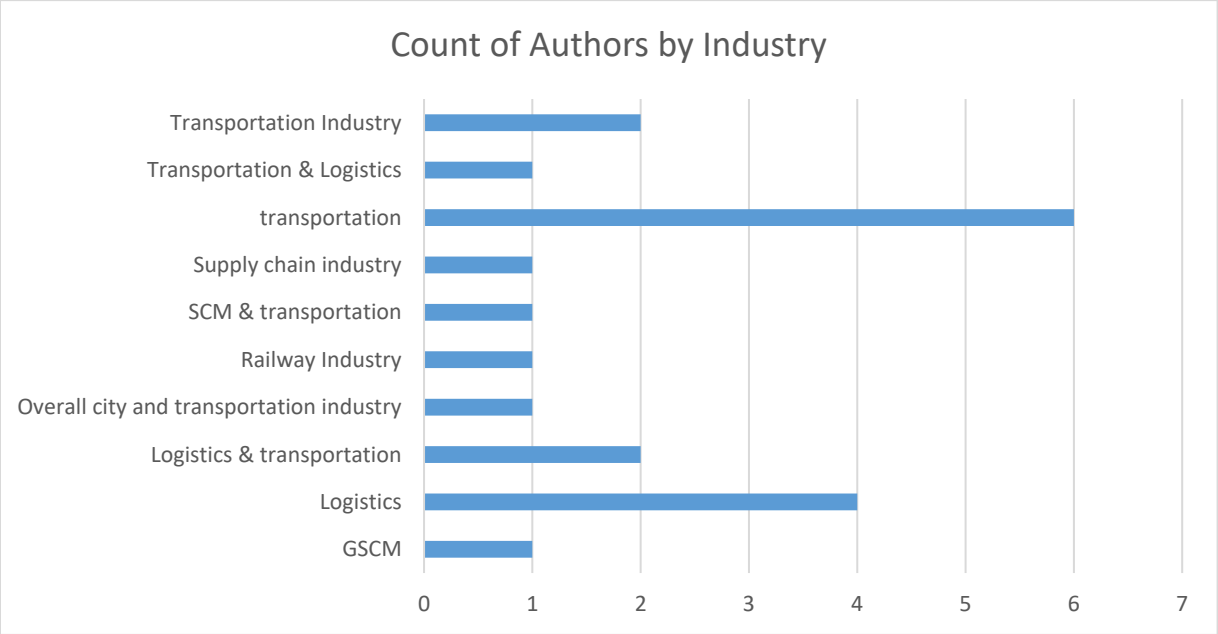

Figure 3. Publications by Industry

3.2 RO2: The Impact of Industry 4.0 Adoption on Sustainability in The Transportation Industry

The impact of Industry 4.0 adoption on sustainability in the transportation industry has been significant and holds great potential for positive change. The most important features of Industry 4.0 in transportation are data-driven proactive planning, real-time decision-making, and autonomous operations (Sun et al., 2021). Industry 4.0, characterized by the integration of digital technologies and automation, has introduced various advancements that contribute to sustainability in transportation. To have long-term sustainability in industrial and social organizations Industry 4.0 technologies play a key role in guiding them (Jabbour, et al., 2018). With the adoption of industry 4.0 features such as interoperability, digitization, visualization, and automation, companies can enjoy horizontal and vertical integration for collaboration and better utilization of resources and can make their production, manufacturing, and logistics supply chains smarter, adaptive, faster, smoother, and efficient. Also, Industry 4.0 has great implications for the logistics and supply chain through automation, real-time tracking, route optimization, risk management, and horizontal & vertical integration (Landge & Jaiswal, 2021). By optimizing operations and reducing energy usage, Industry 4.0 adoption helps to mitigate the environmental impact of transportation activities.

A study conducted by Cézanne, Lorenz, & Saglietto (2020) discusses the impact of Industry 4.0 on the environment are both positive and negative. Some researchers have pointed out that there are negative environmental impacts of energy in the manufacturing of new devices on the other hand other researchers see Industry 4.0 as having a major transformative possibility that will contribute to the achievement of the United Nations' Sustainable Development Goals. Industry 4.0 makes logistics management more efficient. Hosman & Rusch (2017) discussed that the connectivity of products and services through the Internet such as blockchain technology will enable the decentralized control of value chains. They also state that digital connectivity offers the possibility of improving automated

production as well as the self-optimized production of goods and services, including delivery without the presence of the human agent. Moreover, Witkowski, (2017) discusses the importance of IoT technology particularly in the logistics and transportation sector. Another benefit of IoT is that it provides real-time information on logistics vehicles for improved logistics services, which results in cost reduction through controlled and optimized fuel consumption (Liu et al., 2019).

