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Synthetic Data for Resilient Urban Traffic Systems: A Methodological Framework

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Abstract Urban traffic models often struggle with rare and disruptive events because real-world data for such situations are limited. This article presents the SynTraffic project, which explores the use of synthetic traffic data to support more robust and resilient traffic modelling. The proposed approach combines real-world observations with artificially created traffic scenarios to expand the range of conditions available for model development. The methodology is demonstrated using the city of Žilina as a representative urban case with complex traffic patterns and long-term monitoring infrastructure. The article focuses on the theoretical background, methodological design, and expected benefits of synthetic data in intelligent transportation systems, highlighting its potential to address data scarcity, support privacy-aware analysis, and improve the handling of unusual traffic conditions.

Keywords synthetic traffic data, urban traffic modelling, intelligent transportation systems, traffic resilience

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1. Introduction

Urban mobility systems face persistent challenges arising from traffic congestion, inefficiencies, and operational disruptions. In the European Union, urban traffic jams are estimated to cost €110 billion annually, reflecting substantial losses in productivity and environmental quality [1]. Cities like Žilina (a mid-sized transport hub in Slovakia) grapple with these pressures as travel demand continues to grow while infrastructure capacity remains limited.

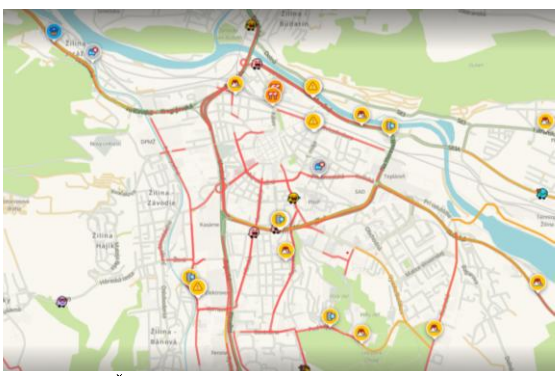

Figure 1. The Žilina traffic volume during extreme traffic conditions.

As illustrated in Fig. 1, extreme traffic conditions in Žilina can escalate rapidly, revealing how sensitive the network is to adverse or unexpected situations. Traditional traffic management strategies (fixed-timed signals, static models) often struggle to perform under such dynamic or extreme circumstances, including accidents or severe weather events. These limitations highlight the need for more adaptive, responsive, and data-informed approaches.

These challenges explain why modern traffic systems increasingly rely on flexible and predictive decision-support tools capable of handling unexpected disruptions. The field has seen a marked rise in the adoption of Intelligent Transportation Systems (ITS) supported by Artificial Intelligence (AI). Deep learning techniques are now widely explored for traffic prediction, adaptive control, and incident detection [2]. Recent research has shown that AI models, particularly those using generative techniques, can maintain strong performance even under adverse or unusual conditions. For instance, Liu et al. [3] proposed a two-stage deep model that delivers robust scene segmentation in heavy fog and snow, while Lee et al. [4] demonstrated that a Generative Adversarial Network can translate LIDAR data from clear weather into rainy or foggy conditions, , thereby improving model generalization and enhancing perception in adverse environments. Such findings underscore the potential of AI to enhance traffic safety and operational efficiency.

A fundamental limitation of these methods is the need for large, diverse, and representative training datasets. Real traffic data often captures only standard conditions, making it difficult to model rare but high-impact situations, such as a sudden citywide jam during a blizzard. Collecting such data is not only costly but also constrained by privacy and legal regulations. Camera-based and connected-vehicle data may include personal identifiers, restricting how they can be shared or processed under frameworks like GDPR [5]. These constraints create a data bottleneck, where the scenarios most relevant for improving system resilience are precisely the ones with the least available data.

Synthetic traffic data provides a practical solution to this challenge. It consists of artificially generated datasets that retain key statistical patterns of real traffic without exposing personal information. Modern generative models make it possible to create realistic artificial samples that supplement real-world training data [6]. This approach helps fill gaps related to rare events, increases overall data volume, and inherently supports privacy protection. Forecasts from the European Data Protection Supervisor suggest that synthetic data may become the dominant source for AI model training by 2030 [7]. In ITS, synthetic data allows traffic models to learn from accidents, extreme weather, or infrastructure failures without needing these events to happen in real life.

The Synthetic Traffic Data for Mobility and Resilience (SynTraffic) project builds directly on this shift toward synthetic data in AI-based mobility research. Developed at the University of Žilina, the project aims to integrate generative AI and simulation techniques to improve the modelling of urban traffic dynamics. Its methodology is based on combining real and synthetic datasets so that AI-based prediction and control models can learn to operate effectively under both routine and atypical conditions that may arise in a city such as Žilina. The objective is to support the development of traffic management strategies that remain robust, maintaining flow and safety even when the system is exposed to unexpected disturbances. From a theoretical perspective, SynTraffic operates at the intersection of transportation engineering, machine learning, and data science.

The following sections present the theoretical foundations of the SynTraffic methodology and the context in which it is applied. They outline the key concepts that guide the project, including the use of generative models and the integration of real and synthetic data in the modeling process. They also describe the expected improvements in model performance and system resilience and explain how this approach supports both scientific understanding and practical development in smart urban mobility.

