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A Conceptual Framework for Data-Informed Gig Economy Infrastructure Development in Last-Mile Delivery Systems

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Abstract

The rapid expansion of the gig economy has significantly transformed last-mile delivery systems, driven by the increasing demand for fast, flexible, and cost-efficient logistics solutions. However, the infrastructure supporting gig-based delivery operations remains fragmented and lacks optimization, which hinders the potential of these systems. This review proposes a conceptual framework for developing data-informed infrastructure that can enhance the efficiency, sustainability, and scalability of last-mile delivery systems in the gig economy. The framework integrates key components such as data collection and management, technology infrastructure, stakeholder collaboration, and performance metrics to create an ecosystem that enables dynamic, real-time decision-making. Through the use of advanced technologies like AI, machine learning, IoT, and cloud computing, the framework facilitates better route optimization, demand forecasting, and resource allocation, which in turn improve operational efficiency. The framework also emphasizes the importance of collaboration between gig economy platforms, local governments, logistics companies, and other stakeholders, ensuring that data sharing and governance models are well-defined. Moreover, it addresses challenges such as data privacy, platform integration, and fair worker compensation, while highlighting opportunities for growth, including the potential for optimizing sustainability and expanding gig work into underserved regions. By providing a holistic view of the necessary infrastructure components and their interconnections, this conceptual framework offers a pathway to developing robust, data-driven last-mile delivery systems that are responsive, efficient, and scalable. It also sets the stage for future research into the evolving role of data in transforming urban logistics and the gig economy, and it underscores the need for a collaborative, data-centric approach to infrastructure development.

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1. Introduction

The gig economy, characterized by short-term, flexible, and on-demand work, has gained significant traction in recent years, reshaping traditional labor markets. The gig economy has disrupted multiple industries, with delivery services being one of the most notable sectors affected (Ojika *et al*., 2023; Onukwulu *et al*., 2023). Companies like Uber, Lyft, DoorDash, and Postmates have pioneered a new model for delivering goods and services, where independent contractors often referred to as gig workers handle the transportation and delivery tasks on behalf of businesses. This model has proven advantageous for both consumers and service providers, as it enables on-demand flexibility, faster delivery times, and reduced operational costs (Adekunle *et al*., 2023; Ilori *et al*., 2023).

In the context of logistics, last-mile delivery the final leg of the supply chain where goods are delivered from a distribution center to the consumer's doorstep has become a critical component in meeting the growing expectations for speed and convenience (Iwe *et al*., 2023; Agho *et al*., 2023). As e-commerce continues to thrive, the demand for quick and efficient last-mile delivery has surged, placing additional pressure on delivery networks to provide fast, reliable, and cost-effective services. The last-mile segment, often regarded as the most expensive and complex part of the supply chain, typically accounts for a significant portion of total logistics costs (Nwaimo *et al*., 2023; Onukwulu *et al*., 2023). This is where the gig economy plays a crucial role, offering a flexible and scalable solution to address the growing challenges faced by traditional delivery networks.

The integration of gig-based labor into last-mile logistics has revolutionized the sector, offering businesses the ability to tap into a pool of independent workers who can quickly scale delivery operations (Chukwuma-Eke *et al*., 2023; Adekunle *et al*., 2023). This has enabled companies to provide more dynamic, on-demand services that cater to consumer preferences for convenience, speed, and affordability. However, as the gig economy grows, so do the complexities related to its infrastructure, coordination, and optimization, making the need for efficient, data-driven solutions more urgent than ever (Chukwuma-Eke *et al*., 2023; Ayodeji *et al*., 2023).

Last-mile delivery plays a pivotal role in modern supply chains, representing the final step in fulfilling customer orders. It is often seen as a critical touchpoint that can significantly influence customer satisfaction. As e-commerce expands, consumers are increasingly expecting shorter delivery times, tracking transparency, and lower delivery costs (Oyeyipo *et al*., 2023; Adepoju *et al*., 2023). However, these rising consumer expectations place immense pressure on logistics networks to meet their demands efficiently and sustainably. Last-mile delivery accounts for approximately 30% of total logistics costs, and as a result, optimizing this segment has become a key area of focus for companies seeking to reduce expenses while maintaining service quality (Collins *et al*., 2023; Adepoju *et al*., 2023).

Given its complexity, last-mile delivery requires a sophisticated infrastructure that can accommodate a wide range of variables, such as fluctuating demand, route optimization, traffic conditions, and the distribution of delivery personnel (Hamza *et al*., 2023; Onukwulu *et al*., 2023). The traditional models for managing last-mile delivery often reliant on centralized warehouses and fixed routes are increasingly becoming insufficient. This is where the gig economy's flexible model provides significant advantages, allowing for a more adaptive and cost-effective approach to delivering goods to consumers.

The growth of gig-based work has had a transformative impact on last-mile logistics. Gig work in delivery systems is facilitated through digital platforms that connect independent workers with businesses in need of delivery services. The rise of these platforms has led to a surge in gig-based workers, creating an expansive network of individuals capable of fulfilling delivery tasks across vast geographical regions (Adekunle *et al*., 2023; Agho *et al*., 2023). The gig economy's flexibility enables businesses to scale operations rapidly based on demand, without the need for permanent infrastructure investments or fixed labor contracts.

This shift towards gig-based delivery models has brought about several changes in how logistics networks operate. First, it has increased the capacity for on-demand deliveries, as gig workers can be mobilized quickly to meet fluctuating demand. Second, it has created more cost-efficient solutions for businesses by reducing the overhead costs associated with maintaining a large, permanent workforce (Bristol-Alagbariya *et al*., 2023; Hamza *et al*., 2023). Lastly, the gig economy has prompted an evolution in consumer expectations, with the availability of faster, cheaper, and more personalized delivery options becoming a significant competitive advantage.

However, the rapid growth of gig-based work also presents challenges. These include issues related to data management, platform integration, and ensuring fairness for gig workers. As more platforms emerge and competition intensifies, there is an increasing need for robust infrastructure to support these operations (Charles *et al*., 2023; Okolie *et al*., 2023). This brings to the forefront the importance of developing data-driven strategies to optimize the entire last-mile delivery ecosystem.

The purpose of this review is to propose a conceptual framework that integrates data-driven strategies into the development of infrastructure for gig economy-based last-mile delivery systems. Given the increasing complexity and scale of gig-based logistics, data plays an essential role in optimizing delivery routes, managing resources, and improving operational efficiency. The proposed framework seeks to offer a holistic view of the infrastructure needed to support gig-based delivery services, emphasizing the integration of advanced technologies such as artificial intelligence, machine learning, and Internet of Things (IoT) systems to inform decision-making and enhance logistics operations.