According to the previous literature by Khan & Manzoor, (2021) in the supply chain industry 18% of organizations using artificial intelligence, 12% report that their organization is already using autonomous vehicles, 44% of organizations are already users of BDA, only 11 % of organizations are using blockchain technology, 16% of them already using drones for their supply chains, 48% of them are using IoT technology in practice and 29% of the responding organizations are using robotic technology. There are various negative impacts of the adoption of Industry 4.0 in the transportation industry such as the initial investment costs, technological integration, and ensuring data security and privacy. Another negative impact of Industry 4.0 on employment and jobs is that machine learning, robotics, and digitization will eliminate jobs which will result in major job losses (Cézanne et al., 2020). With technological advancement, the risk of cyber-attacks is increasing (Barleta et al., 2020).

Lastly, the impact of Industry 4.0 adoption on sustainability in the transportation industry is substantial. Companies adopting Industry 4.0 are making all their supply chain process digitalize starting from planning, to supply, to manufacturing, to delivery, and to return, which will positively impact logistics processes by improving flows, optimizing work, and reducing lead times (Hamdi & Abouabdellah, 2022).

Table 2. Impact of Industry 4.0 Adoption on Sustainability in the Transportation Industry

Authors	Application of Industry 4.0 Adoption in Transportation to Enhance Sustainability	Impact/Finding
Umar et al. (2021)	Discussion on the advantages of using blockchain technology during products transportation according to Industry 4.0 Strategy.	GSCM practices mediate the effect of Industry 4.0 on both economic and environmental performance. Also, the results indicate that GSCM practices are positively affected by Industry 4.0.
Miler et al. (2016)	To discuss an overview of Industry 4.0 meaning, challenges, and benefits of implementing it.	Provides methodologies to analyze the sustainability of transportation systems.
Esmaeilian et al. (2020)	Aims wasto analyze the challenges and opportunities of adopting i4.0.	The ways by which the scientific community can participate in creating conditions for Industry 4.0 to assist sustainability objectives.
David H. Kaplan (2015)	Presents the challenges and opportunities related to transportation policies that may arise because of emerging autonomous vehicle (AV) technologies.	There are low existing levels of sustainable transportation among students around campus.
Kumar et al.(2021)	Aims to focus on the technology-related difficulties and opportunities and analyses the impact of Industry 4.0) on the transportation sector.	The results show that technologies are impacting e-commerce businesses.
Morteza Ghobakhloo (2020)	Aims to discuss the industry 4.0 opportunities in logistics.	Relationships exist among several sustainability functions of Industry 4.0.
de Sousa Jabbour, et al. (2018)	Discusses Internet of Things (IoT) opportunities in the transportation and logistics sector	Proposes eleven critical success factors in CSF that should be cautiously managed when integrating Industry 4.0 and environmentally sustainable manufacturing.
Sun et al. (2021)	Analyzes the industry 4.0 importance in the logistics and transport industry.	Industry 4.0 technologies provide opportunities for improving the economic efficiency, environmental performance, and social impact of logistics sectors. However, challenges are trade-offs among different sustainability indicators, unclear benefits, lifecycle environmental impact, inequity issues, and technology maturity.

Liu et al. (2019)	Internet of things (IoT) technique has been conducted to investigate and analyze the pros and cons from using this technique for the shipping transportation industry.	It helps in reducing logistics costs and fuel consumption, improving vehicles' utilization rate, and achieving real-time logistics services with high efficiency.
Akhtar (2022)	Aims to categorize the research on environmental sustainability in logistics and transportation.	The benefits of these technologies are sustainability, efficiency, cost reduction, transparency, traceability, and collaboration.
Diabat & Govindan, (2011)	Aims to identify IoT-based entrepreneurial opportunities in the transportation industry and identify their importance.	They identified several drivers of green supply chain management (GSCM by analyzing the GSM literature and by consulting with experts in the industry.
Göçmen & Erol (2018)	Aims to examine the logistics impacts on cost and identify the transportation opportunities	Logistics firms can minimize total costs and provide opportunities to manage transportation. Also, different modes of transportation should be used to transport all the demand.
Hou et al. (2016)	Aims to address the use of advanced technologies to reduce traffic congestions	Intelligent transportation systems use advanced technology to provide drivers with convenient information to help reduce traffic congestion and to increase available road capacity.
Karuppiah et al. Ali (2022)	To study the enablers of smart transportation.	The enablers are the enhancement of cross-departmental cooperation, decision synchronization, technology cooperation, policy cooperation and route optimization as the five most significant enablers of sustainable transportation.
Liyanage et al. (2017)	Aims to evaluate the South Asian transportation sector	South Asian countries need to improve different attributes of their transportation sector such national-level transportation policies. Also, sustainable transportation is not about mobility but also about creating safer, convenient, and environmentally friendly transportation systems.

