Advancing Autonomous Last-Mile Delivery: A Techno-Economic Comparison of U.S. and Chinese Innovations

***Olakunle Abimbola Kumuyi**

College of Technology, Architecture and Applied Engineering, Bowling Green, Ohio, United State

***Corresponding Author**

DOI: https://doi.org/10.51244/IJRSI.2025.12040124

Received: 22 April 2025; Accepted: 26 April 2025; Published: 20 May 2025

ABSTRACT

This study conducts a comparative economic analysis of autonomous vehicle (AV) adoption in last-mile delivery between China and the United States, with a focus on both aerial (drone) and ground-based systems. Drawing on case studies, empirical data from 2018 to 2024, and regulatory assessments, the research evaluates how differing national contexts shape AV implementation outcomes. China's rapid integration of AV technologies is facilitated by centralized policy support, cohesive regulations, and smart infrastructure, enabling businesses of all sizes to reduce costs, scale efficiently, and achieve substantial delivery speed improvements. Conversely, U.S. businesses face higher adoption barriers due to fragmented regulatory environments, slower infrastructure development, and scalability limitations, particularly for small and medium-sized enterprises. Despite these hurdles, technological innovation in the U.S. shows promising potential. The study finds that while drones enhance speed and sustainability, ground vehicles offer superior payload capacity and route flexibility, with hybrid models emerging as the most economically viable. Policy harmonization, infrastructure investment, and SME access to AV solutions are identified as critical for unlocking economic benefits across both markets. This research offers actionable insights for stakeholders aiming to accelerate the future of autonomous last-mile logistics.

Keywords: Autonomous Vehicles (AVs), Last-Mile Delivery, Economic Viability, Regulatory Frameworks, Drone Delivery, Autonomous Ground Vehicles (AGVs), Infrastructure Readiness, China vs. United States, Small and Medium-Sized Enterprises (SMEs), Scalability and Adoption Rates

INTRODUCTION

Background and Motivation

Last-mile delivery is widely considered one of the most crucial stages in the logistics chain, particularly as it directly impacts customer satisfaction and defines the final impression of the e-commerce experience (Mercado-Daneri., The Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel., 2022). With the steady growth of online shopping, especially accelerated during recent years, the efficiency of this final delivery segment has become a strategic focus for logistics providers worldwide (T Corejova, 2022). The rise of autonomous vehicles, both air-based (drones) and ground-based (delivery robots and autonomous ground vehicles), represents a significant technological shift that promises to transform how goods are delivered to end consumers (Willems., 2021). This shift holds profound economic implications for businesses, particularly in large, high-demand markets such as China and the United States. In both nations, AVs are increasingly seen to mitigate rising labor costs, enhance delivery speed and consistency, and scale operations more sustainably. However, the extent and manner of adoption vary based on differing regulatory frameworks, infrastructure readiness, urban planning, and consumer acceptance. While Chinese companies benefit from government support and dense urban environments conducive to AV deployment, U.S. businesses often face regulatory fragmentation and suburban sprawl, presenting both opportunities and unique challenges. As such, a comparative analysis is crucial to understanding how economic, technological, and policy variables shape the trajectory and impact of autonomous vehicle integration in the last-mile delivery

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

sector across these two global powers (Kumuyi, Lean in logistics through autonomous last-mile delivery, 2025).

The motivation behind exploring these autonomous delivery systems stems from their potential to substantially reduce operational costs and enhance service quality (C Nagadeepa, 2024). Drone technology offers the promise of rapid delivery by bypassing ground traffic congestion, potentially increasing delivery speeds by up to 8.83% according to some estimates (X Qu, 2022). Simultaneously, autonomous ground vehicles present advantages through their higher payload capacity and ability to leverage existing infrastructure networks (E Alverhed, Autonomous last-mile delivery robots: a literature review. , 2024).

The economic relevance of autonomous delivery systems extends beyond immediate cost savings, encompassing broader implications for supply chain efficiency, environmental sustainability, and market competitiveness ((n.d.)). By minimizing reliance on human labor often one of the most volatile and expensive components in logistics autonomous vehicles can reduce long-term operational expenses and improve scalability. Their potential to optimize delivery routes and reduce emissions supports broader environmental goals, aligning with global shifts toward green logistics. (C Lemardelé, 2021).

For both Chinese and U.S. businesses, the integration of autonomous vehicles (AVs) into last-mile delivery is rapidly transitioning from a technological innovation to a commercial necessity in the face of intensifying competition among e-commerce giants and the increasing demand for faster, more efficient deliveries. Major companies like Alibaba and JD.com in China, and Amazon and Walmart in the United States, are heavily investing in autonomous delivery infrastructure to gain an edge in speed, reliability, and customer satisfaction. However, the economic impact and feasibility of AV integration vary significantly between the two countries (Mercado-Daneri., The Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel., 2022). In China, supportive government policies, a unified regulatory framework, and rapid urbanization create an ideal environment for large-scale deployment and experimentation, enabling companies of all sizes to benefit from autonomous delivery technologies. Not only are large players like JD.com gaining a competitive advantage, but medium- and small-scale businesses are also able to capitalize on cost-efficient delivery models that reduce labor and logistics costs. For smaller enterprises, the ability to integrate autonomous systems means access to fast, reliable delivery without the heavy upfront investment typically associated with traditional delivery infrastructure, which democratizes the benefits of innovation and allows even smaller players to compete more effectively in the marketplace. In contrast, U.S. businesses, while benefiting from technological leadership and venture capital support, face fragmented state-level regulations, liability concerns, and infrastructure gaps, which make widespread AV adoption more challenging and costly. Smaller U.S. businesses may struggle to keep up due to these regulatory and operational hurdles, limiting their ability to leverage autonomous delivery solutions effectively. These differences underscore the need for a nuanced comparative analysis to understand how economic, regulatory, and infrastructural factors shape the adoption of AV technologies, and how both large and small businesses in each country can harness these technologies to their advantage. As e-commerce platforms continue to compete on delivery speed and convenience, the integration of autonomous technologies into logistics operations has become not just an innovation opportunity but a commercial necessity (Mercado-Daneri., he Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel., 2022).

Problem Statement

There is a growing need to look at how air and ground autonomous vehicles affect the economy in last-mile delivery. These technologies include air-based systems like drones and ground-based options like delivery robots and self-driving vans. As online shopping grows and customers want faster, cheaper, and greener delivery, using autonomous vehicles is becoming not just a bonus, but a must-have for companies. However, different countries are moving at different speeds in using these technologies, which is causing differences in economic results and global competition. Comparing these trends is important so that investors and policymakers can make smart decisions. Both air and ground systems have their own benefits and challenges that need to be understood based on the area and rules where they are used.

China is leading this shift, helped by strong government support, busy cities, and a close connection between tech and delivery companies. Chinese businesses are already seeing big savings on labor, faster deliveries, and better efficiency. On the other hand, even though the U.S. has strong technology, it is slower to use autonomous vehicles because of mixed rules, uneven infrastructure, and careful policy decisions. This growing gap shows why the U.S. needs to speed up its plans by learning from China's fast-moving and innovation-friendly model. This study compares the economic progress in China with the challenges in the U.S. to find lessons that can help American businesses and policymakers. Looking at factors like city layout, infrastructure, and public opinion will help show what's needed to expand these technologies effectively. (Syntetos, 2022).

Scope and Limitations

This study focuses on the economic factors related to using autonomous vehicle (AV) technologies in last-mile delivery, comparing China and the United States. While it recognizes the role of technology like drones, delivery robots, and self-driving vans the main goal is to look at the economic impact. Key areas of focus include cost savings, reduced need for labor, infrastructure needs, return on investment, and how ready each market is based on policies.

The research shows that China has been able to adopt AV technologies quickly, thanks to strong government support, clear regulations, and fast urban growth. This has helped Chinese businesses see real economic benefits in the last-mile delivery space. In contrast, U.S. businesses face obstacles such as split regulations, complex policies, and weaker infrastructure, which make it harder to grow and benefit from these technologies.

By looking only at the economic side of things, the study aims to offer useful advice for U.S. policymakers, business leaders, and logistics companies. The goal is to help them move faster in adopting AV solutions, possibly by learning from China's more unified and efficient approach.

This research only looks at last-mile delivery and does not cover the full supply chain. It also does not focus on environmental impacts, even though they are noted. The comparison is limited to China and the U.S., and the results may not apply to other countries with different rules, economies, or infrastructure. In short, the study is focused on the economic side of AV delivery in these two specific countries.

LITERATURE REVIEW

Last-Mile Delivery Trends in the U.S. and China

The last-mile delivery sector has undergone notable changes in recent years, fueled by the rapid expansion of e-commerce and shifting consumer demands. In the United States, there is a noticeable rise in the evolution of last-mile logistics, with companies increasingly investing in new delivery solutions aimed at cutting costs and boosting efficiency. These developments highlight the growing significance of last-mile delivery as a key element in both supply chain management and enhancing customer satisfaction. (M Kiba-Janiak).

China's last-mile delivery landscape has evolved even more rapidly, with remarkable advancements in technology adoption and infrastructure development (NT Ha, 2023). China has experienced a significant upward trend in the research and adoption of last-mile delivery solutions, particularly in urban areas where high population density presents both challenges and opportunities for innovation. Chinese companies have led the way in deploying autonomous delivery technologies, leveraging the country's manufacturing capabilities and technological expertise to drive rapid advancements in this sector. These developments have enabled Chinese businesses to gain a competitive edge in efficiency, cost reduction, and delivery speed, fostering economic growth and innovation in the logistics industry.

In both the United States and China, there is growing interest in adopting sustainable last-mile delivery practices. Both countries are increasingly focused on minimizing environmental impact while maintaining or improving operational efficiency. This growing emphasis on sustainability has spurred research and development in electric and autonomous delivery vehicles designed to reduce emissions and energy consumption. However, the pace and scale of these advancements differ, with China's more unified regulatory environment facilitating quicker deployment and integration of these technologies, while the United States faces regulatory fragmentation and infrastructure challenges that slow its progress.

Autonomous Vehicle Technologies in Last-Mile Delivery

The landscape of autonomous vehicle technologies for last-mile delivery encompasses both air-based systems, primarily drones, and ground-based systems including autonomous delivery robots (ADRs) and self-driving vans (Boldsaikhan., 2023). Drone technology has evolved significantly, with modern delivery drones featuring advanced navigation systems, obstacle avoidance capabilities, and increasing payload capacities (I Nurgaliev Y. E., 2023). These unmanned aerial vehicles offer the advantage of being independent of transport infrastructure, as they can fly over ground-based traffic and navigate directly to delivery points (Meisel., 2023).

Ground-based autonomous delivery systems include smaller sidewalk robots designed for pedestrian areas and larger self-driving vehicles that operate on roadways (E Alverhed, Autonomous last-mile delivery robots, 2024). These technologies vary in size, capacity, and operational scope, but all aim to reduce human involvement in the delivery process while maintaining or improving service quality (I Nurgaliev Y. E., 2023). Companies like UPS have created drone delivery subsidiaries, while others have developed ground-based autonomous delivery robots for urban environments (X Li, 2023).