The framework aims to provide a comprehensive approach that combines the flexibility of the gig economy with the efficiency of data-driven solutions, enabling stakeholders to build and scale infrastructure that is both adaptable and sustainable. It will also offer insights into how data can be leveraged to address common challenges in last-mile delivery, including route optimization, real-time tracking, and demand forecasting (Egbuhuzor *et al*., 2023; Akintobi *et al*., 2023).

This review will explore the key stakeholders involved in gig economy-based last-mile delivery systems, including gig workers, platform providers, infrastructure developers, and consumers. Each of these stakeholders plays a crucial role in the successful implementation and optimization of gig-based logistics operations. The review will examine how these stakeholders can collaborate to create a more efficient and sustainable infrastructure, with a focus on the role that data can play in driving this collaboration.

Data will be a central element in this review, as it is essential for optimizing infrastructure and operations in gig-based last-mile delivery systems. Through data collection and analysis, logistics platforms can gain valuable insights into delivery patterns, customer behavior, and traffic conditions, all of which can inform better decision-making (Onyeke *et al*., 2023; Fiemotongha *et al*., 2023). The review will emphasize how data-driven technologies can enhance the coordination of resources, reduce operational costs, and improve the overall customer experience in last-mile delivery.

In conclusion, this framework aims to bridge the gap between the gig economy and the infrastructure necessary to support it, with a particular focus on how data-driven strategies can

enhance the development of scalable, efficient, and responsive last-mile delivery systems.

2. Methodology

The PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is commonly used for structured and systematic literature reviews. For the development of a conceptual framework for data-informed gig economy infrastructure in last-mile delivery systems, the PRISMA approach would be applied in the following manner to ensure comprehensive and transparent reporting of the research process.

The first step in applying the PRISMA methodology involves identifying the research question, which, in this case, is focused on understanding the role of data-driven strategies in developing infrastructure for gig economy-based last-mile delivery systems. The next step is to conduct a thorough search for relevant literature on this topic. The search would involve multiple databases such as Google Scholar, Scopus, Web of Science, and specialized journals related to logistics, gig economy, data analytics, and infrastructure development. Keywords such as "gig economy," "last-mile delivery," "data-driven logistics," "infrastructure optimization," and "AI in logistics" would be used to ensure a comprehensive capture of all relevant studies.

Once the initial search is complete, inclusion and exclusion criteria are established to determine which studies are most relevant for the framework. Studies included in the review must focus on gig economy-based models in logistics, last-mile delivery systems, or data-driven infrastructure optimization. Exclusion criteria would rule out studies not directly addressing these themes, or those that focus on broader supply chain management without the specificity of gig-based labor or last-mile operations. Studies would also be excluded if they focus on regions or markets that do not align with the research context.

After applying the inclusion and exclusion criteria, the next step is the extraction of data from the selected studies. Key pieces of information would include the methodologies used, the technologies examined, the challenges addressed, and the solutions proposed. The extracted data would be categorized into relevant themes, such as infrastructure design, data collection techniques, route optimization, gig worker management, and the application of AI and machine learning in logistics. These themes would inform the structure of the conceptual framework, helping to identify key components that should be included in the model for data-driven last-mile delivery infrastructure.

Following data extraction, the studies are critically evaluated for quality and relevance. This involves assessing the robustness of the data, the clarity of the methods used, and the extent to which the findings are applicable to the research question. Any inconsistencies or gaps in the literature would be noted, and areas for further research or refinement would be identified. This evaluation will guide the synthesis of findings into a conceptual framework for integrating data-driven strategies into the development of infrastructure for gig economy-based last-mile delivery systems.

Finally, the results are synthesized and presented as part of the conceptual framework. The framework would outline the key components required for developing a data-informed last-mile delivery infrastructure, emphasizing the roles of technology, data management, and stakeholder collaboration. The synthesis would highlight how data-driven decision-making, including the use of AI, machine learning, and real-time data processing, can optimize delivery routes, resource allocation, and overall operational efficiency. This framework would also address potential challenges such as data privacy concerns, integration of multiple platforms, and fair compensation for gig workers.

2.1. Literature Review

The gig economy refers to a labor market characterized by short-term, flexible, and on-demand jobs typically mediated through digital platforms. Gig work allows individuals to offer their services on a temporary basis, often as independent contractors rather than full-time employees. In recent years, gig work has surged, driven by technological advancements that facilitate the connection between freelancers and businesses needing services (Onukwulu *et al*., 2023; ADIKWU *et al*., 2023). In the context of delivery systems, gig workers are typically individuals who use their own vehicles or tools to deliver goods or services for companies operating through online platforms, such as Uber, Lyft, Postmates, DoorDash, and many others.

The evolution of gig work has been influenced by several factors, including the rise of e-commerce, technological advancements, and shifts in consumer behavior. Gig-based delivery systems emerged as a flexible solution to the growing demand for fast, convenient, and affordable delivery services. These systems thrive on the ability to quickly scale delivery capacity based on demand, utilizing independent workers who can be easily mobilized to meet consumer needs. The digital platforms that connect workers and customers enable businesses to tap into a vast and dispersed workforce, minimizing overhead costs and maximizing operational flexibility (Fredson *et al*., 2023; Ozobu *et al*., 2023).

Key features of gig-based delivery systems include their on-demand nature, where consumers can request delivery services in real time, often with minimal lead times. Gig workers benefit from flexibility in choosing their working hours and locations, which makes gig work attractive for those seeking autonomy. However, this flexibility comes with challenges such as irregular income, lack of job security, and limited benefits, all of which have prompted debates about the future of gig work and the need for better regulation to ensure fair treatment for workers. Despite these challenges, gig-based delivery systems remain a powerful solution to the increasing demands for rapid delivery services, particularly in urban areas where e-commerce is growing rapidly (George *et al*., 2023; Dosumu *et al*., 2023).

Last-mile delivery is the final step in the logistics process, where goods are transported from a distribution center to the end consumer. This segment of the supply chain is critical as it directly influences customer satisfaction and is often the most costly and complex component of logistics operations (Nyangoma *et al*., 2023; Ogunwole *et al*., 2023). The last-mile segment is particularly challenging due to the need to navigate congested urban environments, manage fluctuating demand, and ensure timely delivery, all while maintaining cost efficiency.