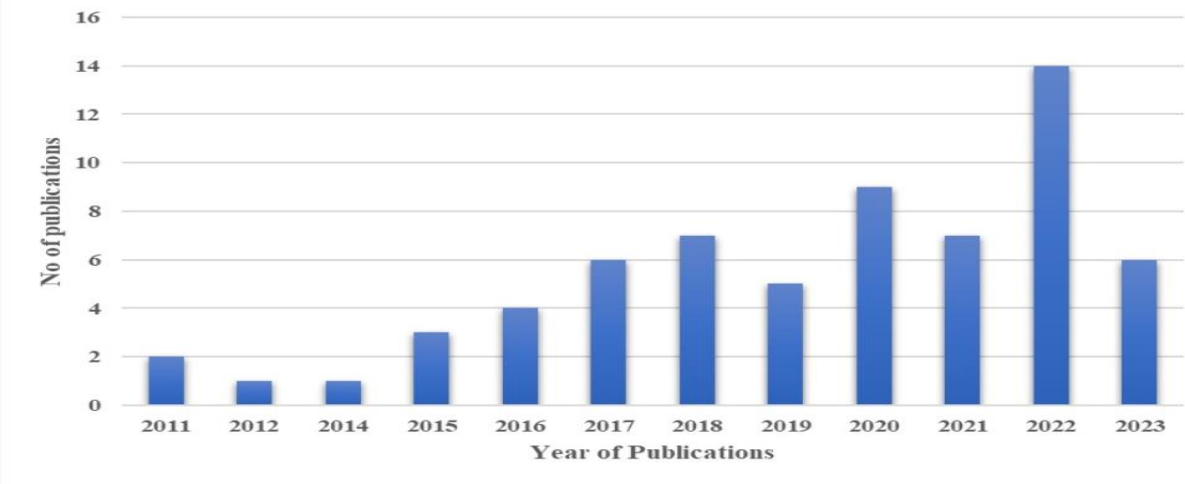

Figure 4. Yearwise Publication and their Selection

3.3 RO3: The Potential Benefits of Industry 4.0 Adoption for The Transportation Industry in Terms of Sustainability.

We have reviewed a lot of literature to identify the potential benefits of the adoption of Industry 4.0 in the transportation industry and we find out that it brings numerous benefits in terms of sustainability. Through the

integration of digital technologies and automation, Industry 4.0 can enhance energy efficiency (Mnyakin, 2023) by optimizing route planning, reducing idle times, and enabling predictive maintenance, thereby lowering fuel consumption and emissions. (Sun et al., 2021) conducted a study and the results show that Industry 4.0 technologies come up with opportunities for logistics sectors in improving economic efficiency, environmental performance, and social impact.

Using and connecting information from Industry 4.0 with intelligent transport systems could result in very effective, demand-oriented, and higher productivity of manufacturing enterprises as well as sustainable development of society (Lom et al., 2016). However, an IoT-based real-time status-sensing model of logistics vehicles can reduce the logistics cost and fuel consumption and can improve vehicles' utilization rate, and achieve real-time logistics services with high efficiency (Liu et al., 2019). Moreover, the utilization of the Internet of Things (IoT) can benefit the transportation industry to enhance sustainability such as they enable connected vehicles, real-time fleet management, smart parking, traffic monitoring, and remote diagnostics (Mnyakin, 2023). Furthermore, Industry 4.0 can facilitate the adoption of electric and autonomous vehicles, reducing carbon emissions and promoting sustainable mobility. Technology like Artificial Intelligence AI can be used for autonomous vehicles, traffic management, predictive maintenance, driver assistance, and demand forecasting (Mnyakin, 2023). The benefits of cloud computing in the transportation industry are they provide vehicle-to-cloud communication, accessible infrastructure, data analytics, mobility-as-a-service, and predictive maintenance (Mnyakin, 2023).