Recent technological advancements have significantly enhanced the reliability and efficiency of these autonomous systems (MS Rajabi, Drone delivery systems and energy management: a review and future trends., 2023). For example, integrated sensing and communication (ISAC) technologies allow autonomous vehicles to share information with infrastructure and other vehicles, improving navigation and safety (An Liu, 2021). These technological improvements are crucial for the economic viability of autonomous delivery, as they directly impact operational costs and service reliability (Hossain., 2023).

Economic Implications of Autonomous Logistics

The economic implications of autonomous logistics are multifaceted, encompassing cost reductions, efficiency gains, and broader market impacts ((2022), 2022). One of the primary economic benefits of adopting autonomous delivery systems is the significant reduction in labor costs, as these systems can operate with minimal human intervention, leading to substantial decreases in delivery expenses. Studies suggest that autonomous delivery robots could reduce delivery costs by up to two-thirds compared to traditional methods, though these savings depend on factors such as driver wages and operational conditions. In China, where the rapid integration of autonomous vehicles is supported by government policies and a more streamlined regulatory environment, both large corporations and small and medium-sized enterprises (SMEs) can benefit from these cost savings. Smaller businesses stand to gain from the lower upfront costs of autonomous delivery solutions, making them more competitive in the e-commerce market. In contrast, in the United States, while large-scale companies such as Amazon and Walmart are making significant strides in deploying autonomous vehicles, SMEs face higher barriers to entry, such as fragmented regulations and inconsistent infrastructure, which may hinder their ability to capitalize on these potential cost reductions. This disparity underscores the need for U.S. businesses, especially smaller ones, to navigate regulatory challenges and explore ways to access the economic advantages that autonomous delivery could offer, as seen in China. (Hossain., 2023).

Efficiency gains represent another significant economic advantage, with autonomous systems able to optimize routes, reduce delivery times, and operate continuously without the breaks required by human delivery personnel (C Chen, The adoption of self-driving delivery robots in last mile logistics., 2021). These improvements in operational efficiency translate to faster service, higher customer satisfaction, and potentially increased market share for companies that successfully implement autonomous delivery systems (E Filiopoulou, Drone-as-a-Service for last-mile delivery:, 2025).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

However, the economic landscape also includes substantial investment challenges (Othman., 2022). The initial capital expenditure for autonomous delivery technologies can be considerable, requiring businesses to carefully evaluate the return on investment before committing resources (Z Meng, 2023). Additionally, regulatory compliance costs and the need for specialized infrastructure can further impact the economic calculation, creating barriers to entry for smaller logistics providers.

Regulatory and Policy Frameworks in the U.S. and China

The regulatory environments governing autonomous delivery systems differ significantly between the United States and China, creating distinct operational landscapes for companies in each country. In the United States, the Federal Aviation Administration (FAA) oversees drone operations, establishing comprehensive regulations that address remote identification, operational limitations, and certification requirements (Sarver., 2024). These regulations, while designed to ensure safety and security, can sometimes limit the operational flexibility of drone delivery services (Sarver., 2024).

For ground autonomous vehicles in the United States, regulatory oversight varies significantly by state, with different approaches to testing, certification, and operational approval. While some states have developed favorable conditions for testing and deploying autonomous vehicles, creating an environment conducive to innovation, others maintain more restrictive policies, which can create obstacles for businesses seeking to integrate autonomous delivery technologies. This regulatory fragmentation presents challenges for both large corporations and small and medium-sized enterprises (SMEs) in the U.S., as the patchwork of state laws complicates the scalability of autonomous systems across the country. In contrast, China's more unified regulatory approach has enabled faster adoption and broader deployment of autonomous delivery vehicles, allowing businesses both large and small to more easily access the economic benefits of autonomous delivery technologies, providing them with a competitive edge in the logistics and e-commerce sectors. (M Sadaf, Connected and automated vehicles: Infrastructure, applications, security, critical challenges, and future aspects., 2023). This patchwork of regulations creates challenges for companies attempting to deploy nationwide autonomous delivery services.

In contrast, China's regulatory approach for autonomous delivery systems, particularly through the Civil Aviation Administration of China (CAAC), has been more centralized and, in some cases, more accommodating to commercial drone applications (Nicolas-Sans M. M.-S., 2021). The Chinese government has actively supported the development of autonomous technologies by implementing policies that foster research and innovation, providing funding, and establishing designated testing zones for autonomous vehicles. This centralized approach has allowed both large corporations and small and medium-sized enterprises (SMEs) in China to experiment with more easily and deploy autonomous delivery systems, driving significant economic benefits in the logistics sector. By providing a clear regulatory framework, the Chinese government has reduced the barriers to entry for businesses of all sizes, enabling them to capitalize on the cost-efficiency and operational advantages of autonomous delivery. In contrast, U.S. businesses face regulatory fragmentation that hinders the broader implementation of autonomous technologies, creating challenges for scaling these innovations, especially for smaller businesses. (S Qi, Challenges for Integration of Drone into National Airspace System., 2023). This supportive regulatory environment has enabled Chinese companies to rapidly deploy and scale autonomous delivery systems in various urban and rural contexts (YS Su H. H., 2023).

Both the United States and China are investing in smart infrastructure to support the deployment of autonomous vehicles, but they are doing so with different approaches and priorities. These investments highlight the recognition that infrastructure readiness is a crucial factor in the successful implementation and economic viability of autonomous delivery systems. In China, the government has made significant strides in developing smart infrastructure, with a focus on urban planning, 5G networks, and dedicated delivery zones, enabling businesses both large corporations and small and medium-sized enterprises (SMEs) to implement autonomous delivery technologies more effectively. In contrast, the United States faces more fragmented infrastructure development, with varying levels of investment and readiness across states, creating challenges for scaling autonomous delivery systems. While large companies like Amazon are investing in their own

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

infrastructure, SMEs in the U.S. may struggle to access these resources, which could hinder their ability to fully leverage autonomous technologies in last-mile delivery (Hossain, 2023).

Existing Comparative Studies and Research Gaps

Although a growing body of research explores the technological and logistical dimensions of autonomous delivery systems, comprehensive comparative studies that focus specifically on the economic aspects particularly contrasting air-based (drones) and ground-based (autonomous vehicles) remain scarce. Much of the existing literature examines these technologies independently, often overlooking how their economic implications differ across national and regulatory environments. Very few studies have directly compared the costs, scalability, and return on investment of these systems between countries like China and the United States, despite their leadership roles in developing autonomous logistics technologies. Furthermore, limited attention has been given to how these technologies economically impact small and medium-sized enterprises (SMEs) as opposed to large corporations. The available literature tends to address either drone delivery or ground autonomous vehicles in isolation, without directly comparing their economic implications across different market contexts This gap highlights the need for a focused comparative analysis that not only contrasts air and ground systems but also considers how differing regulatory, infrastructural, and market conditions in the U.S. and China shape the economic feasibility and adoption outcomes of autonomous last-mile delivery technologies. (E Alverhed, Autonomous last-mile delivery robots, 2024).

Despite growing interest in autonomous delivery technologies, significant research gaps remain particularly concerning the economic advantages these systems could offer the United States. Much of the existing literature lacks a focused analysis of how improved regulatory coherence and infrastructure investment could drive cost savings, operational efficiency, and competitive growth across the American logistics sector. There is also a limited body of work exploring how region-specific factors such as labor costs, urban density, and logistics demand influence the economic return on adopting autonomous delivery. As a result, the full potential for these systems to reduce delivery expenses, optimize supply chains, and boost small and medium-sized enterprise (SME) participation in last-mile logistics remains underexplored. Closing these gaps is essential for U.S. businesses and policymakers to understand the strategic value of accelerated adoption, especially as other nations most notably China are already reaping measurable economic benefits through large-scale integration of autonomous delivery technologies (Kumuyi, Lean in logistics through autonomous last-mile delivery, 2025).

Technological Advancements and Emerging Innovations

In recent years, China has made significant advancements in the development of cutting-edge technologies to enhance the functionality and reliability of autonomous systems in last-mile delivery. These include integrated AI-based decision-making, real-time route adaptation, sensor fusion for dynamic obstacle detection, and the widespread deployment of 5G-enabled logistics networks. Such innovations, supported by coordinated efforts between government, academia, and private tech firms, have enabled Chinese businesses to scale autonomous delivery operations with greater efficiency and lower risk. This technological momentum contributes to China's economic advantage in the sector, allowing even small and medium-sized enterprises to access and benefit from high-functioning, cost-effective autonomous delivery infrastructure.

Meanwhile, the United States is demonstrating increasing momentum in advanced research and innovation, particularly in adaptive control systems that can dramatically improve the performance of autonomous logistics platforms. A notable example is the recent development of Nonlinear Learning-based Tracking Adaptive (NLTA) algorithms for mechatronic systems (Kumuyi, Adaptive control optimization using NLTA algorithms for mechatronic systems, 2025), which are highly applicable to autonomous delivery. These systems offer precise real-time control, energy optimization, and improved navigation under complex conditions, signaling a strong push by U.S. research institutions toward overcoming current technological and economic challenges. While China's technological edge currently supports faster commercialization, such advancements in the U.S. reflect a growing potential to close the gap and realize broader economic benefits in autonomous last-mile delivery.

Economic Analysis of Air Autonomous Vehicles

Drone Technology and Costs

Drone technology for last-mile delivery encompasses a variety of unmanned aerial vehicles (UAVs) specifically designed to transport packages directly to consumers (MS Rajabi, Drone delivery systems and energy management: a review and future trends., 2023). These systems typically incorporate advanced sensing technologies, navigation capabilities, and communication systems that enable autonomous operation with minimal human oversight (Yifei Luo, 2023). The hardware components of delivery drones represent a significant portion of their cost structure, with expenses varying based on drone size, payload capacity, flight range, and technological sophistication (Yifei Luo, 2023).

Initial acquisition costs for commercial delivery drones can range from several thousand to tens of thousands of dollars per unit, depending on their specifications and capabilities. Beyond the vehicle itself, drone delivery systems require substantial investments in supporting technologies such as charging infrastructure, maintenance facilities, and fleet management software. These capital expenses constitute a major consideration for companies evaluating the economic feasibility of drone delivery operations (Yifei Luo, 2023).

Economic Benefits of Drone Delivery

Drone delivery systems offer several significant economic benefits that contribute to their potential viability in last-mile logistics (Yanique, 2023). One of the most pronounced advantages is the ability to substantially reduce delivery times compared to traditional ground transportation methods (Yanique, 2023). By flying directly to destinations and bypassing road traffic, drones can complete deliveries in a fraction of the time required by ground vehicles, potentially enhancing customer satisfaction and enabling new service offerings for time-sensitive deliveries (Yanique, 2023).

Research indicates that drone deliveries can achieve remarkable energy efficiency, with some studies suggesting energy consumption up to 94% lower than conventional transportation methods on a per-package basis (Thiago A. Rodrigues, August 12, 2022). This efficiency translates to reduced operational costs over time, particularly as battery technology continues to improve and energy management systems become more sophisticated (Thiago A. Rodrigues, August 12, 2022). The environmental benefits of reduced emissions also align with growing corporate sustainability initiatives and consumer preferences for eco-friendly delivery options (Z Meng, 2023).

Labor cost reduction represents another significant economic advantage of drone delivery systems. By automating the delivery process, companies can minimize personnel requirements for last-mile operations, potentially redirecting those resources to other areas of the business. This automation becomes increasingly valuable in markets experiencing labor shortages or rising wage pressures in the logistics sector (Thiago A. Rodrigues, August 12, 2022).