Several challenges arise in last-mile delivery, including high delivery costs, traffic congestion, and the need to balance delivery speed with operational costs. According to studies, last-mile delivery accounts for around 30% of total logistics costs, making it a critical area for optimization. Traditional delivery systems, which rely on fixed routes and centralized

distribution centers, are increasingly inadequate in meeting the growing demand for faster and more flexible deliveries. This is particularly true in the face of rapid e-commerce growth, which has led to expectations for faster, cheaper, and more convenient delivery options.

To address these challenges, technological advancements have played a key role in transforming last-mile logistics. Innovations such as route optimization algorithms, predictive analytics, and autonomous delivery vehicles have helped streamline the process and improve efficiency. The gig economy has further enhanced last-mile delivery systems by providing a scalable, flexible labor force that can be quickly mobilized to meet fluctuating demand (Okolo *et al*., 2023; Ogunnowo *et al*., 2023). Gig workers, often using their own vehicles, contribute to reducing operational costs for businesses, and their flexibility allows them to adapt to real-time delivery requests.

Gig-based delivery models are particularly effective in urban environments, where demand for rapid delivery is high, and where the need for flexible, scalable workforce solutions is paramount. By leveraging gig workers, businesses can more easily adjust to peak demand periods, ensuring that deliveries are completed quickly and cost-effectively. However, the success of gig-based last-mile delivery systems hinges on the development of the right infrastructure to support these operations, including data-driven approaches that optimize routing, manage resources, and ensure timely delivery.

In the modern landscape of logistics, data-driven approaches have become essential in optimizing last-mile delivery systems. By leveraging data analytics, Internet of Things (IoT) technologies, and artificial intelligence (AI), businesses can improve efficiency, reduce costs, and enhance customer satisfaction (Ogunwole *et al*., 2023; Ojadi *et al*., 2023). These technologies provide the tools necessary to optimize routing, predict demand, monitor real-time traffic conditions, and make data-informed decisions that improve operational performance.

Data analytics plays a central role in infrastructure optimization by enabling logistics companies to analyze large volumes of data in real-time. By collecting data from various sources, including GPS tracking systems, traffic monitoring sensors, and consumer behavior patterns, companies can make more accurate predictions about delivery times, optimize delivery routes, and manage resources more effectively. Data analytics can also provide insights into customer preferences, helping businesses tailor their services to meet consumer demands and improve overall service quality.

The IoT is another critical technology in the development of data-informed infrastructure. IoT devices, such as sensors and smart vehicles, provide real-time information about the status of deliveries, the condition of goods in transit, and the location of gig workers (Ojadi *et al*., 2023; Bristol-Alagbariya *et al*., 2023). This data can be used to improve route planning, monitor the health of the delivery process, and ensure the safe and efficient transportation of goods. By connecting all elements of the last-mile delivery network, IoT can help optimize logistics operations in ways that were not possible with traditional systems.

Artificial intelligence (AI) also plays a pivotal role in data-driven infrastructure development. AI algorithms, particularly machine learning models, can be used to predict demand patterns, optimize delivery routes, and even forecast the performance of gig workers based on factors such as historical data, traffic conditions, and weather. AI can automate many of the decision-making processes that were once time-consuming and prone to human error, enabling real-time adjustments to delivery schedules and improving overall system efficiency.

Several case studies demonstrate the successful application of data-informed infrastructure in logistics. For example, companies like UPS have employed route optimization software that uses real-time data to determine the most efficient delivery paths, reducing fuel consumption and improving delivery times. Similarly, platforms like Uber and DoorDash use machine learning algorithms to match gig workers with delivery requests in real time, ensuring that deliveries are made quickly and cost-effectively (Bristol-Alagbariya *et al*., 2023; Ozobu *et al*., 2023). These case studies highlight the potential of data-driven technologies to transform last-mile delivery systems, making them more responsive, efficient, and scalable.

The combination of gig economy labor and data-driven technologies holds significant promise for optimizing last-mile delivery systems. As businesses continue to embrace flexible, gig-based labor models, integrating data analytics, IoT, and AI into infrastructure development will be essential for overcoming the challenges of last-mile logistics (Bristol-Alagbariya *et al*., 2023; Nyangoma *et al*., 2023). These technologies not only help streamline operations but also enable companies to meet the increasing demands of consumers for faster, cheaper, and more personalized delivery services.

2.2 Theoretical Foundations

The gig economy, characterized by flexible, short-term, and freelance employment arrangements, has attracted considerable attention from economists, as it challenges traditional labor market structures. Several economic theories help explain the rise of the gig economy, particularly the increased labor market flexibility it provides. From the perspective of labor economics, the gig economy offers workers the opportunity to engage in multiple, simultaneous job opportunities, thereby increasing their autonomy and flexibility (Onukwulu *et al*., 2023; Nyangoma *et al*., 2023). Labor market flexibility is a core feature of the gig economy, allowing workers to choose when and where they work, thereby adapting to changing market conditions and personal preferences. This flexibility benefits both workers and employers, as businesses can access an on-demand labor force while workers can select jobs that fit their schedules and lifestyles.

However, economic theories also highlight the trade-offs associated with gig work, particularly regarding income security and job stability. While flexibility may lead to higher job satisfaction, it also results in income volatility, reduced benefits, and fewer protections for workers. The economic theory of labor market segmentation helps to explain this divide between gig and traditional work, with gig workers often falling into a segment that lacks the job security and benefits of permanent employment. In the context of last-mile delivery systems, this duality is evident as gig workers often face challenges related to wage instability, lack of insurance, and limited access to social security, despite the advantages of flexibility.

Another critical economic theory applicable to gig economy-based delivery systems is the theory of cost-efficiency and scalability. Gig-based models offer significant cost

advantages to businesses compared to traditional delivery systems. By outsourcing labor to independent contractors, businesses can reduce overhead costs, such as wages, employee benefits, and training expenses. The scalability of gig-based systems allows companies to rapidly adjust the size of their workforce based on demand fluctuations, which is particularly advantageous in industries like e-commerce and logistics where delivery needs are unpredictable (OJADI *et al*., 2023; Abimbade *et al*., 2023). For last-mile delivery systems, gig models provide a dynamic solution to demand spikes, helping businesses efficiently meet peak delivery requirements without maintaining a large, permanent workforce.

Smart cities represent a significant development in urban planning, where data and technology are harnessed to enhance the quality of life for residents and optimize urban operations. Smart city frameworks rely heavily on the integration of data infrastructures, such as Internet of Things (IoT) devices, sensors, and data analytics, to create efficient, sustainable, and connected urban environments. These infrastructures are central to optimizing logistics operations, including last-mile delivery systems.