The advanced technologies of Industry 4.0 such as CPS, IoT, BD, and CC provide traceability, monitoring, and controlling of logistics with the help of sensors and these technologies are helpful for logistics in tracking, route optimization, diversion, security, and risk management (Landge & Jaiswal, 2021). Akhtar, (2022) concluded that the advanced technologies of Industry 4.0 such as big data analytics (BDA), artificial intelligence (AI), machine learning (ML), internet of things (IoT) and sensors, blockchain technology (BCT), robotic systems (RS), cloud computing (CC), cyber-physical system (CPS), etc. has many benefits i.e., sustainability, efficiency, cost reduction, transparency, traceability, and collaboration. However, he also mentioned that there are many challenges in implementing Industry 4.0. Additionally, the implementation of smart infrastructure and connected systems can enhance traffic management, reducing congestion and improving overall transportation efficiency. By embracing Industry 4.0, the transportation industry can make significant strides towards sustainability, minimizing environmental impacts and paving the way for a greener and more efficient future.

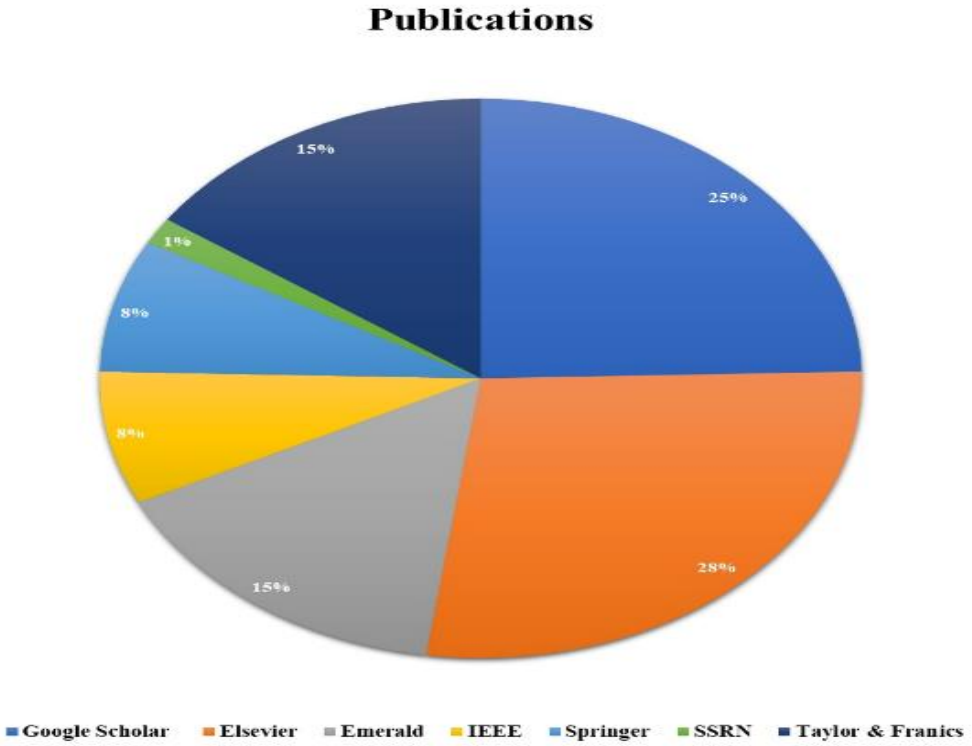

Figure 5. Publications and Databases in Selection

Table 3. Benefits of IR 4.0 Adoption in Transporttion

Authors	Technology	Benefits
Dmitriy et al. (2020)	Block Chain Technology	There are challenges in implementing blockchain, particularly in transport logistics within the framework of Industry 4.0 Strategy.
Mohamed Mamad (2018)	Industry 4.0 technologies	The various benefits and challenges of Industry 4.0 implementation.
Dalmarco et al. (2019)	Aug. Real., Additive Manufac., Big Data, Cloud Computing, Cyber-Physical Systems, Cybersecurity, Smart Robotics, Simulation, and System Integration	The major challenges found are the analysis of data generated, the integration of new technologies with available equipment, and the workforce. However, the opportunities are efficiency, flexibility, productivity, cybersecurity, quality of products and services
Bagloee et al.(2016)	Autonomous vehicle (AV)	They proposed a conceptualized navigation model for the AV which leads to highly efficient traffic circulations. Also, they discuss the opportunities and challenges of AV technology.
Erkollar& Oberer (2018)	Robotics, Artificial Intelligence, the Internet of Things, Sophisticated Sensors, Cloud Computing	In the logistics sector, big data analytics are being utilized to perform various operations. Also, it indicates that the application of Industry 4.0 concepts, technologies, and systems can extend across different transportation modes.
Hofmann & Rüsch (2017)	Cyber-physical systems (CPS), IoT, IoS, Smart factory	Identify the opportunities in terms of decentralization, self-regulation, and efficiency. Also, precisely recognize the potential Industry 4.0 implications in the context of Just-in-Time/Just-in-Sequence and cross-company Kanban systems.