2. Materials and Methods

This section outlines the methodological foundation of the SynTraffic project, which combines generative modelling, data integration, and resilience-oriented design to enhance the performance of urban traffic prediction and control systems. It first presents the generative approaches used to create synthetic traffic data, including data-driven models and microscopic simulation tools. It then describes the framework for integrating synthetic and real datasets to ensure consistent, balanced, and reliable training conditions for machine learning models. Finally, it introduces the theoretical principles that guide the project's focus on resilience, explaining how diverse data sources and systematic validation contribute to robust behaviour under both typical and stress conditions.

2.1. Generative Modelling for Synthetic Data

Generative modelling forms a central component of the SynTraffic project because it provides a way to create synthetic traffic data that reflects the patterns found in real measurements from the transport system. The project focuses on developing and evaluating generative models for creating synthetic traffic data, in particular Generative Adversarial Networks (GANs) [8], [9] and Variational Autoencoders (VAEs) [10]. In parallel, microscopic traffic simulation tools are used as a separate source of scenario-based data. Together, these approaches support the generation of synthetic images, time series, and traffic scenarios that represent a broad range of conditions, including situations that are difficult to capture through real-world observations.

GANs will be developed and tested in SynTraffic to learn how traffic situations appear in real datasets and to generate new samples that follow the same structure. A GAN consists of two neural networks trained together. The generator produces synthetic data, while the discriminator evaluates whether the data looks real or artificial. Through repeated updates, the generator gradually improves its ability to produce samples that the discriminator cannot reliably differentiate from the real data. This makes GANs useful for producing high-fidelity synthetic traffic images and time series, especially in situations where traffic patterns vary strongly with environmental context. The project uses established techniques to improve training stability and to encourage the model to produce a broad variety of scenarios, including during different times of day or under different weather conditions. The resulting synthetic datasets can extend the coverage of the real dataset, thereby supporting the development of more robust prediction and detection models.

VAEs provide a complementary approach. A VAE learns a latent space that captures the essential structure of real traffic data, and from this space it can sample new variations. The model consists of an encoder, which compresses the data into a latent representation, and a decoder, which reconstructs the data from this representation. This probabilistic framework allows the model to generate smooth variations of typical traffic behaviour and to provide plausible values in regions of the dataset where real measurements may be missing. In SynTraffic, VAEs will be used primarily for numerical data, such as traffic flows or speeds, where learning a structured latent space can support the generation of consistent synthetic sequences and help describe how different traffic states relate to one another.

Alongside data-driven generative models, SynTraffic uses microscopic traffic simulation tools. Simulation provides a controlled virtual environment in which traffic demand, roadway layout, weather, and incidents can be introduced with precision. This enables the generation of physically consistent data for rare or safety-critical situations that cannot easily be collected in real operations. Simulation also provides complete ground truth for all elements of the system, which is valuable when training or evaluating machine learning models [11]. In the project, simulation serves two purposes. First, it produces synthetic datasets for underrepresented scenarios. Second, it acts as a reference for checking whether GAN- or VAE-generated data remains consistent with the expected physical behaviour of the transport network.

Together, GANs, VAEs, and microscopic simulation provide a diverse toolbox for generating synthetic data. Each method contributes different strengths: GANs for realistic detail, VAEs for structured variation and stability, and simulation for physical consistency. Table 1 summarises the roles of these approaches in the project.

Table 1. Approaches for Synthetic Traffic Data Generation

Approach	Strengths	Challenges
GAN e.g., to create realistic traffic images or time-series	– High realism in outputs; captures complex correlations in data *implicitly*. – Can produce detailed, high-fidelity synthetic examples (e.g., sharp images of traffic scenes).	– Difficult to train (adversarial instability). – May suffer from mode collapse (missing some scenario types). – Requires large training dataset and careful tuning to get broad coverage.
VAE e.g., to model distribution of traffic flows and generate new variations	– Stable training with explicit likelihood optimization. – Learns an organized latent space of traffic patterns, enabling controlled sampling and interpolation. – Good for data augmentation and imputing missing data with uncertainty.	– Generated data can be blurred or less precise (tendency to average outputs). – Lower detail for visual data; might miss fine nuances without further refinement.
Traffic Simulation e.g., to simulate accidents, roadworks, or new infrastructure virtually	– Ensures physical and logical consistency (traffic obeys rules of the road). – Can produce rare dangerous events safely and provide complete ground truth labels. – Flexible scenario design (any "what-if" can be tested by setting initial conditions in the sim).	– Relies on quality of simulation models (driver behaviour, vehicle dynamics); if those are imperfect, data may not reflect real human behaviour. – Computationally intensive for large networks or many repeated runs. – Needs expert input to set up realistic scenarios (calibration to real city conditions).

2.2. Integrating Synthetic and Real Data in Traffic Models

The value of synthetic data depends on how effectively it can be combined with real measurements for model training and analysis. SynTraffic therefore develops a structured framework for integrating synthetic and real traffic data so that machine learning models can treat them as a unified information source. This includes harmonizing data formats, balancing the contribution of different data types during training, and validating the integrated dataset to ensure that synthetic data supports rather than distorts model behaviour.

The first step is data harmonization. All synthetic samples generated by GANs, VAEs, or simulation tools are transformed to match the structure and feature space of the real dataset. If the real data contains fields such as timestamp, location, vehicle count, and average speed, the synthetic data is required to follow the same schema. Units and measurement scales are aligned, and multi-source data is placed on a common timeline. This reduces the risk that the learning algorithm identifies accidental cues that distinguish synthetic from real data. Scenario metadata may be used during training when appropriate, either to test model sensitivity or to enrich the variability of training conditions.