In smart cities, the deployment of IoT sensors allows for real-time data collection across multiple domains, such as traffic flow, air quality, and energy usage. For last-mile delivery systems, smart city frameworks facilitate efficient routing and delivery optimization. The integration of smart city infrastructure with delivery platforms ensures that both logistics providers and gig workers have access to accurate, up-to-date information that helps streamline the entire delivery process (Ihekoronye *et al*., 2023; Aina *et al*., 2023). Furthermore, data infrastructures in smart cities support urban logistics optimization by facilitating the integration of multiple stakeholders, such as local authorities, delivery companies, and consumers. These infrastructures create a seamless flow of information that allows for more efficient resource allocation and decision-making. In the context of gig economy-based delivery systems, smart city data can be leveraged to improve last-mile delivery efficiency by coordinating demand and supply in real time, optimizing delivery routes, and minimizing congestion. Additionally, data-driven infrastructure helps businesses analyze trends and predict demand, allowing for better workforce planning and the use of resources.

The role of data infrastructure in urban logistics is increasingly recognized as vital for optimizing delivery systems, and as cities become more connected, the importance of leveraging this data for effective last-mile delivery systems will continue to grow.

Systems theory provides a comprehensive framework for understanding complex, interconnected systems. Applied to logistics and infrastructure development, systems theory emphasizes the importance of considering all components within a delivery system as part of a broader, integrated network. Systems theory focuses on the interactions between various elements such as logistics providers, gig workers, consumers, and infrastructure suggesting that optimization can only be achieved when all elements are aligned and function cohesively (Akintobi *et al*., 2023; Okolo *et al*., 2023). The theory is particularly relevant for the development of data-driven solutions in gig economy-based delivery systems, where the efficiency of the system relies on the effective integration of various subsystems, including data infrastructure, transportation networks, and workforce management.

In the context of last-mile delivery, systems theory suggests that optimizing individual elements (e.g., delivery routes, workforce scheduling) is insufficient if they are not integrated into the larger system. A more holistic approach is necessary to design infrastructure that supports the dynamic and interconnected nature of gig-based delivery systems. By utilizing systems theory, the development of infrastructure for gig economy-based delivery systems can ensure that all elements work in synergy, maximizing efficiency and improving overall service delivery.

Applying systems theory to logistics and infrastructure development also allows for the identification of feedback loops that can help continuously improve the system. This adaptability is crucial for the success of gig economy-based delivery systems, where fluctuating demand and the diverse nature of gig work require continuous optimization (Ogunwole *et al*., 2023; Okolo *et al*., 2023).

The integration of systems theory with data-driven approaches in the context of last-mile delivery systems provides a framework for creating robust, efficient, and sustainable infrastructure (OJIKA *et al*., 2023). By considering the entire system, from gig workers and platform providers to infrastructure and consumers, a more holistic and optimized approach to last-mile delivery can be achieved. This systems-based approach to infrastructure development helps ensure that gig economy-based delivery systems can meet the growing demands of consumers while maintaining operational efficiency and cost-effectiveness.

Economic theories related to labor market flexibility and cost-efficiency, the integration of smart city data infrastructures, and systems theory all provide essential insights into the development of data-driven gig economy-based last-mile delivery systems. These theoretical foundations offer a robust framework for understanding the complexities and dynamics of modern delivery systems and provide a pathway for the optimization of infrastructure through the strategic use of data.

2.3 Key components of the framework

The success of any data-informed framework for gig economy-based last-mile delivery systems hinges on efficient data collection and management. To optimize delivery operations and infrastructure, it is essential to identify and integrate relevant data sources that can provide insights into various aspects of the delivery process. Key data sources include traffic information, delivery times, consumer preferences, vehicle performance, and gig worker activity as shown in figure 1. Similarly, consumer preferences, such as preferred delivery windows or location-based preferences, can enhance personalization and improve customer satisfaction (Adekunle *et al*., 2021; Chukwuma-Eke *et al*., 2021).

Effective data collection also involves capturing information from a variety of sensors and devices, such as GPS tracking on delivery vehicles, IoT sensors that monitor vehicle condition, and mobile apps used by gig workers to report their status or performance. Integrating these various data sources is crucial for creating a comprehensive dataset that can be used for analysis and decision-making. Furthermore, the process of real-time data processing ensures that data is immediately actionable, enabling gig economy platforms to make adjustments to delivery schedules, routes, and workforce allocation as new information arises.

The management of this data requires robust data governance practices, ensuring data quality, consistency, and security. Data must be structured in a way that facilitates seamless integration and analysis, and platforms must implement mechanisms for handling large volumes of real-time data from diverse sources (Oyedokun, 2019; Elujide *et al*., 2021). Establishing clear data standards and processes for cleaning and validating data is crucial to ensure that it is reliable and actionable.

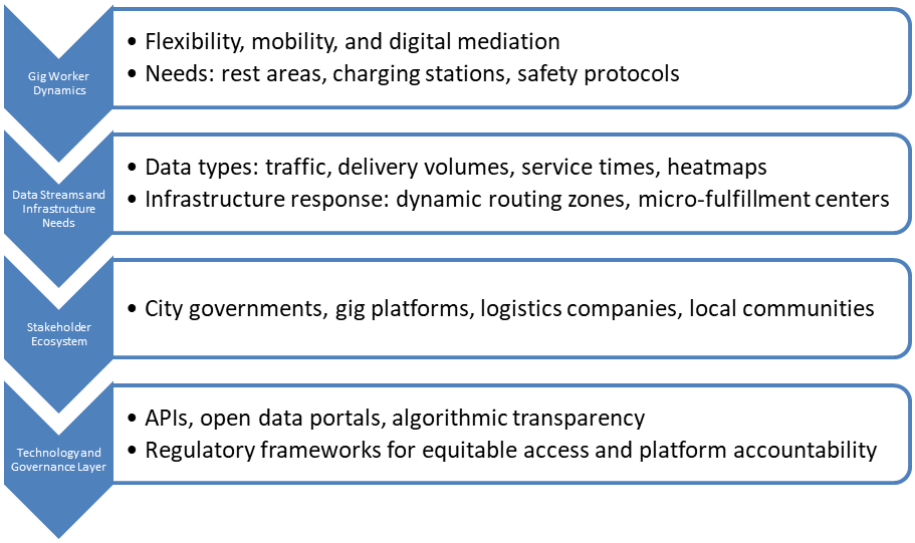

Fig 1: Key Components of the Conceptual Framework

A crucial aspect of developing data-informed gig economy-based last-mile delivery systems is the integration of advanced technological infrastructure. Cloud computing plays a pivotal role in supporting the storage, processing, and accessibility of large datasets in real-time (Elujide *et al*., 2021; Agho *et al*., 2021). Cloud platforms allow for scalable and cost-effective storage solutions, enabling gig economy platforms to process and analyze vast amounts of delivery-related data without the need for significant on-premises infrastructure. The flexibility of cloud computing also ensures that the system can handle peak demand periods, such as during holiday seasons, when the volume of deliveries is significantly higher.