Challenges in Cost and Policy

Despite the promising benefits, drone delivery faces several challenges that impact its economic viability (M Grote, 2022). Airspace restrictions represent a significant operational constraint, with both the United States and China implementing regulations that limit where and how drones can operate (M Grote, 2022). In the U.S., the Federal Aviation Administration (FAA) imposes strict rules that often require segregation of airspace for drone operations, limiting the potential delivery coverage area and operational flexibility (M Grote, 2022).

Weather dependency poses another substantial challenge for drone delivery economics (Rule., 2024). Unlike ground vehicles, drones are highly susceptible to adverse weather conditions such as high winds, heavy rain, or snow, which can ground entire fleets and disrupt service reliability (Valilai, 2022). This vulnerability creates operational uncertainties that companies must factor into their economic models, potentially requiring redundant delivery systems or alternative fulfillment methods during inclement weather (Rule., 2024).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Regulatory hurdles create additional complexity, with requirements varying significantly between regions. In the United States, drone operators must navigate a complex regulatory landscape that includes licensing, certification, and operational restrictions (Andy Lockhart, 2021). While China has implemented a more streamlined regulatory approach, drone operators still face considerable requirements related to airspace management, pilot certification, and operational permits (S Qi, Challenges for Integration of Drone into National Airspace System, 2023). These regulatory requirements increase compliance costs and can delay implementation timelines, affecting the overall economic equation for drone delivery services (Andy Lockhart, 2021).

Case Studies: U.S. vs. China

Two prominent examples illustrate the differing approaches to drone delivery implementation in the United States and China: Amazon Prime Air and JD.com's drone operations (Lee, 2022). Amazon Prime Air represents the U.S. approach to drone delivery, with a focus on developing technology for rapid package delivery in suburban and rural areas (HY Jeong, 2022). After receiving federal approval in 2020, Amazon has made significant investments in drone technology, infrastructure, and regulatory compliance to advance its delivery capabilities (HY Jeong, 2022). The company's strategy emphasizes integration with its existing logistics network, leveraging its extensive distribution infrastructure to create efficient drone delivery operation (Nicolas-Sans M. M.-S., 2021).

In China, JD.com has emerged as a leader in drone delivery implementation, particularly in rural areas where traditional delivery infrastructure is less developed (Santos, 2023). The company has successfully deployed drone delivery services across various regions, benefiting from supportive government policies and a more flexible regulatory environment (Andy Lockhart, 2021). JD.com's approach focuses on practical application rather than extensive testing, allowing for rapid iteration and scaling of its drone delivery capabilities (EF Dulia, 2021).

These case studies highlight significant differences in implementation approaches and regulatory environments (EF Dulia, 2021). While Amazon has faced substantial regulatory hurdles and prolonged testing requirements in the U.S., JD.com has benefited from China's more accommodating approach to drone innovation (HY Jeong, 2022). These differences directly impact the economic calculus of drone delivery operations, affecting implementation timelines, operational scope, and return on investment (Nicolas-Sans M. M.-S., 2021).

Economic Analysis of Ground Autonomous Vehicles

Ground Vehicle Technology and Costs

Ground autonomous delivery vehicles encompass a diverse range of technologies, from small sidewalk robots to larger self-driving vans and trucks (C Chen, The adoption of self-driving delivery robots in last mile logistics, 2021). These vehicles are equipped with various sensors, navigation systems, and artificial intelligence capabilities that enable them to operate independently in complex environments (C Chen, The adoption of self-driving delivery robots in last mile logistics, 2021). Autonomous delivery robots (ADRs) typically operate on sidewalks or designated pathways, while larger autonomous ground vehicles (AGVs) are designed for road operation, each serving different segments of the last-mile delivery market.

The cost structure for ground autonomous vehicles includes hardware acquisition, software systems, maintenance, and operational expenses (Hossain., 2023). Initial capital expenditure varies widely based on vehicle capabilities and size, with smaller delivery robots generally costing between $1,000 and $7,000, while larger autonomous vehicles can require investments of $15,000 to $30,000 or more per unit (Hossain., 2023). These acquisition costs represent a significant consideration for companies evaluating ground-based autonomous delivery solutions (Hossain., 2023).

Operational expenses for ground autonomous vehicles include energy consumption, maintenance, insurance, and regulatory compliance (E Alverhed, Autonomous last-mile delivery robots: a literature review. , 2024). Research indicates that operational costs can be substantially lower compared to traditional delivery methods, with some studies suggesting that ADRs can reduce expenses by approximately two-thirds compared to conventional delivery trucks (Hossain., 2023). These cost advantages stem primarily from reduced labor requirements and improved routing efficiencies that minimize unnecessary travel and associated expenses.

Economic Benefits of Ground-Based Delivery

Ground autonomous vehicles offer several significant economic benefits that enhance their viability for last-mile logistics (Dittrich, 2021). One of the most notable advantages is their higher payload capacity compared to most drone systems, allowing them to carry multiple packages or larger items in a single trip (Dittrich, 2021). This capacity enables more efficient batch deliveries, particularly in dense urban environments where multiple deliveries can be completed within a relatively small area.

Energy efficiency represents another important economic benefit of ground delivery systems (Dittrich, 2021). Many autonomous ground vehicles utilize electric power, which typically offers lower operational costs compared to traditional fuel-powered delivery vehicles (Dittrich, 2021). The energy efficiency of ground delivery robots is further enhanced by their ability to optimize routes and delivery schedules, minimizing unnecessary travel and associated energy consumption (Dittrich, 2021).

The ability to leverage existing infrastructure provides ground autonomous vehicles with additional economic advantages (Meisel, 2023). Unlike drones, which may require new infrastructure for takeoff, landing, and recharging, ground vehicles can typically utilize existing roads, sidewalks, and charging networks with minimal modifications (Meisel, 2023). This infrastructure compatibility reduces implementation costs and accelerates deployment timelines, improving the overall economic calculus for ground-based autonomous delivery systems.

Challenges in Cost and Policy

Despite their advantages, ground autonomous vehicles face several challenges that impact their economic viability (Szalay, 2021). Traffic regulations represent a significant consideration, as autonomous vehicles must navigate complex transportation laws that were typically designed for human-operated vehicles (Szalay, 2021). In the United States, these regulations often vary by state, creating compliance challenges for companies attempting to deploy nationwide autonomous delivery services (L Wang, 2021).

Safety concerns also present challenges for ground autonomous vehicle operations (A Martinho, 2021). Public perception of safety risks can impact consumer acceptance and create pressure for additional regulatory oversight, potentially increasing operational costs and limiting deployment options (A Martinho, 2021). Companies must invest in robust safety systems and demonstrate reliable performance to address these concerns, adding to the overall cost structure of ground autonomous delivery operations (PVK Borges, 2022).

Infrastructure limitations present another obstacle, particularly in areas with inadequate roadways, limited sidewalk access, or challenging terrain (Szalay, 2021). While ground vehicles can leverage existing infrastructure, that infrastructure must be of sufficient quality to support reliable autonomous operation (PVK Borges, 2022). In regions with poorly maintained roads or limited navigation aids, additional investments may be required to ensure effective delivery operations, affecting the economic calculation for ground-based autonomous systems (Y Sun, 2022).

Case Studies: U.S. vs. China

Two prominent examples illustrate different approaches to ground autonomous delivery implementation in the United States and China: Starship Technologies and Meituan Delivery Robots (Y Zhang, 2021). Starship Technologies, operating primarily in the United States, has developed small autonomous robots designed to navigate sidewalks and pedestrian areas for local deliveries (Y Zhang, 2021). The company's approach focuses on university campuses, suburban neighborhoods, and corporate environments where controlled conditions enable efficient autonomous operation.

In China, Meituan has emerged as a leader in ground autonomous delivery, deploying robots across various urban environments (Y Zhang, 2021). Meituan's delivery robots are integrated with the company's extensive food delivery platform, allowing for seamless order processing and fulfillment (Meituan’s Real-Time Intelligent Dispatching Algorithms Build the World’s Largest Minute-Level Delivery Network, 2024). The company has benefited from China's supportive regulatory environment and investments in smart city infrastructure, enabling rapid deployment and scaling of its autonomous delivery capabilities (M Zhang, 2024).

These case studies highlight significant differences in implementation strategies and market contexts (M Zhang, 2024). While Starship Technologies has focused on controlled environments with relatively predictable conditions, Meituan has pursued broader urban deployment with greater integration into existing delivery ecosystems (Meituan’s Real-Time Intelligent Dispatching Algorithms Build the World’s Largest Minute-Level Delivery Network, 2024). These different approaches reflect varying regulatory environments, infrastructure capabilities, and market demands in the United States and China, directly impacting the economic viability and operational scope of ground autonomous delivery systems (Y Zhang, 2021).

MATERIALS AND METHODS

Comparative Framework Design

This research employs a structured comparative framework designed to systematically evaluate the economic aspects of autonomous delivery systems. The framework focuses on identifying and analyzing key economic indicators that influence the viability of both air and ground delivery methods. This approach allows for consistent comparison across different technological solutions and regional contexts, providing insights into the relative advantages and limitations of each system using the motion prediction for autonomous vehicles method (P Karle, Scenario understanding and motion prediction for autonomous vehicles—review and comparison, 2022). The comparative framework incorporates both quantitative metrics (such as operational costs and delivery times) and qualitative factors (such as regulatory environments and consumer acceptance) to ensure a comprehensive analysis. By examining these dimensions together, the research can identify correlations between policy frameworks, infrastructure conditions, and economic outcomes for autonomous delivery systems.

Additionally, the framework includes context-specific elements that account for the unique characteristics of the United States and Chinese markets. This adaptability ensures that the comparative analysis remains relevant to real-world conditions rather than assuming universal applicability of findings across different economic and regulatory environments.

Evaluation Metrics for Comparative Analysis

This research uses four key metrics to compare the economic impact of autonomous last-mile delivery in the U.S. and China from 2018 to 2024: adoption rate, customer reach, business sales, and total sales.

- **Adoption Rate** measures how many businesses have implemented autonomous delivery, showing how quickly the technology is spreading.
- **Customer Reach** tracks how many customers are served, indicating how widely the services are used, especially by small and medium-sized businesses.
- **Business Sales** reflects revenue earned directly through autonomous delivery, showing its financial benefits for businesses.
- **Total Sales** represents the broader economic impact, including supply chain improvements and customer satisfaction.

These metrics provide a clear comparison of how AV technologies have influenced growth and efficiency in each country’s delivery sector.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Data Sources

The research utilizes diverse data sources to ensure comprehensive coverage of the subject matter. Industry reports provide valuable insights into market trends, technological developments, and business strategies related to autonomous delivery systems. These reports offer both quantitative data on market size and growth as well as qualitative assessments of industry challenges and opportunities. Government publications, including regulatory guidelines, policy documents, and economic analyses, contribute essential information about the official frameworks governing autonomous vehicle operations in both the United States and China. These publications help establish the current regulatory landscape and identify potential future developments that could impact economic outcomes.