A central methodological consideration is avoiding bias when mixing synthetic and real data. If the datasets were simply concatenated, one type of data could dominate the training process. SynTraffic will therefore use controlled sampling and weighting strategies. For example, early training may include more synthetic samples to expose the model to diverse conditions, while later refinements may rely more heavily on real data. This reflects standard ideas from domain adaptation, where synthetic data is treated as a related source domain. After training on mixed data, a fine-tuning step on purely real data can correct small differences between the two domains. This strategy aligns with findings from related work in advanced driver assistance systems, where combining synthetic and real data and then fine-tuning on real examples produced the best performance [12].

SynTraffic also performs statistical checks to validate the combined dataset. Model outputs are compared across real, synthetic, and mixed inputs to detect whether the model reacts differently depending on the data source. If a model consistently predicts unrealistic patterns when fed synthetic samples that should match real-world conditions, this signals a domain shift that must be corrected. Validation is carried out both on holdout sets of real data and on synthetic scenarios with known ground truth from simulation. Any discrepancies feed back into refining the generative models or adjusting the synthetic-to-real data ratio.

Data quality assurance is included throughout the integration process. Real traffic data may contain noise, outliers, or missing values, and synthetic data can occasionally produce artifacts. SynTraffic applies filtering and outlier detection to remove or correct values that violate expected physical constraints, such as negative traffic counts or sensor malfunctions. The goal is to produce a coherent dataset that is both diverse and reliable. Conceptually, this approach addresses the bias-variance trade-off by reducing variance through data cleaning and reducing bias by incorporating a wider variety of synthetic scenarios.

After integration and training, the project performs resilience testing of the resulting models. The models are evaluated under stress conditions generated through simulation or synthetic data to confirm that the integration process has achieved the intended improvements in robustness. If performance does not meet expectations, the integration loop is repeated with revised weighting or updated generative models. This iterative testing reflects the project's focus on robust optimization and resilience assessment for urban traffic systems.

2.3. Theoretical Basis for Resilience in Traffic Systems

A central goal of SynTraffic is to strengthen the resilience of urban traffic systems by improving the quality and diversity of data used to train predictive and control models. In theory, resilience refers to the ability of a system to absorb disturbances, adapt to changing conditions, and recover quickly from disruptions. In the context of traffic networks, this means that during events such as accidents, extreme weather, or sudden increases in demand, the system should continue to operate at an acceptable level and restore normal flow without cascading failures.

Synthetic data contributes to resilience by filling knowledge gaps that make traffic models fragile. Many operational models perform poorly during extreme or unusual situations simply because they were never exposed to them during development. By incorporating synthetic examples of severe weather, infrastructure failures, or unexpected demand surges into training, SynTraffic broadens the range of conditions that the AI system can recognize and respond to. This follows the same logic used in other safety-critical fields, where simulation is used to prepare systems for low-frequency, high-impact events. The theoretical basis is expanded scenario coverage: models trained with synthetic data effectively gain experience with a wider portion of the system's state space.

A predictive model that remains reliable under stress allows traffic management strategies to be implemented proactively. If the model can forecast that a specific combination of conditions, such as a major event combined with heavy rain, will result in congestion within a short time frame, operators can adjust signal timings, reroute vehicles, or issue traveller information in advance. Without this predictive capability, intervention would occur only after congestion fully develops, which is often too late to prevent large delays. The principle is straightforward: better and more diverse information directly enhances the system's ability to act resiliently.

Resilience also involves the ability to handle situations that were not explicitly seen during training. No dataset can include all possible future scenarios, so SynTraffic emphasizes generalization. By exposing the models to a wide range of synthetic variations, the approach reduces dependence on narrow correlations and encourages learning of broader patterns, such as the effect of weather on vehicle speeds or how traffic shifts when a major link becomes unavailable. This aligns with established theory in machine learning that adding diverse samples near the edges of the input domain can significantly improve a model's performance in novel or partially unfamiliar contexts [13].

Another source of resilience in SynTraffic comes from redundancy in data and modelling approaches. Because the project uses synthetic and real data together, along with multiple generative models and simulation tools, it avoids reliance on any single data stream or method. If one model produces unrealistic outputs for a particular scenario, others can provide a corrective reference. This ensemble of data sources creates a safety net and supports the idea of hybrid modelling, where physics-based and data-driven components can complement each other to improve robustness in complex systems.

Ethical and legal considerations also form part of the theoretical basis for resilience. Traffic data often includes sensitive information, and its use is constrained by privacy regulations. Synthetic data offers a practical way to reduce dependence on personal data while still enabling detailed analysis and model development. This aligns with principles of data protection by design. Synthetic data can also be used to correct imbalances in the real dataset and improve fairness. If certain regions or conditions are underrepresented in real data, additional synthetic samples can be generated to balance the distribution. The project monitors model performance across different subsets of the dataset to detect potential biases and address them through targeted synthetic data generation. In this way, synthetic data supports not only technical resilience but also compliance and fairness in the modelling process.

The theoretical foundation of SynTraffic rests on expanding scenario knowledge, improving generalization, incorporating redundancy, and embedding ethical safeguards. These elements together form a coherent strategy for building urban traffic models that can withstand disruptions and continue to operate reliably under a wide range of conditions.

3. Study Area and Data

This section introduces the study area selected for the SynTraffic project and describes the types of real-world data that form the basis for the methodological development. The aim is to provide a clear contextual background of the urban transport environment and to explain how available data sources support research focused on traffic behaviour under both normal and disrupted conditions.