IoT (Internet of Things) technologies contribute significantly to this infrastructure by enabling the real-time collection of data from various devices, such as GPS trackers, delivery vehicles, and environmental sensors. IoT sensors can provide continuous streams of data, such as location tracking, vehicle conditions (e.g., fuel levels, temperature), and even driver performance, which can be analyzed to optimize delivery operations.

Artificial Intelligence (AI) and machine learning are also central to supporting data-informed decision-making. AI-powered algorithms can analyze vast datasets to predict delivery times, optimize routes, and forecast demand. Machine learning models can continuously adapt to new data, improving their accuracy over time and enabling more precise predictions. By integrating AI into delivery systems, companies can automate routine decision-making processes, leading to more efficient and responsive operations (Kolade *et al*., 2021; Egbuhuzor *et al*., 2021).

Moreover, robust digital platforms must be developed to facilitate the interaction between gig workers and the infrastructure. These platforms serve as the central hub for gig workers to receive tasks, provide real-time status updates, and receive feedback. The platforms must be user-friendly, responsive, and integrated with other elements of the delivery system, such as traffic management, route optimization tools, and customer communication channels. They also enable seamless communication between all stakeholders, ensuring that both gig workers and logistics companies have access to accurate, real-time information.

Successful implementation of data-informed infrastructure for gig economy-based last-mile delivery systems requires active collaboration among multiple stakeholders (Ajayi and Osunsanmi, 2018; James *et al*., 2019). These include gig economy platforms, local governments, logistics companies, consumers, and infrastructure developers. Each of these stakeholders plays a critical role in the development and optimization of the delivery system.

Collaboration among these stakeholders is essential for the efficient functioning of the system. For instance, local governments can provide valuable data on traffic patterns, road conditions, and urban planning initiatives that can impact delivery operations. Logistics companies contribute their expertise in managing fleets and optimizing delivery routes. Gig economy platforms, which act as intermediaries between consumers and gig workers, play a crucial role in coordinating and monitoring the delivery process.

Data sharing is a critical component of stakeholder collaboration. For effective data-informed decision-making, stakeholders must agree on common data-sharing protocols and governance models. These models ensure that data is shared securely, fairly, and transparently. Data privacy concerns must be addressed, particularly when dealing with sensitive consumer or worker data. Establishing clear data governance frameworks, which outline how data is collected, stored, and shared among stakeholders, is essential for maintaining trust and ensuring compliance with regulations (Abimbade *et al*., 2017; Olanipekun, 2020).

The efficiency of last-mile delivery systems is often evaluated using key performance indicators (KPIs) that measure various aspects of the operation, such as delivery time, cost per delivery, route optimization, and customer satisfaction. These KPIs help assess the effectiveness of the gig economy-based delivery model and the data-informed

infrastructure that supports it.

One critical KPI is delivery time, which measures the time it takes for a package to reach its destination. This metric is essential for ensuring that customers receive their goods within the expected time frame. Other important KPIs include delivery cost, customer feedback, fleet utilization, and gig worker performance. Tracking these KPIs provides valuable insights into areas where improvements can be made, allowing for continuous optimization of the delivery process (Akinyemi and Ojetunde, 2020; Adelana and Akinyemi, 2021).

Techniques for continuous optimization based on data insights include predictive analytics, real-time monitoring, and adaptive routing. Predictive analytics uses historical data to forecast demand patterns, helping delivery platforms plan resources more effectively. Real-time monitoring allows for the dynamic adjustment of delivery routes based on changing conditions such as traffic, weather, or road closures. Adaptive routing algorithms continuously update delivery plans to optimize efficiency and reduce delays. By leveraging data insights, last-mile delivery systems can be constantly refined and improved, leading to better service, reduced costs, and increased customer satisfaction.

The key components of a conceptual framework for data-informed gig economy-based last-mile delivery systems include robust data collection and management practices, advanced technological infrastructure such as cloud computing, IoT, and AI, effective stakeholder collaboration, and continuous performance optimization through data-driven metrics (Akinyemi, 2013; Famaye *et al*., 2020). These components work together to create an efficient, scalable, and responsive delivery system that can meet the evolving demands of modern consumers.

2.4 Data-driven decision-making in last-mile delivery

Data-driven decision-making has become a cornerstone of optimizing last-mile delivery systems in the gig economy. By harnessing real-time data, predictive models, and continuous feedback loops, logistics companies and gig platforms can enhance operational efficiency, improve customer satisfaction, and ensure scalability. The application of data-driven strategies in last-mile delivery can be categorized into key areas: route optimization, demand forecasting and resource allocation, and monitoring and feedback loops (Adeniran *et al*., 2016; Akinyemi and Ebimomi, 2020). Each of these components leverages data to make real-time decisions that drive operational success.

Route optimization is one of the most critical areas where data-driven decision-making has a profound impact. Traditionally, delivery routes were planned manually or based on static assumptions, which often led to inefficiencies and delays. Today, real-time data allows for dynamic route planning that adjusts as conditions change throughout the day. Traffic, weather conditions, road closures, and other unpredictable factors can now be incorporated into route optimization algorithms, allowing for more accurate and efficient delivery paths.

Using real-time data for dynamic route planning involves leveraging GPS data, IoT sensors, and traffic monitoring systems that provide up-to-the-minute updates on road conditions. By integrating this information, delivery systems can automatically reroute drivers to avoid congested areas or road closures, thus minimizing delays (Aremu and Laolu, 2014; Akinyemi and Ojetunde, 2019).

Additionally, factors such as weather conditions and consumer demands also play a significant role in route optimization. In adverse weather conditions, such as rain or snow, the system may automatically suggest slower, safer routes. Similarly, by understanding consumer preferences and delivery windows, route optimization can prioritize deliveries based on the time frames that consumers are available, ensuring timely and satisfactory delivery experiences. Incorporating these elements into the decision-making process helps reduce delivery time, optimize fuel consumption, and enhance overall operational efficiency.