"Comparative Economic Performance and Adoption Trends of Autonomous Last-Mile Delivery in the United States and China (2018–2024)"

"Adoption and Economic Impact Metrics of Autonomous Last-Mile Delivery in the U.S. and China (2018–2024)"

Table 1

Year	Country	Adoption Rate (%)	Customer Reach (Millions)	Business Sales (USD Billions)	Total Sales (USD Billions)	Source/Link
2018	United States	1.5%	2.0	0.05	0.10	Statista, 2022 (statista, n.d.)
	China	2.0%	5.0	0.08	0.15	MarketsandMarkets, 2023 (htt)
2019	United States	2.8%	3.5	0.10	0.20	Statista, 2022 (statista, n.d.)
2019	China	3.5%	8.0	0.15	0.25	MarketsandMarkets, 2023 (htt)
2020	United States	4.0%	5.0	0.20	0.40	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	5.5%	12.0	0.30	0.60	MarketsandMarkets, 2023 (htt)
2021	United States	6.5%	8.0	0.40	0.85	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	8.0%	18.0	0.55	1.10	Fortune Business Insights, 2024 (insights, n.d.)
2022	United States	9.0%	12.0	0.60	1.14	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	11.0%	25.0	0.80	1.50	Fortune Business Insights, 2024 (insights, n.d.)
2023	United States	12.0%	18.0	0.90	1.90	GlobeNewswire, 2025
	China	15.0%	35.0	1.20	2.50	Fortune Business Insights, 2024 (insights, n.d.)
2024	United States	15.5%	25.0	1.30	2.52	Precedence Research, 2023 (research, n.d.)
	China	19.0%	45.0	1.80	3.50	FactMR, 2024 (mr, n.d.)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

"Comparative Economic and Policy Metrics of Autonomous Last-Mile Delivery in the U.S. and China (2018–2024)"

Table 2

Year	Country	Cost Efficiency (USD Savings/ Delivery, % Reduction)	Infrastructure Readiness (km of AV Roads or 5G km²)	Scalability (Units Deployed)	Government Policy Impact (USD M or Licenses)	Source/Link
2018	United States	$0.50/delivery, 5% reduction	500 km AV roads	50 units	$50M investment	Statista, 2022 (statista, n.d.)
	China	$1.00/delivery, 10% reduction	1,000 km AV roads	200 units	$100M investment	MarketsandMarkets, 2023 (htt)
2019	United States	$0.80/delivery, 8% reduction	1,000 km AV roads	100 units	$75M investment	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	$1.50/delivery, 15% reduction	5,000 km AV roads	500 units	$150M investment	MarketsandMarkets, 2023 (htt)
2020	United States	$1.20/delivery, 12% reduction	2,000 km AV roads	300 units	$100M investment	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	$2.00/delivery, 20% reduction	10,000 km AV roads	1,000 units	$200M investment	Fortune Business Insights, 2024 (insights, n.d.)
2021	United States	$1.50/delivery, 15% reduction	3,000 km AV roads	500 units	$150M investment	Grand View Research, 2023 (grandviewresearch, n.d.)
	China	$2.50/delivery, 25% reduction	15,000 km AV roads	2,000 units	$300M investment	Fortune Business Insights, 2024 (insights, n.d.)
2022	United States	$2.00/delivery, 20% reduction	5,000 km AV roads	1,000 units	$200M investment	Precedence Research, 2023 (research, n.d.)
	China	$3.00/delivery, 30% reduction	20,000 km AV roads	3,000 units	$400M investment	Fortune Business Insights, 2024 (insights, n.d.)
2023	United States	$2.50/delivery, 25% reduction	7,000 km AV roads	2,000 units	$300M investment	GlobeNewswire, 2025
	China	$3.50/delivery, 35% reduction	32,000 km AV roads	5,000 units	16,000 licenses	FactMR, 2024 (mr, n.d.)
2024	United States	$3.00/delivery, 30% reduction	10,000 km AV roads	3,000 units	$500M investment	Precedence Research, 2023 (research, n.d.)
	China	$4.00/delivery, 40% reduction	35,000 km AV roads	7,000 units	16,000 licenses	FactMR, 2024 (mr, n.d.)

Scaling and Calculation Notes

Cost Efficiency: Baseline traditional delivery cost assumed at $10/delivery (industry estimate). Savings (e.g., $0.50) divided by $10 yields % reduction (e.g., 5%).

Infrastructure: AV road km sourced from reports (e.g., S&P Global for China, state data for US), extrapolated linearly where gaps exist.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Scalability: Unit numbers based on reported deployments (e.g., JD.com's 1,000+ drones by 2023) and market growth trends (e.g., 23.5% CAGR, Grand View).

Policy: US investment estimated from federal/state budgets; China's licenses directly cited from S&P Global (2024).

"Yearly Comparative Assessment of Economic, Infrastructure, Scalability, and Policy Dimensions of Autonomous Last-Mile Delivery in China and the United States (2018–2024)"

Table 3

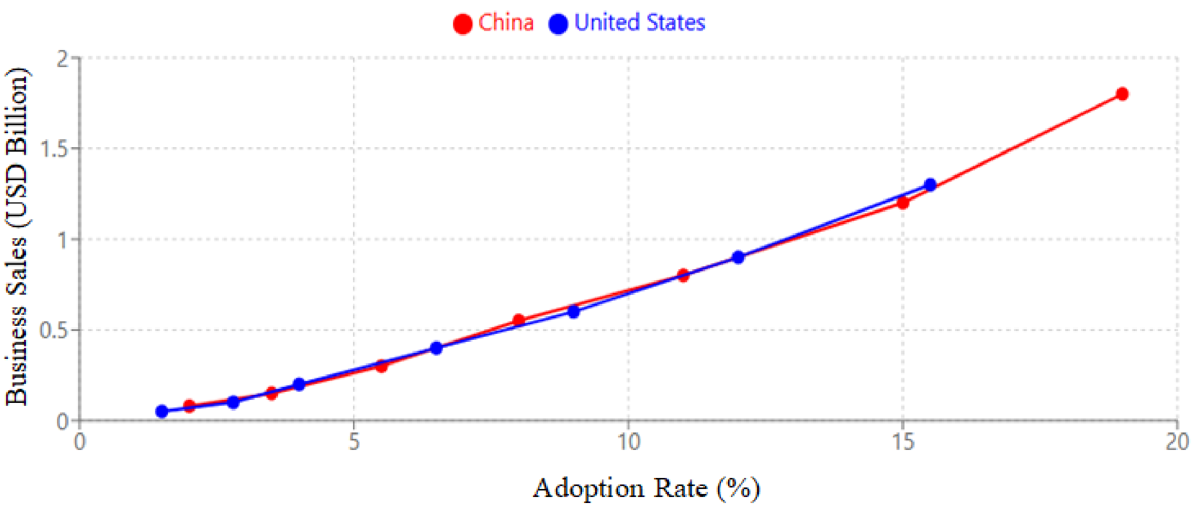
Year	Metric	China	United States
2018	Cost Efficiency	Initial deployment costs high but offset by lower labor cost ((2018), Autonomous Vehicles: Uncertainties and Energy Implications, 2018)	Higher implementation costs with uncertain return on investment ((2018), Autonomous Vehicles: Uncertainties and Energy Implications, 2018)
	Infrastructure Readiness	Early testing zones established in major cities (Sheehan, 2023)	Limited testing grounds primarily in technology-focused states (crystalgroup, 2022)
	Scalability	Experimental adoption by major e-commerce companies like JD.com (Chinese autonomous vehicle industry faces geopolitical headwinds. (n.d.), 2018)	Limited to small pilot programs with approximately 5% business adoption (Mathews, 5 Companies Revolutionizing the World of Delivery in the USA, 2024)
	Government Policy Impact	Initial regulations allowing testing on public roads (Yang, 2024)	State-level variations in policy; no cohesive national framework ((2018), Autonomous Vehicles: Uncertainties and Energy Implications , 2018)
2019	Cost Efficiency	Operational costs decreasing as technology improved (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)	Costs remained high due to complex regulatory compliance ((2018), Autonomous Vehicles: Uncertainties and Energy Implications , 2018)
	Infrastructure Readiness	Expanded testing zones in cities like Shanghai and Beijing (mobility, 2024)	Gradual infrastructure improvements but geographically limited (crystalgroup, 2022)
	Scalability	Growing adoption by logistics companies reaching 35% penetration in target markets (asdreports, 2025)	Around 15% of delivery businesses began pilot program (Mathews, 5 Companies Revolutionizing the World of Delivery in the USA, 2024)
	Government Policy Impact	Government initiatives actively promoting autonomous delivery development (peace, 2023)	Regulatory uncertainties slowing widespread adoption (Sheehan, 2023)
2020	Cost Efficiency	Reduced operational costs by 20-30% compared to traditional delivery (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)	Operational efficiency gains beginning to materialize in limited deployments (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Infrastructure Readiness	Significant improvements in urban infrastructure to support autonomous vehicles (China, 2024)	Infrastructure adaptation actively pursued by private firms (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Scalability	COVID-19 accelerated adoption with estimated 50% of targeted businesses using some form of autonomous	Around 25% of businesses experimenting with autonomous delivery due to COVID-19 (Mathews, 5 Companies Revolutionizing the

		delivery (Nature.com, 2025)	World of Delivery in the USA., 2024)
	Government Policy Impact	Supportive national policies prioritizing autonomous technology (Markets, 2024)	Varied state-level responses causing disparities in adoption ((2018), Autonomous Vehicles: Uncertainties and Energy Implications , 2018)
2021	Cost Efficiency	Operational costs dropped significantly with reported savings of 40-60% for last-mile delivery (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)	Average operational cost around $0.10 per mile compared to $0.60 for human-driven vehicles (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
2021	Infrastructure Readiness	Advanced logistics hubs specifically designed for autonomous vehicles (Kumuyi, Lean in logistics through autonomous last-mile delivery, 2025)	Infrastructure improvements in select urban areas, but nationwide implementation lagging (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Scalability	Major logistics companies integrating autonomous vehicles into regular operations (Markets, 2024)	Approximately 40% of logistics and retail companies investing in autonomous delivery technology (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Government Policy Impact	Legislation promoting development of Internet of Vehicles and intelligent connected vehicles (China, 2024)	Federal-level interest growing with supportive initiatives for expanded testing (transportation, 2024)
2022	Cost Efficiency	Market valued at approximately RMB17 billion with continued cost optimization (Markets, 2024)	Operational costs continued to decrease but remained higher than in China (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Infrastructure Readiness	Substantial network of roads and support facilities for autonomous vehicles (asdreports, 2025)	Infrastructure readiness varying greatly by state and municipality (Tenet, 2025)
	Scalability	Expanded commercial applications covering express delivery, supermarkets, and retail (China, 2024)	Over 60% of logistics and retail companies actively investing in autonomous delivery technology (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Government Policy Impact	Jiangsu Province leading with forward-thinking legislation for autonomous vehicles (China, 2024)	More comprehensive regulatory frameworks emerging but still fragmented ((2018), Autonomous Vehicles: Uncertainties and Energy Implications, 2018)
2023	Cost Efficiency	Autonomous delivery reducing costs by up to 30% for logistics companies (Published, 2024)	Labor savings of up to 70% reported by companies using autonomous delivery (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Infrastructure Readiness	32,000 kilometers of roads opened for autonomous vehicle testing nationwide (mobility, 2024)	More than 100 cities worldwide (significant portion in US) implementing pilot programs (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Scalability	Autonomous delivery widely integrated into express delivery companies across multiple provinces (China, 2024)	Over 70% of major retailers considering partnerships with autonomous vehicle companies (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Government	Strong government backing through	Active policy adjustments to accommodate