Kumar & Dash (2017)	IoT	Findings indicate that the adoption of IoT in transportation is very effective and profitable.
Holubčík et al,(2021)	AI, DSS (Decision Support System), MIP (Mixed Integer Programming), and CP (Constraint Programming)	Decision-making can become easy for the overall supply chain using Industry 4.0.
Tien Anh Tran (2023)	Industry 4.0	Discusses the overall sight in researching new technologies where IoT has been investigated from this research.
Marchet et al. (2014)	IR 4.0	Environmental sustainability within logistics and freight transportation are less.
Pour et al. (2023)	Internet of thing IoT	Classified entrepreneurial opportunities into five main categories, that are “smart vehicles”, “business partners/smart transportation supply side”, “supporting services”, “infrastructures”, and “smart transport management and control”. The infrastructures group of opportunities ranked the highest amongst the identified groups.

RO4: Key challenges for the transportation industry to enhance sustainability through Industry 4.0 adoption.

As every technology comes with benefits and opportunities, many challenges also come with the transformation in technology (Sun et al., 2021). So, the transportation industry also faces several key challenges in enhancing sustainability through the adoption of Industry 4.0. One of the primary challenges is the technological integration required to incorporate Industry 4.0 technologies into existing transportation systems (Sun et al., 2021). This involves retrofitting or replacing outdated infrastructure and vehicles with smart and connected systems. A large investment is required for implementing Industry 4.0 (Vaidya et al., 2018) and the complexity of this integration can be a significant barrier, requiring substantial investments and careful planning. Additionally, ensuring interoperability and

compatibility between different technologies and systems can pose challenges, as standardization and harmonization efforts are necessary to ensure seamless connectivity and data exchange.

One of the most important and major challenges is the need for skilled and qualified personnel who can effectively operate and maintain the advanced technologies associated with Industry 4.0 (Mohamed, 2018). Training and upskilling the workforce to harness the full potential of these technologies can be time-consuming and resource-intensive (Dalmarco et al., 2019). Furthermore, as cyber security threats increase dramatically, ensuring data security and privacy in an interconnected and data-driven environment is critical. Protecting sensitive data from cyber threats and maintaining data integrity requires robust cybersecurity measures and protocols (Vaidya et al., 2018). Overcoming these challenges necessitates collaborative efforts among stakeholders, including government bodies, industry players, and technology providers, to create supportive policies, invest in research and development, and foster an ecosystem conducive to sustainable Industry 4.0 adoption in the transportation industry.