Another key area where data-driven decision-making is revolutionizing last-mile delivery is in demand forecasting and resource allocation. Predicting delivery volumes is essential for ensuring that the right number of gig workers and vehicles are available at the right time. By analyzing historical data, machine learning models can predict peaks in demand based on various factors such as time of day, seasonality, local events, and even macroeconomic trends (Adewoyin, 2021; Dienagha *et al*., 2021). This predictive capability allows logistics companies to better prepare for fluctuations in demand, ensuring that resources are allocated efficiently. By leveraging these insights, gig platforms can proactively allocate workers, vehicles, and infrastructure to meet the anticipated demand. This reduces the chances of delays or overburdening workers, which can lead to lower customer satisfaction.

Resource allocation is further enhanced by the ability to optimize gig worker assignments. Data on worker performance, location, and availability allows platforms to assign deliveries to the most suitable workers. Similarly, if a worker's route is near completion, the system can assign them a new task in the same geographic area, minimizing downtime and improving operational efficiency.

Balancing supply and demand through data-informed planning is essential for maintaining a flexible and responsive delivery system. Real-time data ensures that resources are used efficiently, preventing underutilization of workers or overcommitment, both of which can result in higher costs or delays (Oluokun, 2021; Ogunnowo *et al*., 2021). By continuously adjusting resource allocation based on real-time data, logistics platforms can maintain high service levels while minimizing operational costs.

Effective monitoring and feedback mechanisms are critical for continuous improvement in last-mile delivery systems. Data-driven decision-making does not end with route optimization or resource allocation; it must be part of an ongoing process of performance evaluation and system refinement (OJIKA *et al*., 2021; Oyeniyi *et al*., 2021). Real-time tracking of deliveries and gig worker performance provides insights into operational bottlenecks, inefficiencies, and areas for improvement.

Real-time tracking systems, powered by GPS and IoT sensors, allow logistics companies to monitor the status of deliveries in real-time. This data not only informs immediate decision-making, such as rerouting deliveries or adjusting schedules, but it also contributes to performance analytics. By aggregating this data, platforms can analyze key performance indicators (KPIs) like average delivery times, customer satisfaction ratings, and fleet utilization rates.

The use of performance analytics enables the identification of inefficiencies or underperforming areas in the system. Similarly, if certain gig workers have consistently low customer satisfaction scores, it may prompt the platform to

provide additional training or adjust workload distribution.

Mechanisms for ongoing feedback and system improvements are integral to refining the data-driven decision-making process. Feedback from gig workers and customers can be collected through digital platforms, surveys, or in-app features, which are then analyzed to gain actionable insights (Chima *et al*., 2021; Fredson *et al*., 2021). Customer feedback can be used to fine-tune delivery windows, communication protocols, and service offerings, while worker feedback can highlight challenges faced on the job, such as traffic patterns, safety concerns, or platform usability issues.

This feedback loop ensures that delivery systems are not static but evolve based on real-world data and experiences. By continuously collecting and integrating feedback from both workers and consumers, logistics platforms can improve operational efficiency, customer satisfaction, and worker engagement over time. Furthermore, these improvements can lead to the development of better algorithms and decision-making tools, creating a cycle of continuous optimization that benefits all stakeholders.

Data-driven decision-making plays a pivotal role in the optimization of last-mile delivery systems in the gig economy. Through dynamic route optimization, demand forecasting, resource allocation, and continuous monitoring and feedback loops, logistics companies can enhance their operational efficiency, reduce costs, and improve customer satisfaction (Chima and Ahmadu, 2019; Okolie *et al*., 2021). The integration of real-time data and advanced analytics into the decision-making process is critical for addressing the challenges of last-mile delivery and ensuring the scalability of gig-based systems. As the gig economy continues to evolve, data-informed strategies will be increasingly crucial for meeting the demands of modern consumers and creating more sustainable, efficient, and responsive delivery infrastructures.

2.5 Challenges and Opportunities

As data-driven strategies continue to shape last-mile delivery systems in the gig economy, significant challenges and opportunities arise. These systems, which rely heavily on real-time data, advanced analytics, and gig-based labor, face multiple hurdles, from data privacy concerns to maintaining worker welfare. However, they also present substantial opportunities for optimization, sustainability, and expansion into new markets as shown in figure 2 (Chima and Ahmadu, 2019; Okolie *et al*., 2021). This explores both the challenges and the opportunities inherent in data-informed gig economy infrastructure development in last-mile delivery systems.

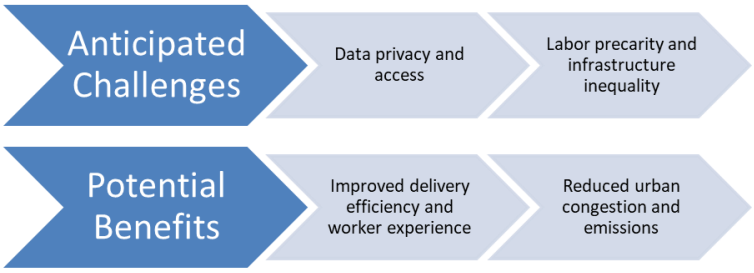

Fig 2: Challenges and opportunities

One of the foremost challenges in data-driven last-mile delivery systems is data privacy and security concerns. As gig platforms collect vast amounts of personal data from workers, consumers, and other stakeholders, safeguarding this information becomes crucial. The reliance on real-time tracking, GPS data, and consumer preferences introduces vulnerabilities to potential data breaches, exposing sensitive information to misuse. The gig economy, characterized by a large number of small-scale, often independent, platforms, complicates data security further. Ensuring compliance with data protection regulations, such as the General Data Protection Regulation (GDPR) in the EU or the California Consumer Privacy Act (CCPA), requires rigorous security protocols and governance structures. Addressing these concerns is essential to maintaining trust among consumers, workers, and stakeholders in the gig economy.

The integration of diverse data sources and platforms represents another significant challenge. Last-mile delivery systems depend on a variety of data sources, including traffic monitoring systems, weather forecasts, customer preferences, and gig worker performance data. These data come from disparate platforms and technologies, making integration and synchronization difficult. Data silos often emerge, where information from one system is not compatible with another, hindering the optimization of delivery routes, worker assignments, and customer service (Okolie *et al*., 2021; Isibor *et al*., 2021). Effective integration requires the development of interoperable platforms, standardized data formats, and robust APIs (Application Programming Interfaces) that facilitate seamless communication across systems. Without proper integration, the potential for inefficiencies and errors increases, undermining the effectiveness of data-informed decision-making.