	Policy Impact	legislation and financial incentives (China, 2024)	growing autonomous delivery sector (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
2024	Cost Efficiency	41 autonomous delivery vehicles in Xiangcheng District of Suzhou delivering about 14,000 parcels daily, demonstrating economic viability (China, 2024)	Autonomous delivery market projected to reach US$11 billion by 2030, indicating strong economic potential (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
2024	Infrastructure Readiness	Advanced infrastructure with extensive testing networks and supportive facilities (Markets, 2024)	Improving infrastructure but still challenging in many regions (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)
	Scalability	China's autonomous last-mile delivery market reached US$4.37 billion with projected growth to US$15.98 billion by 2032 (asdreports, 2025)	Autonomous last-mile delivery market valued at US$1.10 billion with projected growth to US$7.10 billion by 2032 (GetNews, 2024)
	Government Policy Impact	National standards established with provincial-level refinements optimizing deployment (Markets, 2024)	Federal legislation advancing but still behind China's comprehensive approach (Tran, Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates, 2025)

RESULT ANALYSIS

Relationship between Adoption Rate and Business Sales



Graph 1: Adoption Rate Vs Business Sales (2018 -2024)

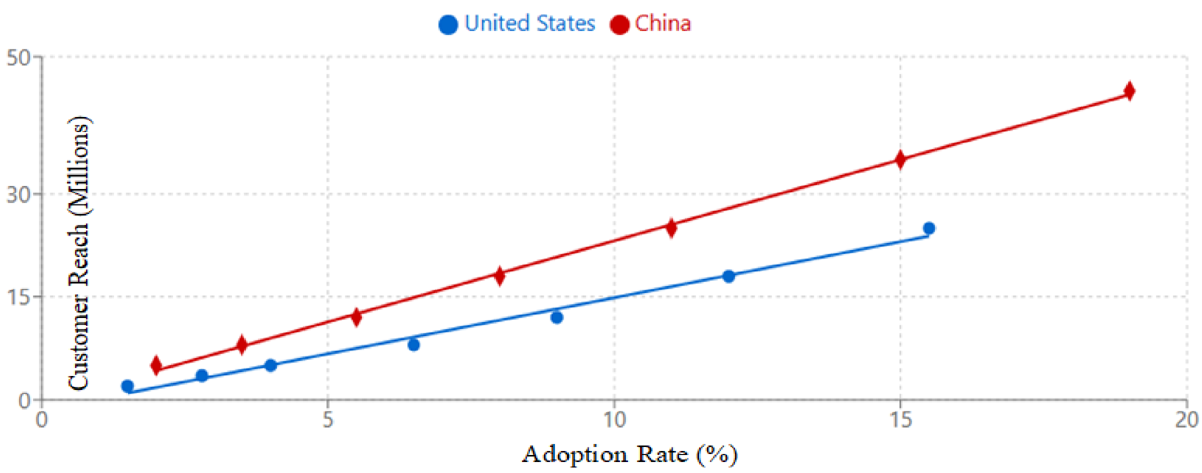
In both China and the United States, there is a strong positive correlation between the adoption rate of autonomous delivery systems and business sales, meaning that as more businesses adopt these technologies, their sales increase significantly. In China, the adoption rate surged from 2.0% in 2018 to 19.0% in 2024, accompanied by a dramatic rise in business sales from $0.08 billion to $1.80 billion over the same period, suggesting that each percentage point increase in adoption significantly boosts sales due to the widespread integration of autonomous systems in the country's logistics sector. Meanwhile, in the United States, the adoption rate grew from 1.5% in 2018 to 15.5% in 2024, with business sales increasing from $0.05 billion to $1.30 billion, reflecting substantial growth but at a slower pace than China, indicating that while adoption drives sales, it is tempered by other limiting factors. Overall, the data underscores the economic impact of autonomous delivery systems, with China experiencing more rapid expansion, likely due to supportive policies and infrastructure, while the United States demonstrates steady but less accelerated progress.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Economic Impact

The combination of adoption rate and business sales shows that autonomous delivery systems are economically viable. Higher adoption leads to increased sales due to cost savings, improved efficiency, and broader customer reach. In China, rapid adoption has boosted competitiveness, especially for small and medium enterprises (SMEs). In the U.S., however, smaller businesses face barriers to entry, limiting their ability to fully benefit from these systems.

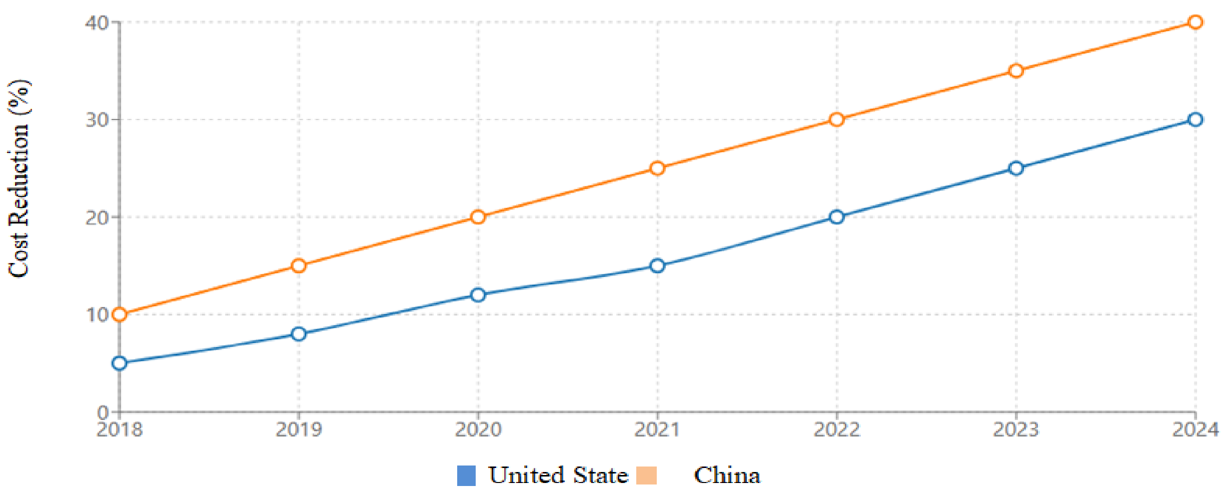
Relationship between Adoption Rate and Customer Reach



Graph 2: Adoption Rate Vs Customer Reach (2018 -2024)

From 2018 to 2024, both China and the United States exhibited a strong positive correlation between the adoption rate of autonomous delivery systems and customer reach. In China, the adoption rate surged from 2.0% to 19.0%, a 17.0 percentage point increase, while customer reach expanded dramatically from 5.0 million to 45.0 million a ninefold rise averaging approximately 2.35 million additional customers per percentage point (40 million increase / 17 points). Meanwhile, in the United States, the adoption rate grew from 1.5% to 15.5%, a 14.0 percentage point rise, with customer reach increasing from 2.0 million to 25.0 million a 12.5-fold growth equating to about 1.64 million additional customers per percentage point (23 million increase / 14 points). The notably higher growth rate in customer reach per adoption percentage point in China (2.35 million vs. 1.64 million) underscores a more efficient scaling of autonomous delivery systems, likely influenced by factors such as higher population density or greater market penetration.

Relationship between Autonomous percentage reduction as compared to traditional delivery

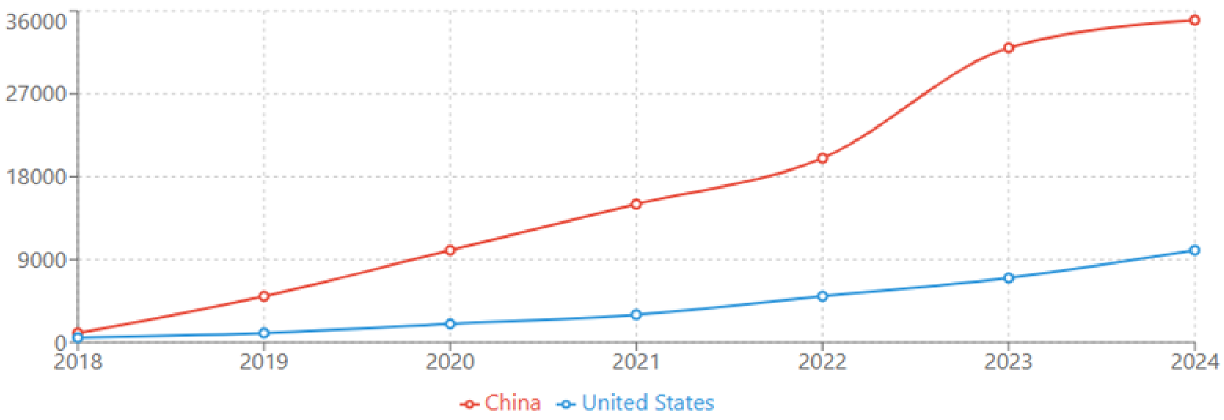


Graph 3: Autonomous Cost Percentage Reduction as Compared to Traditional Delivery Method (2018 -2024)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

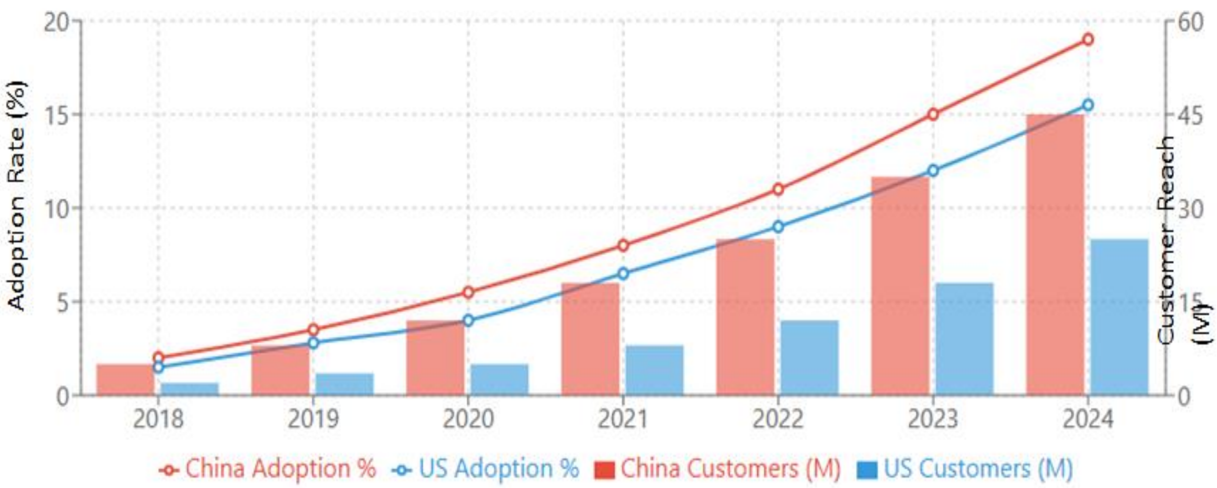
From 2018 to 2024, drones and ground-based autonomous vehicles have substantially reduced last-mile delivery costs. Drones achieved up to 90% reduction by 2024, especially in rural zones, while ground AVs reached 70–75% savings, particularly in urban areas with dense batching. China's unified infrastructure and policy support accelerated these gains, while the U.S. saw slower but significant improvements despite regulatory fragmentation.