3.1. Study Area: The City of Žilina

The study area of the SynTraffic project is the city of Žilina, a medium-sized urban area located in northwestern Slovakia. Owing to its geographical position, Žilina represents an important node within both the national and regional transport system. Several major transport corridors intersect in the city, linking domestic routes with cross-border connections towards the Czech Republic and Poland. Žilina also functions as a key road and rail hub, which is directly reflected in the intensity and diversity of traffic flows within its territory.

The transport system of the city is characterized by the simultaneous presence of multiple traffic types. Local urban traffic, suburban commuting, freight transport, and transit flows all overlap within a relatively compact road network.

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In transport research, such an environment is typically described as having a high level of demand heterogeneity, where local and supra-local traffic relations intersect and interact. This structure makes the system sensitive to changes in traffic organization and external disturbances.

From a spatial perspective, Žilina has a compact urban core connected by a system of radial access roads and collector routes linking the city center with surrounding residential areas and the regional road network. This configuration is typical for Central European cities, where historically developed urban structures must accommodate modern traffic demand, including increasing regional and transit movements.

The city's road network includes several capacity-sensitive sections and signalized intersections that act as natural bottlenecks. Major road corridors such as the D1 and D3 motorways, which are part of the TEN-T network, pass through or near the city and are complemented by first-class roads including I/11, I/18, I/60, and I/61. Road I/18, connecting north and south, plays a particularly critical role, as transit traffic is frequently redirected through the city during motorway maintenance or incidents, especially in the Strečno section. The city ring road, known as "Veľká okružná" (I/60), concentrates a large share of both urban and transit traffic and represents a structurally vulnerable element of the network.

Traffic conditions in Žilina exhibit strong temporal and spatial variability. Daily traffic patterns change with commuting cycles, while weather conditions and extraordinary events such as accidents or infrastructure restrictions can rapidly degrade traffic performance. Long-term observations indicate growing levels of individual car traffic, which, combined with limited urban space, result in recurring congestion and increased sensitivity to disruptions. These characteristics create favourable conditions for studying unbalanced and dynamic traffic states.

Another important factor is the ongoing evolution of the city's transport system. Changes in traffic organization, interventions on higher-level road infrastructure, and regulatory measures related to parking or access management continually reshape traffic behaviour. Such processes increase the need for monitoring, prediction, and evaluation of transport system resilience.

3.2. Justification of the Site Selection

The selection of Žilina as the study area for the SynTraffic project is based on a combination of transport characteristics, data availability, and continuity of research activities. From a traffic engineering perspective, the city offers a compact yet complex system in which urban, suburban, and transit flows naturally overlap. This allows traffic behaviour to be observed and analysed at multiple scales within a single territory.

The structural complexity of the road network, including major entry radials, capacity-limited sections, and signal-controlled junctions, creates situations in which traffic conditions can deteriorate quickly due to increased demand, adverse weather, or partial infrastructure failures. These properties make Žilina a suitable environment for examining system behaviour under stress and non-standard conditions.

A key reason for choosing Žilina is the availability of long-term, consistent real-world traffic data. Previous research and implementation projects have established a monitoring infrastructure that enables continuous data collection with comparable structure over time. Initiatives such as CleverNet and EnCLOD laid the foundation for what is often referred to as a Living Urban Laboratory, where traffic data is used not only for research but also to support decision-making at the city level.

The fact that Žilina has already served as a reference area in traffic modelling and simulation studies further confirms its suitability for methodologically oriented research. Within SynTraffic, the city provides a realistic framework for exploring approaches based on the integration of real and synthetic data in the context of an operating urban traffic system.

3.3. Data Sources and Data Types

The SynTraffic project is based on a heterogeneous set of real-world data sources that together provide a comprehensive view of urban traffic behaviour. Rather than relying on a single data stream, the project integrates multiple data types capturing both traffic dynamics and external influencing factors. This multi-layered data structure forms the empirical foundation for subsequent analytical and modelling tasks.

The primary data layer consists of high-frequency traffic sensor data collected from the existing monitoring infrastructure in the city. These data include vehicle counts, traffic intensities, speed measurements, and basic flow characteristics. High temporal resolution is essential for capturing short-term fluctuations and transient phenomena typical of real traffic, such as sudden speed changes or gradual congestion formation.

Camera-based data represent an important complementary source. Video recordings and still images from selected road sections and intersections provide a visual representation of traffic conditions. This data supports the interpretation of sensor measurements, allows observation of interactions between road users, and helps identify non-standard situations that may not be fully reflected in numerical data alone.

Environmental and microclimatic data form another essential component. These data include meteorological variables such as precipitation, temperature, visibility, lighting conditions, and road surface state. Such factors have a well-documented influence on driver behaviour, network capacity, and safety, and are therefore critical for understanding variability in traffic performance.

The project also uses historical traffic records collected in previous research and operational projects. These include long-term traffic counts, accident records, and information on infrastructure failures or maintenance activities. Historical data provide context for current observations and are particularly important for characterizing rare but impactful events, which cannot be reliably analysed without empirical reference.

4. Expected Theoretical Outcomes

SynTraffic is designed as a methodological project, so the expected outcomes focus on theoretical advances supported by previous studies and early experiments. By training traffic models on a combined set of real and synthetic data, the project anticipates measurable improvements in predictive accuracy and operational robustness across a wide range of traffic conditions.