Table 4. Industry 4.0 Adoption Chanllenges

Authors	Technology	Challenges
Barreto et al. (2017)	Internet of Things, RFID, Sensors, and GPS	The result of this paper shows that Logistics 4.0 paradigm focuses on optimizing inbound and outbound logistics using intelligent systems, software, and databases and information is shared through Internet of Things (IoT) systems to achieve a higher degree of automation.
Mohamed Mamad (2018)	Industry 4.0 technologies	The results discuss the various benefits and challenges of Industry 4.0 implementation.
Dalmarco et al. (2019)	Augmented reality, Additive Manufacturing, Big Data, Cloud Computing, Cyber-Physical Systems, Cybersecurity, Smart Robotics, Simulation, and System Integration	The major challenges found are the analysis of data generated, the integration of new technologies with available equipment, and the workforce. However, the opportunities are efficiency, flexibility, productivity, cybersecurity, quality of products and services
Bagloee et al.(2016)	Autonomous vehicle (AV)	In this research, they proposed a conceptualized navigation model for the AV which leads to highly efficient traffic circulations. Also, they discuss the opportunities and challenges of AV technology.
Wang et al. (2023)	Internet of Things, big data, cloud computing, blockchain, and artificial intelligence	The results concluded that there is a gap between the application of digital technology in green supply chains
John et al. (2022)	Artificial Intelligence (AI), Internet of Things (IoT), Cloud Computing, Big Data, Cybersecurity, Modelling and Simulation, Smart Decision Support Systems (SDSS), Computer Vision, and Virtual Reality (VR).	The paper recognizes nine technologies that make contributions to tackle the identified problems in the railway industry and the combination of these can lead to better results or innovative solutions.
Erkollar & Oberer (2018)	advanced robotics, artificial intelligence, the Internet of Things, sophisticated sensors, cloud computing	The study shows that in the logistics sector, big data analytics are being utilized to perform various operations. Also, it indicates that the application of Industry 4.0 concepts, technologies, and systems can extend across different transportation modes.
Popova et al.(2021)	RFID	The finding of this study is that the application of RFID technology would significantly increase the efficiency of logistics processes.
Vaidya et al. (2018)	Big data, cloud computing, IoT, and Autonomous Robots	To conclude the results nine pillars of Industry 4.0 are explained with the examples to understand the application of Industry 4.0 as well as used to identify the challenges and issues with the implementation of Industry 4.0.

Chhabra & Singh (2022)	Industry 4.0	In the results this research identifies 16 barriers of implementing green logistics. Also, findings will help manufacturing organizations in developing strategies for implementing green logistics to achieve long-term sustainability.
Tien Anh Tran (2023)	Industry 4.0	This research discusses the overall sight in researching new technologies where IoT has been investigated from this research.
Baig et al. (2022)	N/A	The result reveals that safety and infrastructural factors are the most dominant ones that affecting sustainable mobility within the campus.

3.3 RO5: Recommendations for The Transportation Industry to Enhance Sustainability Through Industry 4.0 Adoption.

To enhance sustainability through Industry 4.0 adoption, the transportation industry can implement several recommendations. Firstly, the organization can adopt smart fleet management systems. Although a fleet management system is a complicated network to manage and control (Hu et al., 2015) it utilizes real-time data and IoT sensors that can optimize routes, reduce idle times, and improve fuel efficiency, thereby minimizing emissions and resource wastage. Moreover, the adoption of predictive maintenance strategies, utilizing machine learning algorithms and sensor data, can proactively address maintenance needs, reducing downtime, improving vehicle reliability, and extending asset lifespan, thus promoting sustainability.

Thirdly, investing in electric and autonomous vehicles can significantly reduce carbon emissions and optimize traffic flow, reducing congestion and enhancing fuel efficiency. Autonomous vehicles (AV) technologies can help in decreasing transportation costs and reduce crashes, energy consumption, pollution, and congestion while at the same time increasing transport accessibility (Bagloee et al., 2016). Additionally, integrating smart infrastructure and connected systems can improve traffic management, reducing environmental impacts and enhancing overall transportation efficiency. Also, autonomous robots can use in the transportation industry because it can help transport materials, sortation, loading and unloading activities, product making, product finalizing, packaging, etc. (Landge & Jaiswal, 2021). By implementing these recommendations, the transportation industry can effectively leverage Industry 4.0 technologies to enhance sustainability, minimize environmental footprints, and foster a greener and more efficient future.

Table 5. Recommendations for IR 4.0 adoption in Transportation

Authors	Application of IR 4.0 to Enhance Sustainability	Recommendations
Umar et al. (2021)	Aims to examine the impact of Industry 4.0 on economic and environmental performance through the mediation of green supply chain management (GSCM) practices in an emerging economic context, like Pakistan.	The result shows that GSCM practices mediate the effect of Industry 4.0 on both economic and environmental performance. Also, the results indicate that GSCM practices are positively affected by Industry 4.0.
Miller et al. (2016)	Discusses the relationship between public transportation and sustainability.	Provides methodologies to analyze the sustainability of transportation systems.
Michal et al. (2016)	To propose the combination of the Smart City Initiative and Industry 4.0.	The conjunction of Industry 4.0 with intelligent transport systems of the smart city can help to create very effective, demand-oriented, and higher productivity of manufacturing enterprises as well as sustainable development of society.
Rossi et al. (2020)	Aims to introduce a new transport paradigm for perishable food that overcomes the barriers to the application of intermodal transportation.	Proposed a new model (called the 'traveling stock' model) of perishable food transport and the implementation of this model says that the intermodal system is both environmentally and economically sustainable.