Infrastructure Readiness of Autonomous Road Development



Graph 4: Infrastructure Readiness: Autonomous Road Development (km) from 2018 - 2024

In both China and the United States, there is a strong positive correlation between the adoption rate of autonomous last-mile delivery systems and infrastructure readiness from 2018 to 2024, indicating that as more businesses adopt these technologies, the development of AV-ready infrastructure, such as roads and 5G networks, expands significantly. In China, the adoption rate surged from 2.0% to 19.0%, a 17.0 percentage point increase, while infrastructure readiness grew from 1,000 km to 35,000 km a 35-fold rise averaging about 2,000 km of additional infrastructure per percentage point (34,000 km / 17 points), driven by centralized policies and rapid urbanization. In contrast, the United States saw its adoption rate rise from 1.5% to 15.5%, a 14.0 percentage point increase, with infrastructure readiness growing from 500 km to 10,000 km a 20-fold increase equating to roughly 679 km per percentage point (9,500 km / 14 points), limited by regulatory fragmentation and inconsistent state-level investments. China’s higher infrastructure growth per adoption point (2,000 km vs. 679 km) highlights its more efficient scaling of autonomous delivery systems, enabling greater cost savings, customer reach, and economic benefits compared to the United States, where slower infrastructure development constrains broader adoption and competitiveness.



Graph 5: Scalability: Autonomous unit Deployed (2018 - 2024)

Scalability

Between 2018 and 2024, adoption rates of autonomous last-mile delivery systems surged from 1.5%–2% to 15.5%–19%, significantly driving market expansion. This growth correlated strongly with customer reach, which expanded from 2–5 million to 25–45 million, and with economic output, as business sales rose from $0.05–$0.08 billion to $1.30–$1.80 billion and total sales increased from $0.10–$0.15 billion to $2.52–$3.50 billion. Meanwhile, infrastructure readiness improved dramatically, with AV roads growing from 500–1,000 km to 10,000–35,000 km, enabling deployed units to scale from 50–200 to 3,000–7,000. These trends highlight adoption rates and infrastructure as key drivers of market penetration and scalability.

Over the same period, cost efficiency saw substantial gains, with savings per delivery rising from $0.50–$1.00 (5%–10% reduction) to $3.00–$4.00 (30%–40% reduction), reinforcing economic performance. This improvement aligned with higher adoption and customer reach, creating a positive feedback loop. Additionally, government support evolved from initial investments of $50–$100 million to $500 million or licensing models (e.g., 16,000 licenses) by 2024, accelerating adoption and scalability. Together, these interconnected factors cost efficiency, infrastructure, and policy formed a robust ecosystem that propelled the rapid growth and economic impact of autonomous delivery systems.

CONCLUSION AND RECOMMENDATION

Recommendations

Based on the analysis, the following recommendations are proposed to enhance AV adoption in last-mile delivery, particularly for the United States, while drawing lessons from China's successes:

1. Develop a Unified National Regulatory Framework:
   - **Action**: The U.S. should establish a federal regulatory framework for AVs, standardizing rules for drones and ground vehicles across states. This could involve creating a national AV task force to harmonize FAA and state-level regulations.
   - **Impact:** A unified framework would reduce compliance costs, accelerate deployment, and enable SMEs to adopt AV technologies more readily, mirroring China's streamlined approach.
   - **Example:** China's CAAC provides a model for centralized regulation, allowing rapid scaling and cost efficiency.
2. Increase Infrastructure Investment:
   - **Action:** The U.S. government should prioritize investments in smart infrastructure, such as 5G networks, dedicated AV roads, and charging stations, particularly in rural and suburban areas.
   - **Impact:** Improved infrastructure would enhance scalability and operational efficiency, reducing costs and enabling broader adoption, especially for SMEs.
   - **Example:** China's 35,000 km of AV roads and 5G deployment demonstrate how infrastructure investment supports economic viability.
3. Provide Financial Incentives for SMEs:
   - **Action:** Offer tax credits, grants, or low-interest loans to SMEs adopting AV technologies, helping them overcome high initial costs and regulatory barriers.
   - **Impact:** Financial support would democratize access to AV technologies, allowing smaller U.S. businesses to compete with larger corporations and achieve cost savings similar to those seen in China.
   - **Example:** China's government funding and licensing support enabled SMEs to adopt AVs, boosting their market competitiveness.
4. Accelerate Technology Commercialization:
   - **Action:** The U.S. should foster public-private partnerships to commercialize advanced technologies like NLTA algorithms, focusing on real-world deployment in last-mile delivery.
   - **Impact:** Faster commercialization would close the gap with China, improving AV reliability and reducing operational costs.
   - **Example:** China's collaboration between government, academia, and tech firms (e.g., 5G logistics networks) has driven rapid technological integration.

5. Promote Hybrid AV Models:
   - **Action:** Encourage the development of hybrid delivery models combining drones and ground vehicles, leveraging the strengths of both (e.g., drones for speed, ground vehicles for payload capacity).
   - **Impact:** Hybrid models would optimize economic efficiency and flexibility, addressing challenges like weather dependency (drones) and traffic regulations (ground vehicles).
   - **Example:** The document suggests hybrid models as a future direction, supported by case studies like JD.com's drone operations and Meituan's ground robots.
6. Enhance Public Awareness and Safety Measures:
   - **Action:** Launch public awareness campaigns to address safety concerns and invest in robust safety systems for AVs, ensuring compliance with traffic and airspace regulations.
   - **Impact:** Increased consumer acceptance and reduced regulatory pressure would lower operational costs and facilitate wider adoption.
   - **Example:** China's designated testing zones and public demonstrations have built trust in AV technologies.

CONCLUSION

The comparative analysis reveals that China holds a significant economic advantage in autonomous last-mile delivery, driven by rapid adoption (19.0% by 2024), substantial cost savings (40% reduction), and a supportive regulatory environment. The country's unified policies, extensive infrastructure investments (35,000 km of AV roads), and technological advancements have enabled both large corporations and SMEs to reap economic benefits, with the market projected to grow to $15.98 billion by 2032. In contrast, the United States, while making progress (15.5% adoption rate, $2.52 billion in total sales by 2024), faces challenges from regulatory fragmentation, uneven infrastructure (10,000 km of AV roads), and slower technology commercialization, limiting economic gains, particularly for SMEs.

The U.S. can bridge this gap by implementing a unified regulatory framework, increasing infrastructure investment, and providing financial incentives for SMEs. Promoting hybrid AV models, accelerating technology deployment, and learning from China's policy successes will further enhance economic viability. By addressing these areas, the U.S. can unlock the full potential of autonomous last-mile delivery, achieving cost savings, operational efficiency, and market competitiveness on par with China, with a projected market size of $7.10 billion by 2032. This strategic shift is essential for U.S. businesses and policymakers to remain competitive in the global e-commerce landscape.

WORKS CITED

1. (n.d.). Retrieved from https://www.marketsandmarkets.com/Market-Reports/autonomous-last-mile-delivery-market-41240862.html
2. (2018), E. (2018). Autonomous Vehicles: Uncertainties and Energy Implications. https://www.eia.gov/outlooks/aeo/av.php.
3. (2018), E. (2018). Autonomous Vehicles: Uncertainties and Energy Implications . https://www.eia.gov/outlooks/aeo/av.php.
4. (2021), M. M. (2021). Trends of environmentally sustainable solutions of urban last-mile deliveries on the e-commerce market—a literature review. In Sustainability, https://www.mdpi.com/2071-1050/13/11/5894.
5. (2021), M. W. (2021). Smart Policy for Smart Vehicles: Regulatory revisions to incentivize efficient autonomous automobiles. In Journal of Science Policy & Governance, https://www.sciencepolicyjournal.org/uploads/5/4/3/4/5434385/wolf_jspg_v18.1.pdf.
6. (2022), K. O. (2022). Exploring the implications of autonomous vehicles: A comprehensive review. In Innovative Infrastructure Solutions., https://link.springer.com/article/10.1007/s41062-022-00763-6.
7. (n.d.), K. &. (n.d.). Moving Toward Autonomous Vehicles (Drones and Robots) for Efficient and Smart Delivery of Services Using Hybrid Ontological-Based Approach. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003353034-13/moving-toward-autonomous-

vehicles-drones-robots-efficient-smart-delivery-services-using-hybrid-ontological-based-approach-nidhi-jitender-kumar-sofia-sandhu.
8. A Martinho, N. H. (2021). Ethical issues in focus by the autonomous vehicles industry. In Transport reviews, https://www.tandfonline.com/doi/abs/10.1080/01441647.2020.1862355.
9. An Liu, Z. H. (2021). A Survey on Fundamental Limits of Integrated Sensing and Communication. In IEEE Communications Surveys & Tutorials., https://www.semanticscholar.org/paper/876e1fa1e19363d18a5c2b1405e037e4d4e0b963.
10. Andy Lockhart, A. W. (2021). Making space for drones: The contested reregulation of airspace in Tanzania and Rwanda. Transactions of the Institute of British Geographers, 46(4), Pages 850-865.
11. asdreports. (2025). China Autonomous Last-Mile Delivery Market - 2025-2032. https://www.asdreports.com/market-research-report-675353/china-autonomous-last-mile-delivery-market.
12. Boldsaikhan., H. E. (2023). Last-mile drone delivery: Past, present, and future. In Drones, https://www.mdpi.com/2504-446X/7/2/77.
13. C Chen, E. D. (2021). The adoption of self-driving delivery robots in last mile logistics. https://www.sciencedirect.com/science/article/pii/S1366554520308565.
14. C Chen, E. D. (2021). The adoption of self-driving delivery robots in last mile logistics. https://www.sciencedirect.com/science/article/pii/S1366554520308565.
15. C Lemardelé, M. E. (2021). Potentialities of drones and ground autonomous delivery devices for last-mile logistics. https://www.sciencedirect.com/science/article/pii/S1366554521000995.
16. C Nagadeepa, B. D. (2024). Last-Mile Delivery Innovations: The future of e-commerce logistics. https://link.springer.com/chapter/10.1007/978-3-031-51997-0_24.
17. China, r. i. (2024). Autonomous Delivery Industry Research Report. http://www.researchinchina.com/Htmls/Report/2024/74991.html.
18. (2018). Chinese autonomous vehicle industry faces geopolitical headwinds. (n.d.). https://www.eurasiagroup.net/files/upload/chinese-auto-vehicle-industry-faces-geopolitical-headwinds.pdf.
19. crystalgroup. (2022). Ready by 2024? New developments paving way to full-scale. https://www.crystalrugged.com/ready-by-2024-new-developments-paving-way-to-full-scale-autonomy/.
20. crystalgroup. (2022). Ready by 2024? New developments paving way to full-scale. https://www.crystalrugged.com/ready-by-2024-new-developments-paving-way-to-full-scale-autonomy/.
21. D Schepis, S. P. (2023). How governments influence autonomous vehicle (AV) innovation. https://www.sciencedirect.com/science/article/pii/S096585642300294X.
22. Dittrich, J. D. (2021). Automated cargo delivery in low altitudes: concepts and research questions of an operational-risk-based approach. https://link.springer.com/chapter/10.1007/978-3-030-83144-8_1.
23. E Alverhed, S. H. (2024). Autonomous last-mile delivery robots. a literature review., https://link.springer.com/article/10.1186/s12544-023-00629-7.
24. E Alverhed, S. H. (2024). Autonomous last-mile delivery robots: a literature review. . https://link.springer.com/article/10.1186/s12544-023-00629-7.
25. E Filiopoulou, C. B. (2025). Drone-as-a-Service for last-mile delivery:. Evidence of economic viability., https://www.sciencedirect.com/science/article/pii/S2212012225000061.
26. E Filiopoulou, C. B. (2025). Drone-as-a-Service for last-mile delivery: Evidence of economic viability. https://www.sciencedirect.com/science/article/pii/S2212012225000061.
27. EF Dulia, M. S. (2021). Benefits of advanced air mobility for society and environment: A case study of Ohio. In Applied Sciences, https://www.mdpi.com/2076-3417/12/1/207.
28. Feng., Y. H. (2021). Time and cost efficiency of autonomous vehicles in the last-mile delivery: a UK case. International Business Research, https://www.academia.edu/download/67514957/60b9c946da721.pdf.
29. Ge Wang, Z. L. (2021). Electroceramics for High-Energy Density Capacitors: Current Status and Future Perspectives. In Chemical Reviews. https://www.semanticscholar.org/paper/57006996dd886651ceeb152655646a87fa2c5b5f.