One expected outcome is improved performance in forecasting key traffic variables such as flow, speed, and travel time. Models trained with synthetic augmentation should achieve lower error rates than models trained only on real data, especially in scenarios that are rare or difficult to capture. Prior work supports this expectation. Zhu et al. [13] demonstrated that adding synthetic samples to real traffic volume data reduced forecasting error in a graph neural network model, particularly during peak and off-peak transitions. In SynTraffic, a deep learning model exposed to synthetic incident scenarios should predict the effects of real incidents more accurately than a model lacking such exposure, with anticipated error reductions consistent with the 10–20% improvements reported in related studies.

For vision-based tasks, such as incident detection or vehicle classification in camera streams, synthetic images of rare events are expected to enhance recognition performance. Dewi et al. [8] showed that generating additional images of rare traffic signs using a DCGAN improved a CNN's classification accuracy. SynTraffic aims to achieve similar benefits for detecting anomalies in road scenes. Early tests with YOLO-based models already indicate fewer false negatives when synthetic incident scenes are included in training, suggesting that exposure to a broader spectrum of examples helps the model recognize events that seldom appear in real footage.

Resilience is another key expected outcome. The models developed within SynTraffic should remain stable when confronted with scenarios they have not seen before, because the synthetic data broadens the domain of conditions the model has learned to interpret. In simulation-based stress tests, models trained with synthetic augmentation remain reliable under combinations of events that would typically cause baseline models to fail. For example, during a combined snowstorm and partial signal blackout, a conventional model might behave unpredictably, whereas a SynTraffic-trained model can still provide meaningful predictions by drawing on related synthetic examples seen during training. Similar patterns were observed by Jelić et al. [12] in the ADAS domain, where hybrid models trained with both synthetic and real data-maintained performance under domain shifts that caused real-only models to degrade.

The project envisions improvements in system-level behaviour once such models are applied in traffic control contexts. More accurate and robust predictions are expected to support proactive interventions, such as early rerouting or adaptive signal adjustments. At this stage, these effects are conceptual and will be explored in future simulation-based studies. The expectation is that control strategies informed by SynTraffic-enhanced models could help reduce congestion duration and limit queue formation during high-impact events when compared to traditional approaches.

A further anticipated outcome is the transferability of SynTraffic's methodology. By demonstrating in Žilina that synthetic data improves model accuracy and resilience, the project contributes a generalizable framework that can be adapted to other cities and transport domains. This includes applications such as public transport modelling, active mobility planning, or emergency response analysis. The framework shows how synthetic data can systematically fill gaps in real datasets and support more robust decision-support tools.

These outcomes will be substantiated through analytical evaluation and comparison with prior literature. Studies such [3], [8], [13] provide external references for expected improvements, while SynTraffic's internal evaluations will document specific error reductions, stability measures, and performance across incident scenarios. Results will include quantitative indicators, such as forecast accuracy under stress conditions, and qualitative assessments of model robustness in novel or unexpected environments. Together, these outcomes represent the theoretical advances expected from combining real and synthetic data in urban traffic modelling.

5. Discussion

The SynTraffic project offers several important insights for the field of urban mobility, particularly regarding how synthetic data and generative modelling can support more resilient traffic systems. One of the clearest contributions is demonstrating a practical approach to overcoming data scarcity in complex system modelling. Traditional traffic models have always been limited by the range of events captured in historical data or by simplifying assumptions needed for analytical models. SynTraffic expands this space by generating new, domain-consistent scenarios that enrich the learning process. This represents a shift in how transportation researchers can think about data: the dataset is no longer a fixed constraint but something that can be actively shaped to support better modelling. Similar shifts have already reshaped domains like robotics and autonomous driving, where simulation and synthetic data are routinely used to expose algorithms to conditions unlikely to be observed in practice. SynTraffic shows how the same principle can extend to traffic modelling by incorporating both empirical observations and hypothetical scenarios into a unified learning framework.

The project also highlights how data-driven intelligence can enhance urban resilience. Historically, resilience in traffic networks has depended on physical redundancy and incident response strategies. While these remain important, SynTraffic demonstrates that informational resilience can offer comparable benefits. A city may not be able to expand its infrastructure, but with predictive tools that have been trained on a broad range of synthetic scenarios, it can operate the existing network more effectively and prevent gridlock in cases where previous systems would fail. This has broader

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implications for planning and policy. Investments in data, analytics, and predictive modelling can complement traditional infrastructure projects and, in some contexts, provide more cost-effective improvements in system reliability. The methodological approach developed in SynTraffic could integrate naturally with emergency response planning, climate adaptation strategies, and long-term mobility development by revealing which parts of the network are most vulnerable under synthetic stress scenarios and therefore require attention.

A distinctive feature of SynTraffic will be the coordinated use of generative models and traffic simulation within a single methodological framework. While many studies rely on individual techniques such as GAN-based data augmentation or standalone simulations, SynTraffic will combine these tools in a structured manner. Simulation will be used to create physically consistent traffic scenarios, while generative models will be explored to capture and extend patterns observed in data. This combined approach is expected to support a more flexible research workflow in which data-driven and model-based methods complement each other. It also suggests that advanced ITS methodologies can be developed for mid-sized cities using open-source tools and focused research efforts, without requiring large-scale or complex infrastructure.