A third challenge centers around maintaining worker welfare and fair compensation within gig-based models. While gig work offers flexibility, it often comes at the expense of worker benefits, such as health insurance, retirement savings, and job security. Many gig workers face fluctuating incomes and lack protections typically afforded to traditional employees. This can result in dissatisfaction, high turnover, and potential exploitation, as workers are paid per delivery rather than a steady wage. Ensuring fair compensation, providing health and safety benefits, and addressing the legal and ethical issues surrounding gig labor are critical to sustaining a healthy workforce. Furthermore, the constant need for gig workers, often relying on suboptimal wages and working conditions, can create tensions between platforms, workers, and consumers. Addressing these disparities is vital for long-term system sustainability.

Despite the challenges, there are numerous opportunities for further optimization, sustainability, and growth within data-driven last-mile delivery systems (Fredson *et al*., 2021).

One major opportunity lies in the use of artificial intelligence (AI) and machine learning (ML) for further optimization.

These technologies have the potential to revolutionize route planning, demand forecasting, and resource allocation. Similarly, machine learning models can predict delivery volumes, consumer preferences, and gig worker availability, improving resource allocation and reducing inefficiencies (Chukwuma-Eke *et al*., 2022; Bristol-Alagbariya *et al*., 2022). By continuously learning from operational data, AI and ML systems can fine-tune their predictions and decisions, leading to more efficient delivery operations. This ability to adapt to changing conditions and predict future trends makes AI and ML indispensable tools in optimizing last-mile delivery systems.

In addition to optimization, data-driven systems offer the opportunity to improve sustainability in delivery operations. The traditional delivery model, particularly in urban environments, contributes significantly to traffic congestion, pollution, and carbon emissions. However, data-informed strategies can make delivery systems more sustainable by reducing fuel consumption and optimizing vehicle usage. For instance, by analyzing traffic patterns, weather conditions, and consumer delivery windows, delivery platforms can minimize the number of vehicles on the road, decreasing emissions and fuel costs. Furthermore, the growing use of electric vehicles (EVs) in last-mile delivery fleets, driven by data-driven insights on vehicle availability and routing, can contribute to reducing the carbon footprint of these systems (Ajiga *et al*., 2022; Bristol-Alagbariya *et al*., 2022). By embracing sustainability through better infrastructure and optimized logistics, gig-based delivery models can align with broader environmental goals.

Another promising opportunity is expanding the gig economy to underserved regions through improved infrastructure (Ogunwole *et al*., 2022). In many rural and remote areas, access to fast and reliable delivery services remains limited. Data-driven approaches to last-mile delivery can bridge this gap by enhancing the infrastructure needed to support gig workers in these regions. By leveraging real-time data, AI, and IoT technologies, delivery systems can adapt to the unique challenges of rural logistics, such as sparse populations, difficult terrain, and low demand. Additionally, improved infrastructure such as enhanced digital platforms, communication networks, and transportation options can empower gig workers to serve underserved areas more efficiently. This expansion not only creates new economic opportunities for workers in these regions but also increases access to goods and services for consumers in remote locations (Ogunwole *et al*., 2022; Okolo *et al*., 2022).

Furthermore, improving the infrastructure of gig economy-based last-mile delivery systems in underserved regions can lead to job creation, economic development, and greater consumer satisfaction. As delivery services become more accessible in these areas, the demand for local goods, services, and employment opportunities increases, thus fostering local economic growth (Ezeafulukwe *et al*., 2022; Chukwuma-Eke *et al*., 2022). By creating a more robust and efficient gig economy infrastructure, platforms can contribute to reducing regional inequalities in service access. While data-driven last-mile delivery systems in the gig economy face significant challenges such as data privacy concerns, integration difficulties, and worker welfare issues, they also present valuable opportunities for optimization, sustainability, and expansion (Ezekiel and Akinyemi, 2022; Ogunnowo *et al*., 2022). Leveraging AI and machine learning for further optimization, improving sustainability through more efficient delivery practices, and expanding the gig economy into underserved regions can drive substantial benefits for all stakeholders. Addressing these challenges while seizing these opportunities will be crucial for the continued success and growth of gig-based last-mile delivery systems, ensuring they are both economically viable and socially responsible in the long term.

2.6 Policy and regulatory considerations

The rapid growth of the gig economy, particularly in the context of last-mile delivery systems, has introduced both opportunities and challenges for policymakers and regulatory bodies. The integration of data-driven technologies in this sector necessitates a framework of regulations that address fair labor practices, infrastructure development, and data governance as shown in figure 3(Govender *et al*., 2022; Okolo *et al*., 2022). Governments have a pivotal role in ensuring that the growth of gig economy-based delivery systems is sustainable, equitable, and secure. This explores the necessary regulations for gig economy work and last-mile delivery systems, the role of the government in infrastructure development, and the critical policy considerations regarding data privacy and access.

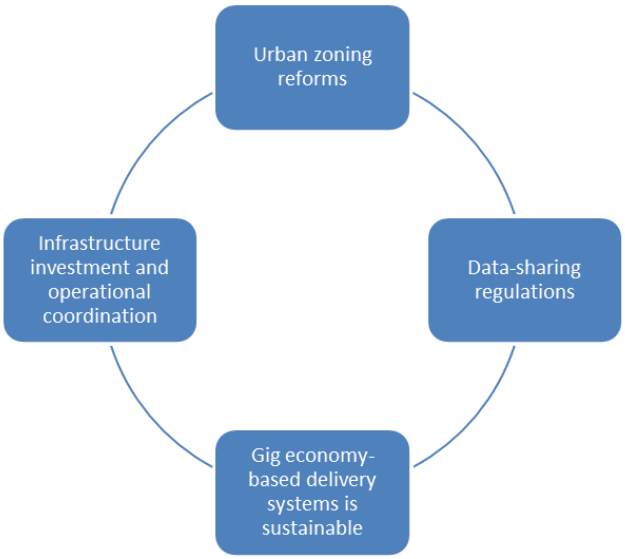

Fig 3: Policy and Regulatory Considerations

As the gig economy expands, ensuring fair labor practices within last-mile delivery systems becomes an increasingly urgent issue (Akinyemi and Ezekiel, 2022; Aremu *et al*., 2022). Gig workers, particularly in delivery services, are typically classified as independent contractors rather than employees. This classification often limits workers' access to essential benefits, such as health insurance, paid leave, and retirement savings plans. Policymakers must develop guidelines that ensure fair wages and equitable working conditions for gig workers, balancing the flexibility of gig work with the need for job security and adequate compensation (Attah *et al*., 2022; Akinyemi *et al*., 2022). Labor regulations need to establish minimum wage standards, protect workers from exploitation, and provide mechanisms for resolving disputes. In particular, setting regulations that define acceptable work hours, delivery expectations, and compensation frameworks will be crucial for maintaining a fair and sustainable workforce.