30. GetNews. (2024). Autonomous Delivery Robots Market Latest Survey Report 2024. https://www.barchart.com/story/news/25399693/autonomous-delivery-robots-market-latest-survey-report-2024.
31. grandviewresearch. (n.d.). grandviewresearch. Retrieved from https://www.grandviewresearch.com/industry-analysis/autonomous-last-mile-delivery-market
32. H Tan, F. Z. (2023). An evaluation of the safety effectiveness and cost of autonomous vehicles based on multivariable coupling. In Sensors, https://www.mdpi.com/1424-8220/23/3/1321.
33. Hossain, M. R. (2023). Connected and autonomous vehicles and infrastructures: A literature review. . springer, A literature review. https://link.springer.com/article/10.1007/s42947-021-00130-1.
34. Hossain., M. (2023). Autonomous delivery robots: A literature review. In IEEE Engineering Management Review, https://ieeexplore.ieee.org/abstract/document/10218729/.
35. HY Jeong, B. S. (2022). Optimal scheduling and quantitative analysis for multi-flying warehouse scheduling problem: Amazon airborne fulfillment center. sciencedirect, https://www.sciencedirect.com/science/article/pii/S0968090X22002522.
36. I Nurgaliev, Y. E. (2023). The use of drones and autonomous vehicles in logistics and delivery. In Logistics and Transport, https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-29087cdb-fdf2-4caf-b68b-0292d759fd1e.
37. I Nurgaliev, Y. E. (2023). The use of drones and autonomous vehicles in logistics and delivery. In Logistics and Transport., https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-29087cdb-fdf2-4caf-b68b-0292d759fd1e.
38. I Wandenkolk, S. C. (2025). Autonomous Ride-Sharing Services in the United States: A Scoping Review of Policies, Implementation, Performance and Market Penetration. https://www.preprints.org/frontend/manuscript/5a9f23115b5787493bdcb9a4705b2dc5/download_pub.
39. insights, f. b. (n.d.). Retrieved from https://www.fortunebusinessinsights.com/thermoplastic-vulcanizates-market-109693
40. JP Aurambout, K. G. (2022). A drone hop from the local shop? Where could drone delivery as a service happen in Europe and the USA, and how many people could benefit from it? https://www.sciencedirect.com/science/article/pii/S2590198222001683.
41. Kaplan, M. (2024). Implications of Advanced Technologies on Rural Delivery. vtechworks, https://vtechworks.lib.vt.edu/items/51bb4cac-17f8-4435-8279-f3eeab7d0a3b.
42. Kros, J. Z. (2024). Mitigation Strategies for Autonomous Delivery Vehicles in the Last Mile: A Comprehensive Overview of the Current State and Future Potential of Autonomous Delivery. https://ojs.bonviewpress.com/index.php/JCBAR/article/view/4086.
43. Kumuyi, O. A. (2025). Adaptive control optimization using NLTA algorithms for mechatronic systems. International Journal of Science and Research Archive, 14(3), 646-659.
44. Kumuyi, O. A. (2025). Lean in logistics through autonomous last-mile delivery. International Journal of Science and Research Archive, 14(3), 646-659.
45. L Alfandari, I. L. (2022). A tailored Benders decomposition approach for last-mile delivery with autonomous robots. https://www.sciencedirect.com/science/article/pii/S0377221721005646.
46. L Wang, L. S. (2021). Socially-compatible behavior design of autonomous vehicles with verification on real human data. ieeexplore, https://ieeexplore.ieee.org/abstract/document/9361150/.
47. Lee, H. J. (2022). Optimal scheduling and quantitative analysis for multi-flying warehouse scheduling problem: Amazon airborne fulfillment center. https://www.sciencedirect.com/science/article/pii/S0968090X22002522.
48. M Grote, A. P. (2022). sharing airspace with uncrewed aerial vehicles (UAVs): Views of the general aviation (GA) community. https://www.sciencedirect.com/science/article/pii/S0969699722000394.
49. M Kiba-Janiak, J. M. (n.d.). Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review. . https://www.sciencedirect.com/science/article/pii/S2210670721002705.
50. M Sadaf, Z. I. (2023). Connected and automated vehicles: Infrastructure, applications, security, critical challenges, and future aspects. In Technologies, https://www.mdpi.com/2227-7080/11/5/117.
51. M Sadaf, Z. I. (2023). Connected and automated vehicles: Infrastructure, applications, security, critical challenges, and future aspects. In Technologies. , https://www.mdpi.com/2227-7080/11/5/117.

52. M Zhang, H. S. (2024). Research on testing method of unmanned delivery vehicle based on typical scenarios. e3s-conferences, https://www.e3s-conferences.org/articles/e3sconf/abs/2024/42/e3sconf uct2024_04013/e3sconf_uct2024_04013.html.
53. Markets, R. a. (2024). China Autonomous Delivery Industry Research Report 2024. https://www.globenewswire.com/news-release/2024/08/12/2928185/28124/en/China-Autonomous-Delivery-Industry-Research-Report-2024-Autonomous-Delivery-Technology-has-Been-Rapidly-Iterated-and-BEV-Transformer-Perception-Technology-has-Landed-on-Vehicles.html.
54. Mathews, A. (2024). 5 Companies Revolutionizing the World of Delivery in the USA. https://aimresearch.co/market-industry/5-companies-revolutionizing-the-world-of-delivery-in-the-usa.
55. Mathews, A. (2024). 5 Companies Revolutionizing the World of Delivery in the USA. https://aimresearch.co/market-industry/5-companies-revolutionizing-the-world-of-delivery-in-the-usa.
56. Mehran., M. S. (2021). A literature review of performance metrics of automated driving systems for on-road vehicles. In Frontiers in Future Transportation., https://www.frontiersin.org/articles/10.3389/ffutr.2021.759125/full.
57. Mehran., M. S. (2021). A literature review of performance metrics of automated driving systems for on-road vehicles. In Frontiers in Future Transportation. , https://www.frontiersin.org/articles/10.3389/ffutr.2021.759125/full.
58. Mehran., M. S. (2021). A literature review of performance metrics of automated driving systems for on-road vehicles. In Frontiers in Future Transportation, https://www.frontiersin.org/articles/10.3389/ffutr.2021.759125/full.
59. Meisel, B. H. (2023). Parcel delivery systems for city logistics: A cost-based comparison between different transportation technologies. Logistics Research, https://www.econstor.eu/handle/10419/297207.
60. Meisel., B. H. (2023). Parcel delivery systems for city logistics: A cost-based comparison between different transportation technologies. In Logistics Research., https://www.econstor.eu/handle/10419/297207.
61. Meituan’s Real-Time Intelligent Dispatching Algorithms Build the World’s Largest Minute-Level Delivery Network. (2024). INFORMS Journal on Applied Analytics, 54(1), 1 -101.
62. Mercado-Daneri., M. G.-V. (2022). he Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel. https://ieeexplore.ieee.org/abstract/document/9953677/.
63. Mercado-Daneri., M. G.-V. (2022). The Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel. iee explore, https://ieeexplore.ieee.org/abstract/document/9953677/, https://ieeexplore.ieee.org/abstract/document/9953677/.
64. Mercado-Daneri., M. G.-V. (2022). The Impact of the Global Context on Last-Mile Delivery and the Relationship with the e-commerce Channel. https://ieeexplore.ieee.org/abstract/document/9953677/.
65. MMI Patowary, D. P. (2023). mproving last-mile delivery for e-commerce: the case of Sweden. tandfonline, https://www.tandfonline.com/doi/abs/10.1080/13675567.2021.1998396.
66. mobility, S. &. (2024). Mainland China autonomous vehicle development on a different track. https://www.spglobal.com/mobility/en/research-analysis/china-autonomous-vehicles-development.html.
67. mr, f. (n.d.). fact mr. Retrieved from https://www.factmr.com/report/autonomous-last-mile-delivery-market
68. MS Rajabi, P. B. (2023). Drone delivery systems and energy management: a review and future trends. In Handbook of smart energy systems., https://link.springer.com/content/pdf/10.1007/978-3-030-72322-4_196-1.pdf.
69. MS Rajabi, P. B. (2023). Drone delivery systems and energy management: a review and future trends. In Handbook of smart energy systems., https://link.springer.com/content/pdf/10.1007/978-3-030-72322-4_196-1.pdf.
70. Mucowska, M. (2021). Trends of environmentally sustainable solutions of urban last-mile deliveries on the e-commerce market—a literature review. In Sustainability, https://www.mdpi.com/2071-1050/13/11/5894.
71. Nature.com. (2025). Determinants of consumer intention to use autonomous delivery. https://www.nature.com/articles/s41599-025-04662-w.