The discussion must also recognize limitations of the approach. Synthetic data is only as comprehensive as the assumptions built into the generative models and simulations. There will always be events that fall outside the imagined scenario space. Sudden societal disruptions, such as pandemic lockdowns, show how quickly mobility patterns can deviate from established norms. SynTraffic reduces this risk by generating a wide variety of scenarios, but the models will still require continuous updates as real conditions evolve. Computational cost is another consideration. Training generative models and running extensive simulations require substantial resources. SynTraffic's use of high-performance computing at the University of Žilina provides insight into these trade-offs and raises questions about scalability. Transfer learning may help address this challenge by allowing models trained in one city to be adapted to another city with similar characteristics, but whether this can be done reliably remains an open question.

Ethical considerations also accompany the use of synthetic data. While synthetic data reduces reliance on personal information and aligns with data protection principles, it introduces new responsibilities. The assumptions encoded in simulated or generated scenarios must be transparent to avoid embedding unintended biases. If certain neighbourhoods, behaviours, or conditions are underrepresented or misrepresented, model performance may degrade in real-world use. SynTraffic addresses this by documenting scenario generation procedures and evaluating model performance across different spatial and temporal subsets. This helps identify gaps and guide the targeted generation of additional synthetic samples. In this way, synthetic data not only supports technical resilience but also strengthens transparency and fairness in model development.

6. Conclusion

The SynTraffic project demonstrates how combining artificial intelligence with simulation can open new possibilities for traffic management. By integrating the adaptive learning capabilities of AI with the structured scenario generation offered by simulation, and supporting both with a coordinated data management framework, the project shows that this hybrid approach is both theoretically robust and practically valuable. The expected improvements in prediction accuracy and system resilience illustrate that investing in data synthesis can be as important as innovating new model architectures. This challenges the long-standing assumption that better AI systems mainly require collecting more real-world data. Instead, SynTraffic shows that intelligently generated synthetic data can expand the operational range of traffic models in meaningful ways.

For practitioners and city planners, the project suggests what future traffic management systems may look like: tools that continually learn from a broad space of possible conditions, simulate upcoming risks, and prepare for emerging challenges. As cities face growing uncertainties related to climate events, changing mobility habits, and infrastructure constraints, such systems can help maintain reliable and efficient operations even under stress.

The findings also reinforce an important theoretical point: the data used for training strongly determines what an AI system can understand and predict. By expanding the dataset with realistic synthetic scenarios, SynTraffic improves model generalization and stability while preserving privacy and reducing dependence on scarce or sensitive real-world measurements. The project contributes to the theoretical development of intelligent transportation systems by demonstrating how synthetic data can be integrated into modelling frameworks and how it influences the behaviour of predictive models across a wider domain of conditions. It also provides a practical pipeline that other cities or research teams can adapt and extend.

More generally, SynTraffic provides an example of how AI-driven systems can be made more resilient by using synthetic data to fill in the gaps in empirical data collection. The methodological principles demonstrated here can extend beyond road traffic to other areas of smart cities where data is limited, expensive, or incomplete. For Žilina and similar cities, approaches like SynTraffic offer a path toward transport networks that operate with greater foresight, adaptability, and robustness. The theoretical insights and methodological tools developed through the project provide a foundation for future work and represent an important step toward building resilient and intelligent urban mobility systems.

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An Appraisal of Drivers’ Attitude towards Road Accident Victims in Nigeria

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Abstract Road Traffic Accidents (RTAs) remain a leading cause of morbidity and mortality worldwide, with developing nations like Nigeria experiencing disproportionately high fatality rates. Despite the presence of a dedicated road safety agency, Nigeria's road traffic fatality rate remains one of the highest globally, with contributing factors including risky driving behavior, inadequate emergency response, and societal attitudes towards accident victims. This study aims to appraise drivers' attitudes toward assisting road accident victims in Nigeria. A survey research design was adopted, utilizing primary data collected through questionnaires administered to five respondent groups: transport operators, commuters, law enforcement agents, health practitioners, and accident survivors. A total of 316 questionnaires were distributed, with 309 returned and analyzed using descriptive statistics and SERVQUAL analysis. A multi-stage sampling technique, incorporating stratified and snowball sampling, was employed. Findings reveal that a majority of respondents were reluctant to assist accident victims due to fears of mob violence and police arrest. This indicates structural and social barriers preventing timely first aid and emergency response. The study concludes that despite the significant impact driver assistance could have in reducing victim fatalities but they reluctant to rescue victims, it was recommended that improving driver education, legal protection for good Samaritans, and structured first-aid training programs could significantly enhance accident survival rates.

Keywords Road Traffic Accidents, Driver Attitude, First Aid, Emergency Response

JEL L91, R41

1. Introduction

Worldwide, accidents cause more morbidity and mortality than any other disease entity (WHO, 2012). In most regions of the world, road-traffic accidents (RTAs) constitute the leading cause of accident-related fatalities and account for a significant portion of these incidents. Worldwide, RTA causes 20–50 million injuries or disabilities and over a million deaths annually (WHO, 2012). According to WHO (2015), road traffic accidents (RTAs) cause an estimated 1.25 million deaths and 50 million injuries worldwide each year. In developing nations, road traffic accidents (RTAs) and the injuries they cause are a serious public health issue. Timely emergency pre-hospital care and transfer of accident victims to a health institution may help minimize the number of accidents and injuries.

Road traffic injury (RTI) is a persistent public health concern in most parts of the world, resulting in significant human and economic costs. Every year, over 1.25 million people die, and nearly 50 million more are wounded or incapacitated, while RTI costs the world economy 1-3% of its GDP. Despite having just 48% of the world's registered automobiles, poor and middle-income nations account for more than 90% of all road deaths.