Akter et al. (2020)	To offer an effortless transportation facility by minimizing the problems faced by passengers, drivers, and the concerned authorities with RFID GPS, and an android application for passengers.	The system will significantly reduce the traffic flow on the road. Also, it will make traveling hassle-free and convenient.
Krzysztof Witkowski (2017)	To discuss some 'smart' solutions which could be innovative solutions in both technology and organization.	These technologies create opportunities to fulfill the needs of customers and contribute to the development of logistics and supply chain management.
Baygin et al. (2022)	Blockchain-based solutions are developed for local cargo networks. With this approach using different technologies, a fast-shipping management architecture that ensures security between the parties is provided.	The proposed approach aimed to provide a faster, more effective, and more secure solution to classical cargo management architectures.
Khan et al. (2022)	Investigates the usage pattern of three-wheeler vehicles and the thoughts on the adoption of electric three-wheelers	Users will adopt hybrid and electric three-wheelers in Pakistan due to economic benefits.
Al-Lawati et al. (2015)	A system to monitor the pick-up/drop-off of school children using the RFID system is presented to enhance the safety of children during their daily transportation from and to school.	The system is promising for daily transportation safety.
Li & Wang (2020)	Introduced a new model of urban and rural passenger transport regulatory information construction and development.	The Internet of Things technology has more technical advantages instead of the traditional way, and the Internet of Things technology has a wide range of applicability in the field of urban and rural passenger services.
Saarika et al. (2018)	Proposed an IoT-based smart parking system along with an intelligent signboard.	A mobile or internet application can be provided to check the availability of parking slots. The sign board will show the place, the distance to that place, weather conditions, temperature, and different routes to those places.
Fong et al. (2019)	This project will provide a proof of concept by using a much weaker form of RFID to show that it is viable for highway tolls.	The results of this system will be proved to be beneficial to the masses because it will reduce the traffic jams at major toll plazas.
Brazález et al. (2022)	Proposes a Pandemic Intelligent Transportation System (PITS) based on different technologies.	Application of PITS provides support for authorities in the decision-making process about mobility restrictions and obtain fast routes for drivers. Also, PITS is a useful proposal which can easily be adapted to other circumstances to tackle different emergency situations.
Pathak et al. (2019)	Proposes a comprehensive framework to evaluate the sustainability performance of freight transportation systems.	The application of this framework is explained through a case example and the results shows that this framework would serve as a reference for decision-makers in selecting the most sustainable freight transportation system.
Modica et al. (2021)	To examine how Logistics 4.0 affects the design and configuration of the transportation process. Also, this study provides a framework for Logistics 4.0 in transportation.	This framework is crucial for supporting the implementation of Logistics 4.0 in transportation and discusses the related opportunities for companies.
Trappey et al. (2017)	To focuses on studying the related technology roadmaps for the adoption of IoT technologies in smart logistic services.	Proposes a roadmap approach to visualize the patent allocations and evolutions related to logistic services at each level. Also, IoT enabled smart logistic patents are analyzed to identify technology-related business strengths and strategies.

Rahman et al. (2020)	Aims to explore the impact of Industry 4.0 on the performance of the cargo logistic business (service sector) in Bangladesh and Canada.	The findings reveal that Industry 4.0 has a substantial role in promoting and improving the performance of the services industry of both economies.