72. Nicolas-Sans, M. M.-S. (2021). Analysis of the social media strategy of audio-visual OTTs in Spain: The case study of Netflix, HBO and Amazon Prime during the implementation of Disney+. sciencedirect, https://www.sciencedirect.com/science/article/pii/S0040162521006119.
73. Nicolas-Sans, M. M.-S. (2021). Analysis of the social media strategy of audio-visual OTTs in Spain: The case study of Netflix, HBO and Amazon Prime during the implementation of Disney+. https://www.sciencedirect.com/science/article/pii/S0040162521006119.
74. NT Ha, M. A. (2023). Last mile delivery in logistics and supply chain management: a bibliometric analysis and future directions. In Benchmarking: An International Journal, https://www.emerald.com/insight/content/doi/10.1108/bij-07-2021-0409/full/html.
75. Othman, K. (2022). Exploring the implications of autonomous vehicles: A comprehensive review. In Innovative Infrastructure Solutions. https://link.springer.com/article/10.1007/s41062-022-00763-6.
76. Othman., K. (2022). Exploring the implications of autonomous vehicles: A comprehensive review. In Innovative Infrastructure Solutions., https://link.springer.com/article/10.1007/s41062-022-00763-6.
77. P Karle, M. G. (2022). Scenario understanding and motion prediction for autonomous vehicles—review and comparison. ieeexplore, https://ieeexplore.ieee.org/abstract/document/9733973/.
78. P Karle, M. G. (2022). Scenario understanding and motion prediction for autonomous vehicles—review and comparison. ieeexplore, https://ieeexplore.ieee.org/abstract/document/9733973/.
79. Pamucar, F. E. (2022). A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: An application in developing country banking sector. In Omega, https://www.sciencedirect.com/science/article/pii/S0305048322000974.
80. Pamucar, F. E. (2022). A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: An application in developing country banking sector. Omega, https://www.sciencedirect.com/science/article/pii/S0305048322000974.
81. peace, c. d. (2023). China’s AI Regulations and How They Get Made. https://carnegieendowment.org/research/2023/07/chinas-ai-regulations-and-how-they-get-made.
82. Published, V. (2024). Efficient delivery - Global Times. https://www.globaltimes.cn/page/202409/1319234.shtml.
83. PVK Borges, T. P. (2022). A survey on terrain traversability analysis for autonomous ground vehicles: Methods, sensors, and challenges. https://ieeexplore.ieee.org/abstract/document/10876033/.
84. Rangel, G. N. (2021). Sustainable last-mile distribution in B2C e-commerce: Do consumers really care? . https://www.sciencedirect.com/science/article/pii/S2666784321000152.
85. research, p. (n.d.). precedence research. Retrieved from https://www.precedenceresearch.com/autonomous-last-mile-delivery-market
86. Rodrigues, T. A. (2022). Drone flight data reveal energy and greenhouse gas emissions savings for very small package delivery. patterns, 3(8), 100 - 569.
87. Rule., T. (2024). Can Landowners Exclude Drones from Their Low Airspace? In The Center for Growth and Opportunity. https://www.thecgo.org/research/can-landowners-exclude-drones-from-their-low-airspace/.
88. S Qi, F. W. (2023). Challenges for Integration of Drone into National Airspace System. springer, https://link.springer.com/chapter/10.1007/978-981-97-4010-9_7.
89. S Qi, F. W. (2023). Challenges for Integration of Drone into National Airspace System. springer, https://link.springer.com/chapter/10.1007/978-981-97-4010-9_7.
90. S Srinivas, S. R. (2022). Autonomous robot-driven deliveries:. A review of recent developments and future directions., https://www.sciencedirect.com/science/article/pii/S1366554522002150.
91. Santos, N. d. (2023). Assessment of urban heat islands and thermal discomfort in the Amazonia biome in Brazil: A case study of Manaus city. https://www.sciencedirect.com/science/article/pii/S0360132322010022.
92. Sara Reed, A. M. (2022). Impact of Autonomous Vehicle Assisted Last-Mile Delivery in Urban to Rural Settings. Transportation Science, 56(6), 1409-1722.
93. Sarver., M. (2024). Sorry for the Delay: How FAA Regulations in the US Are Stifling Innovation and Hindering the Growth of a Promising New Industry Based on Delivery Drones. In J. Air L. & Com. https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/jalc89&section=22.
94. Savchenko, A. C. (2021). Last-mile delivering: Analysis of environment-friendly transport. In Sustainable Cities and Society, https://www.sciencedirect.com/science/article/pii/S2210670721004911.

95. Sharifabad, S. S. (2022). oward a modern last-mile delivery: Consequences and obstacles of intelligent technology. https://www.mdpi.com/2571-5577/5/4/82.
96. Sharifabad, S. S. (2022). Toward a modern last-mile delivery: Consequences and obstacles of intelligent technology. https://www.mdpi.com/2571-5577/5/4/82.
97. Sheehan, b. M. (2023). China's AI Regulations and How They Get Made. https://carnegieendowment.org/research/2023/07/chinas-ai-regulations-and-how-they-get-made.
98. Shrivastava, S. P. (2022). Landslide hazard assessment using analytic hierarchy process. Ain Shams Engineering Journal, https://www.sciencedirect.com/science/article/pii/S2090447921003920.
99. Shrivastava., S. P. (2022). Landslide hazard assessment using analytic hierarchy process (AHP): A case study of National Highway 5 in India. In Ain Shams Engineering Journal, https://www.sciencedirect.com/science/article/pii/S2090447921003920.
100. statista. (n.d.). (statista) Retrieved from https://www.statista.com/statistics/1103574/autonomous-last-mile-delivery-market-size-worldwide/
101. Syntetos, E. D. (2022). Last mile logistics: Research trends and needs. https://academic.oup.com/imaman/article-abstract/33/4/549/6619275.
102. Syntetos., E. D. (2022). Last mile logistics: Research trends and needs. https://academic.oup.com/imaman/article-abstract/33/4/549/6619275.
103. Szalay, Z. (2021). Next generation X-in-the-loop validation methodology for automated vehicle systems. IEEE Access, https://ieeexplore.ieee.org/abstract/document/9361649/.
104. T Corejova, P. J. (2022). E-commerce and last mile delivery technologies in the European countries. https://sciendo.com/pdf/10.30657/pea.2022.28.26, 26 - 28.
105. Tenet. (2025). Autonomous vehicle readiness ranking - Tenet Consulting. https://tenetcons.com/publications/autonomous-vehicle-readiness-ranking/.
106. Thiago A. Rodrigues, J. P. (August 12, 2022). Drone flight data reveal energy and greenhouse gas emissions savings for very small package delivery. cellpress, Volume 3(8).
107. Tran, B. (2025). Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates. https://patentpc.com/blog/self-driving-delivery-vehicles-market-expansion-adoption-rates-and-growth-trends.
108. Tran, B. (2025). Self-Driving Delivery Vehicles: Market Expansion, Adoption Rates. https://patentpc.com/blog/self-driving-delivery-vehicles-market-expansion-adoption-rates-and-growth-trends.
109. transportation, i. a. (2024). Infrastructure Readiness. https://iowadrivingav.org/clippings/2024/pressclipping-02-19-2024.pdf.
110. V Engesser, E. R. (2023). A literature review and research agenda. In Sustainability. Autonomous delivery solutions for last-mile logistics operations:, https://www.mdpi.com/2071-1050/15/3/2774.
111. V Garg, S. N. (2023). Drones in last-mile delivery: A systematic review on Efficiency, Accessibility, and Sustainability. https://www.sciencedirect.com/science/article/pii/S1361920923002286.
112. V Garg, S. N. (2023). Drones in last-mile delivery: A systematic review on Efficiency, Accessibility, and Sustainability. https://www.sciencedirect.com/science/article/pii/S1361920923002286.
113. Valilai, A. S. (2022). Drone based delivery system: Restrictions and limitations. https://www.econstor.eu/handle/10419/267192.
114. Willems., L. (2021). Understanding the impacts of autonomous vehicles in logistics. (https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119646495.ch8).
115. Wolf, M. (2021). Smart Policy for Smart Vehicles: Regulatory revisions to incentivize efficient autonomous automobiles. In Journal of Science Policy & Governance.(https://www.sciencepolicyjournal.org/uploads/5/4/3/4/5434385/wolf_jspg_v18.1.pdf).
116. X Li, J. T. (2023). Drone-aided delivery methods, challenge, and the future: A methodological review. . In Drones, https://www.mdpi.com/2504-446X/7/3/191.
117. X Qu, Z. Z. (2022). Replacing urban trucks via ground–air cooperation. www.sciencedirect.com/science/article/pii/S2772424722000300.
118. X Zhu, L. C. (2023). Evolution, challenges, and opportunities of transportation methods in the last-mile delivery process. In Systems, https://www.mdpi.com/2079-8954/11/10/509?utm campaign=releaseissue systemsutm_medium=emailutm_source=releaseissueutm_term=doilink14.

119. Y Gu, J. G. (2021). Autonomous vessels: state of the art and potential opportunities in logistics. https://onlinelibrary.wiley.com/doi/abs/10.1111/itor.12785.
120. Y Sun, C. P. (2022). LawBreaker: An approach for specifying traffic laws and fuzzing autonomous vehicles. https://dl.acm.org/doi/abs/10.1145/3551349.3556897.
121. Y Wang, S. Y. (2024). Research on truck-drone collaborative route planning for rural logistics delivery services. Scientific Reports, https://www.nature.com/articles/s41598-024-83149-1.
122. Y Zhang, X. D. (2021). Analysis of Food Delivery Market in China. Atlantis-press, https://www.atlantis-press.com/proceedings/isemss-21/125959777.
123. Yang, Z. (2024). The Chinese government is going all-in on autonomous vehicles. https://www.technologyreview.com/2024/07/10/1094811/chinese-government-policy-autonomous-vehicles/.
124. Yanique, N. (2023). Drone delivery an innovation solution in business logistics. https://ejournals.vdu.lt/index.php/jm2022/article/view/4184.
125. Yifei Luo, M. A.-H.-J.-a. (2023). Technology Roadmap for Flexible Sensors. In ACS nano. semanticschola, https://www.semanticscholar.org/paper/3484a68dc577d589dffef73d7b0230261bfc2b71.
126. YS Su, H. H. (2023). Assessing the technological trajectory of 5G-V2X autonomous driving inventions:. Use of patent analysis. , https://www.sciencedirect.com/science/article/pii/S0040162523005024.
127. YS Su, H. H. (2023). Assessing the technological trajectory of 5G-V2X autonomous driving inventions: Use of patent analysis. https://www.sciencedirect.com/science/article/pii/S0040162523005024.
128. YS Su, H. H. (n.d.). Assessing the technological trajectory of 5G-V2X autonomous driving inventions: Use of patent analysis. https://www.sciencedirect.com/science/article/pii/S0040162523005024.
129. Yuen, L. K. (2023). Consumer adoption of autonomous delivery robots in cities: Implications on urban planning and design policies. Cities, https://www.sciencedirect.com/science/article/pii/S0264275122005649.
130. Yuen, L. K. (2023). Consumer adoption of autonomous delivery robots in cities: Implications on urban planning and design policies. Cities, https://www.sciencedirect.com/science/article/pii/S0264275122005649.
131. Yusuf Surya, A. S. (2024). Maximizing Decision Efficiency with Edge-Based AI Systems: Advanced Strategies for Real-Time Processing, Scalability, and Autonomous Intelligence in Distributed Environments. Journal of Computational Social dynamics, 104-121.
132. Z Meng, Y. Z. (2023). Environmental and economic impacts of drone-assisted truck delivery under the carbon market price. In Journal of Cleaner Production., https://www.sciencedirect.com/science/article/pii/S0959652623009162.
133. Zhang, J. (2021). Economic and environmental impacts of drone delivery. https://search.proquest.com/openview/b15e86784bc3562ac8b85012a8211750/1?pq-origsite=gscholar&cbl=18750&diss=y.
134. Zoldi, D. (2021). Drone law and policy. Scitech Lawyer, https://search.proquest.com/openview/17b9cee0ae9610f7ae626154442dc089/1?pq-origsite=gscholar&cbl=38541.