Nowadays, it is rare for a day to pass in Nigeria without a traffic accident, which raises morbidity and death rates overall and costs money to both society and the person concerned.

With an estimated 21.4 accidents per 100,000 people (WHO, 2018), Nigeria's road traffic mortality rate is still among the highest in the world. The global average is 18.2. However, the nation still maintains a number of reputable top-tier road safety organizations (World Bank, 2020). 5483 people died on the roads in 2019, while 35,981 others had injuries (44.1% from speeding, 11.7 from losing control, and 8.2 from reckless driving). As is widely acknowledged for other nations like Cameroon and India, driving while distracted or using a cell phone, drinking alcohol while operating a car or motorbike, and using drugs have all been demonstrated to be important contributors to auto accidents (Zogo et al. 2021).

When emergency pre-hospital medical services and professionals arrived on the spot, many of these injuries and deaths might be prevented with prompt action (Bigdeli et al., 2010). Pre-hospital treatment from the moment of the traffic collision until the patient is admitted to the hospital can reduce the number of fatalities and the severity of injuries sustained by victims. Almost all trauma specialists agree that the initial 60 minutes following an accident what they refer to as "the golden hour" are critical for determining the likelihood of further damage severity or death. After this time, there is thought to be an increased chance of death or serious harm.

Driving behaviour is a significant predictor of traffic accidents. The deliberate and inadvertent traits and behaviours a driver displays when operating a motor vehicle are referred to as driving behaviour. A driver's behaviour can be influenced by a variety of factors, such as age, experience, gender, attitude, emotions, weariness, tiredness, and the driving environment. While some research has linked driving behaviour to collisions, other studies have demonstrated that age and gender have an impact on dangerous driving behaviour (Waseela and Laosee, 2015; Niezgoda, Kamiński, Kruszewski, and Tarnowski, 2013). Socioeconomic variables including monthly income, drivers' educational attainment, and trip distance might also contribute to risky driving behaviour. (Bazzaz, Zarifian, Emadzadeh, and Vakili, 2014; Sheriff, Forbes, Wessely, Greenberg, Jones, Fertout, Harrison, and Fear, 2015; Asefa, Ingale, Shumey, and Yang, 2015) as well as psychological elements like personality type, emotional state, and distraction.

Numerous variables influence Nigerian drivers' attitudes toward accident victims, which can lead to both favorable and bad reactions during emergencies. Programs for driver education and training sometimes place insufficient focus on handling accidents and emergency circumstances, which causes drivers to get confused, panic, or take insufficient action when such events occur. There are often no thorough training courses that include crisis management, basic first aid, and emergency response protocols. In certain situations, vehicles are reluctant to pull over for accident victims out of fear of extortion or mob violence, which is generally caused by a lack of confidence in law enforcement or increased tensions within the community.

According to Larsson, Martensson, and Alexanderson (2002), first aid is the initial care given once a sufferer has been shielded from more injury and help has been called. According to Oxer (1999), the two most likely causes of mortality following an injury-related collision are uncontrolled bleeding and airway blockage that results in asphyxia.

First aid represents an immediate action that must be administered to accident victims or individuals experiencing emergency conditions or sudden illness before the arrival of an ambulance, medical doctor, or other trained personnel. Rajaratenam, Martini, and Lipoeto (2014) note that adequate knowledge can influence a person's attitude toward providing first aid to traffic accident victims. Attitude reflects a person's inclination to act, think, and feel toward a particular situation or object, and when supported by appropriate knowledge, it can lead to a suitable response. Increased knowledge enhances awareness and shapes the attitude that guides one's actions, including the willingness to provide first aid in traffic accident situations (Mastarida, 2020).

Prioritizing their own safety over helping accident victims is acknowledged by the majority of drivers, and a respectable percentage of them assert that they are qualified to provide first aid. Only half of those who claimed to be capable of administering first aid, however, had actually undergone any official training in providing emergency care to victims of traffic accidents. The remaining drivers, who lacked official training, were nonetheless eager to assist and would profit from organized training. Drivers' unwillingness to help accident victims is frequently associated with fear of extortion or mob violence, which is bolstered by mistrust of law enforcement or societal unrest, which probably deters first responders from stepping in.

Sadly, many victims of traffic accidents pass away as a result of delayed first help. In these situations, serious injuries that result in significant blood loss, damage to the brain or organs, obstruction of the airway by objects, breathing difficulties caused by vomit or blood, cardiac arrest, shock, or trauma can all cause death. Extreme environmental exposure can also cause victims to experience hypothermia, dehydration, or heat stroke. Thus, the purpose of this study is to evaluate drivers' attitudes toward victims of traffic accidents.

2. Literature Review

According to many studies (Chukwubuike, 2021; Ogunyemi et al., 2021; Venkatraman et al., 2020), one of the main causes of injuries, fatalities, and disabilities in Nigeria is the country's growing reliance on road transportation. Due to the high rates of sickness, death, and economic loss associated with road traffic events, which are recorded on a daily basis, this scenario constitutes a significant public health burden in the nation. The widespread disregard for traffic laws is largely responsible for the ongoing frequency of traffic accidents. According to Rojas-Rueda (2020), traffic safety which refers to policies intended to lessen traffic accidents by influencing the attitudes and behaviors of road users remains the most significant public health determinant associated with transportation.