Conceptual Framework

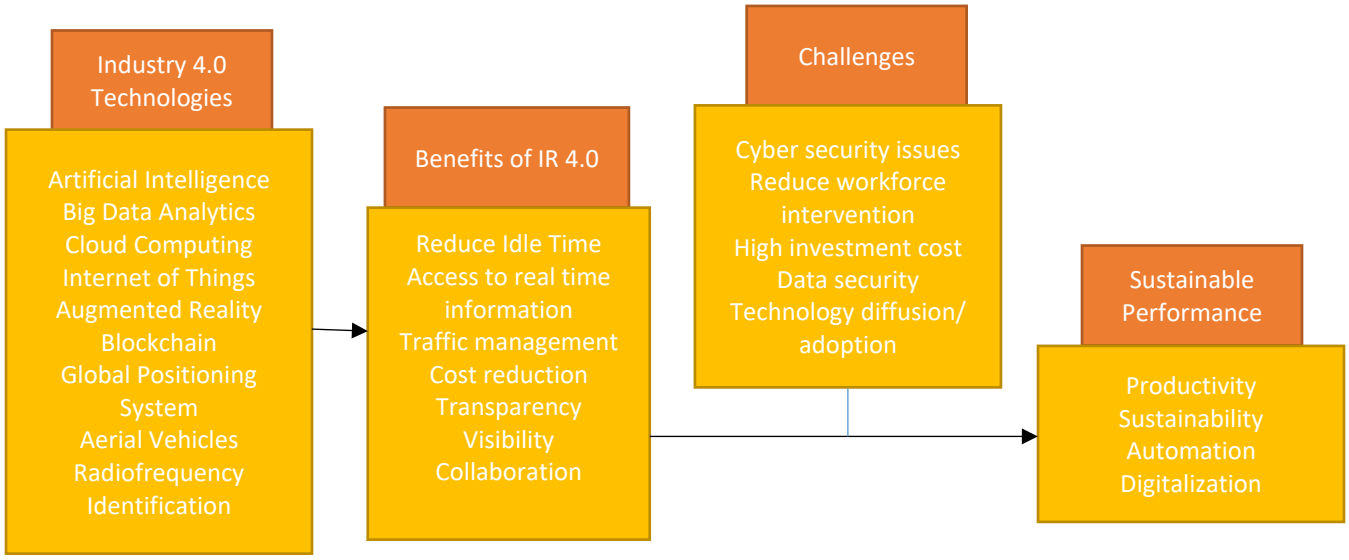

Figure 6. Conceptual Framework
Source: (Author's Conceptualization)

4. Conclusion

A thorough literature review has been conducted to identify the adoption of Industry 4.0 technologies in the transportation industry and their impact on enhancing sustainability. We have gone through google scholar, science direct, and Taylor & Francis databases to collect the scholarly published peer-reviewed journals and identify the 45 articles, and conference proceedings from 2011 to 2023. The literature has provided strong evidence that industry 4.0 technologies have a great impact on transportation industries across the world and it enhances overall sustainability. Further, we identified the different Industry 4.0 technologies used in the transportation industry. Blockchain technology. Internet of Things (IoT). Artificial intelligence (AI), big data analytics (BDA), RFID, GPS, and the use of robotics and sensors are found to be the most prominent technologies used in the transportation industry. In this study, we found that Industry 4.0 technologies can significantly contribute to sustainability in the transportation sector. Besides this, we also identified the potential benefits of these technologies in the transportation industry in the context of sustainability. We also provide critical challenges to implementing these technologies. Higher investment costs, cyber security threats, technological integration, and insufficient qualified and skilled human resources to implement these technologies were the main challenges. In the end, we provided the practical implications and future research directions.

5. Practical Implications and Future Directions

The practical implications of our research are for businesses and policymakers. Businesses adopting Industry 4.0 technologies can lead to cost savings, increased efficiency, and improved environmental performance. Policymakers can support the transition to sustainable transportation systems by creating incentives for businesses to adopt Industry 4.0 technologies and by investing in infrastructure that supports these technologies. We recommend that businesses in the transportation sector explore the potential of Industry 4.0 technologies and consider how they can be integrated

into their operations to promote sustainability. Policymakers should work closely with industry stakeholders to develop policies and regulations that support the adoption of these technologies and facilitate the transition to sustainable transportation systems.

By understanding the practical implications of our research, stakeholders in the transportation sector can make informed decisions about adopting Industry 4.0 technologies and contribute to a more sustainable future. The limitations of our research are that we have only gone through google scholar, science direct, and Taylor and Francis to get the articles related to Industry 4.0 in transportation. Future studies can be conducted to search from other search engines like Scopus, web of Science, etc. to review articles related to this topic. In addition to this, we only reviewed published articles and conference papers. Future studies can induct books, book sections, and trade journals in their research to get more about the topic. However, further research is needed to fully understand the long-term effects of Industry 4.0 on sustainability in the transportation sector. Future studies could investigate the potential for new technologies to further improve transportation systems and explore the barriers to adopting Industry 4.0 technologies in different contexts. Also, researchers can deepen their understanding of the relationship between Industry 4.0 adoption and sustainability in the transportation industry, contributing to the development of strategies, frameworks, and best practices that promote sustainable and efficient transportation systems.

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