Additionally, the development of infrastructure for last-mile

delivery systems should be regulated to ensure that it meets both the technological and operational needs of gig workers and consumers. This includes creating standards for digital platforms, which gig workers rely on for assignments and payments. Regulations should establish protocols for transparency in platform algorithms, ensuring that workers are fairly assigned tasks, receive appropriate compensation, and can work within clearly defined conditions (Akintobi *et al*., 2022; Collins *et al*., 2022). Moreover, local and regional authorities must consider the environmental impact of last-mile delivery services, particularly in urban areas. Policies that regulate vehicle emissions, incentivize the use of electric vehicles (EVs), and promote sustainable delivery models will be critical for mitigating the environmental footprint of gig-based delivery systems.

Another important policy consideration involves data privacy, security, and governance. Gig economy platforms collect vast amounts of data from workers, consumers, and logistics operations, making data protection a top priority (Fredson *et al*., 2022; Attah *et al*., 2022). Governments must establish comprehensive data privacy regulations that safeguard individuals' personal information while allowing platforms to collect necessary operational data. This includes defining data usage rights, consumer consent protocols, and the secure handling of sensitive information. Privacy regulations must also extend to gig workers, ensuring that their location data, work hours, and earnings are not misused. Governments must ensure that data governance frameworks are in place to regulate who has access to the data, how it is stored, and who is responsible for maintaining its integrity (Adepoju *et al*., 2022; Collins *et al*., 2022). As data plays an essential role in optimizing delivery systems, these regulations will help prevent abuse while fostering an environment of trust between workers, consumers, and platforms.

Governments play a crucial role in supporting infrastructure development for gig economy-based last-mile delivery systems, particularly through public-private partnerships (PPPs). The nature of last-mile delivery, especially in urban and underserved areas, requires significant infrastructure investment, including advancements in digital platforms, transportation networks, and logistical operations (Adewoyin, 2022; Ozobu *et al*., 2022). While private sector platforms may lead the innovation in gig-based delivery services, public sector involvement is necessary to provide the foundational infrastructure, such as road networks, communication systems, and energy grids, that support these services.

Public-private partnerships can be a powerful mechanism for financing and developing infrastructure projects that benefit both gig workers and consumers. For example, cities can collaborate with private delivery platforms to create designated delivery zones, improve roadways, or build hubs where goods can be consolidated and efficiently dispatched (Charles *et al*., 2022; Okolie *et al*., 2022). These collaborative efforts can help ensure that gig workers have access to the resources they need to perform their jobs efficiently while reducing congestion and pollution. In particular, PPPs can drive the adoption of electric vehicles in last-mile fleets by creating incentives for businesses and workers to adopt greener transportation methods. Additionally, governments can support the development of charging infrastructure for electric vehicles, facilitating a smoother transition to sustainable transportation.

Moreover, governments must ensure that infrastructure investments are equitable and reach all regions, including underserved or rural areas. A key policy focus should be reducing the digital divide and ensuring equitable access to data and technology (Bristol-Alagbariya *et al*., 2022; Akintobi *et al*., 2022). While major metropolitan areas may benefit from the latest technological advancements, rural and remote areas often lack the necessary infrastructure to support gig economy-based delivery services. Governments must create policies that encourage the expansion of high-speed internet, 5G networks, and digital platforms into underserved regions, providing gig workers and consumers with access to the same technological advantages as those in urban areas. This will help ensure that the benefits of the gig economy are distributed more evenly, rather than concentrating them in regions with better existing infrastructure.

Additionally, regulatory measures should aim to reduce barriers to entry for new players in the gig economy, allowing smaller platforms and businesses to compete with larger companies. Encouraging the development of local and regional delivery platforms can help improve service delivery in underserved markets, create new employment opportunities, and drive competition that benefits consumers. Governments can incentivize innovation in delivery models, such as by providing tax breaks or subsidies to companies that develop new, efficient, and sustainable delivery technologies (Hamza *et al*., 2022; Chukwuma-Eke *et al*., 2022).

Finally, governments must foster the development of universal standards and frameworks for the gig economy and last-mile delivery systems. This includes creating guidelines for data collection, ensuring interoperability between various platforms, and setting standards for vehicle types, delivery times, and customer service (Nwaimo *et al*., 2022). By developing clear regulations and standards, governments can create a more predictable and stable environment for gig economy platforms, workers, and consumers.

The growth of the gig economy in last-mile delivery systems presents both significant opportunities and challenges for policymakers. Regulations must ensure fair labor practices, data privacy and security, and equitable infrastructure development. Governments, through public-private partnerships, can facilitate the necessary investments in infrastructure while ensuring that gig economy services are accessible in all regions. As the gig economy continues to evolve, the development of thoughtful, comprehensive regulatory frameworks will be essential to balance innovation with fairness and sustainability. By addressing these policy and regulatory considerations, governments can help create a gig economy infrastructure that is efficient, equitable, and secure, benefiting all stakeholders involved (Isibor *et al*., 2022; Fredson *et al*., 2022).

3. Conclusion

This proposed a conceptual framework for integrating data-driven strategies into the development of infrastructure for gig economy-based last-mile delivery systems. The framework emphasizes four key components: data collection and management, technology infrastructure, stakeholder collaboration, and performance metrics for optimization. It highlights the importance of real-time data, technological advancements like AI and IoT, and the collaboration among gig workers, platform providers, and local governments in

optimizing the last-mile delivery ecosystem. Additionally, the framework underscores the need for a performance evaluation system, ensuring that last-mile delivery operations remain efficient and adaptable.

The future development of data-driven gig economy infrastructure holds immense promise. One key area for further research involves the optimization of machine learning algorithms to enhance route planning and resource allocation. Exploring the integration of autonomous vehicles and drones in the delivery process could revolutionize last-mile logistics. Another avenue for future research is the exploration of sustainability metrics and their integration into the data-driven decision-making processes, ensuring that gig economy-based delivery services can contribute to environmental goals.

The implications of this framework are far-reaching for various stakeholders. For gig workers, it offers an opportunity for improved working conditions through better allocation of tasks, fair compensation, and enhanced work-life balance. Delivery platforms can benefit from optimized operations, reducing costs and improving customer satisfaction through data-driven insights. Consumers are likely to experience faster and more efficient delivery services, meeting the growing demand for rapid and reliable services. For urban planners, the framework provides valuable insights into designing sustainable, tech-enabled infrastructure that supports the evolving needs of urban delivery systems.

Ultimately, the framework aims to guide the development of a more sustainable, efficient, and equitable gig economy infrastructure for last-mile delivery, benefiting all stakeholders and contributing to the broader evolution of urban logistics.

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