Road users in Nigeria are all people who use the road for different purposes. The goal of efforts to improve traffic safety is to control driving patterns and drivers' reactions to the driving environment. Traffic safety rules, such as speed limits, road signs, and other regulations, are crucial to driving and should be strictly adhered to. The main purpose of traffic safety laws is to prevent risky driving behavior by making such actions illegal (Eby, 2004), but poor traffic safety has long been known to be detrimental to both individual and public health (Singleton et al., 2020).

Any unforeseen and inadvertent incident involving cars on the road, with or without other road users, that results in property damage or human casualties is referred to as a traffic accident. Numerous reasons, such as human mistake, infractions, weather, vehicle conditions, road conditions, and impaired sight, can lead to such incidents. Road, vehicle, and driver-related issues can all have an impact on accidents. The likelihood of growing traffic issues might be increased by rapid transportation expansion (WHO, 2011). Road traffic accidents (RTAs) are a recognized cause of death and injury worldwide, although they are not a recent problem. Preventive measures and point-of-injury care are crucial in lessening the effects of RTAs, according to studies conducted in low- and middle-income countries (LMICs). Despite these initiatives, rising RTA-related morbidity and mortality in LMICs are still a result of increased mobility, lax passenger safety laws, poor road infrastructure, unsafe driving practices, and a lack of organized pre-hospital care (WHO, 2012).

Prolonged response times are sometimes caused by infrastructure and emergency-related issues, such as inadequate emergency services and poor road maintenance. Due to the possibility of legal issues or being held accountable for the collision, this deters vehicles from pulling over to help victims. Investing in better road infrastructure, upgraded emergency response systems, better-equipped ambulances, operational emergency hotlines, and efficient coordination among pertinent agencies are all necessary to address these problems.

First aid is an immediate intervention that must be provided to victims facing emergency conditions due to an accident, sudden illness, or other incidents before medical personnel arrive. Emergencies can occur anywhere, to anyone, and at any time, often resulting from accidents, diseases, chemical exposure, fires, or other unanticipated factors (Margareta, 2012). First aid can preserve life and limit damage until expert assistance arrives (Van de Velde et al., 2009). In workplaces, schools, homes, and public spaces, first aid serves as a vital life-preserving mechanism (Agarwala et al., 2014). These studies emphasise the importance of first aid in saving lives, and effective administration can minimise injury consequences (Howard et al., 2012). Despite the critical role of first aid in road traffic accidents (Oxer, 1999), limited literature explores the role, perception, and actions of first aiders in such situations (Mabbott, 2001).

Delays in providing care for victims or improper initial management by onlookers are frequently the cause of high rates of death and disability following accidents or other crises. In order to prevent disability and preserve lives, first aid is crucial (Swasanti, 2014). Timely emergency pre-hospital care at the accident scene might save many injury-related fatalities. The risk of serious injury or death can be decreased by prompt pre-hospital assistance and prompt transfer to medical institutions. The first 60 minutes following an injury are known as the "golden hour," and trauma specialists emphasize that this is the most critical time for saving lives, with risks rapidly rising beyond this point (Carr et al., 2006).

2.1. The Need for First Aid Training

In 2006, 13 individuals lost their lives on ACT roads (ACT Department of Territory and Municipal Services, 2006). The main objective of basic life support is to sustain airway, breathing, and circulation until professional medical support becomes available. First aid refers to the immediate measures applied after the victim is protected from further harm and help has been called (Larsson, Martensson, and Alexanderson, 2002). Oxer (1999) notes that in crashes involving injuries, the main fatal factors are airway obstruction leading to suffocation and uncontrolled bleeding. Although programs aimed at preventing RTAs are important, such prevention has yet to be achieved fully anywhere. As a result, harm-minimisation strategies are essential for reducing deaths and severe injuries from RTAs. It is feasible to provide communities with skills needed for early intervention to prevent further harm or death among road accident victims. Peterson and Russell (1999) found that both immediately and six months after receiving first aid training, individuals were more likely to stop and offer assistance at a crash. Hussain (1994) and Khangure (1998) similarly argue that at least 7% of road fatalities could be prevented through basic first aid administered at the scene, demonstrating a significant opportunity for community participation in reducing traffic-related deaths and disabling injuries.

Goniewicz (1998) investigated the reasons why individuals are reluctant to step in during an RTA in a Polish research. Psychological obstacles, such as feelings of inadequacy brought on by subpar training or a lack of abilities, were the main causes among 560 government drivers. Additionally, Eisenburger and Safar (1999) contend that psychological barriers affect spectators' willingness to act, pointing out that stage fright and crowds at accident scenes can be frightening.

Rajaratenam, Martini, and Lipoeto (2014) assert that people's opinions toward administering first aid to victims of traffic accidents are greatly influenced by their level of expertise. An individual's inclination to behave, think, and feel in certain situations is reflected in their attitude, which, when accompanied by relevant information, can result in appropriate behavioral reactions. Increased awareness brought forth by greater information affects attitudes and choices, such as the readiness to administer first aid (Mastarida, 2020). According to Kureckova et al. (2017), critical first aid procedures include evaluating the situation (safety, victim count, and overall scene), acting quickly in life-threatening situations (such as unconsciousness, severe bleeding, or breathing problems), and providing care when it's feasible. In a same vein, Kurniawati et al. (2020) point out that successful first aid requires fundamental community skills including victim transportation, splint dressing, and basic life support. When the general population is aware of appropriate first aid procedures for accident victims, these measures can be effectively carried out.

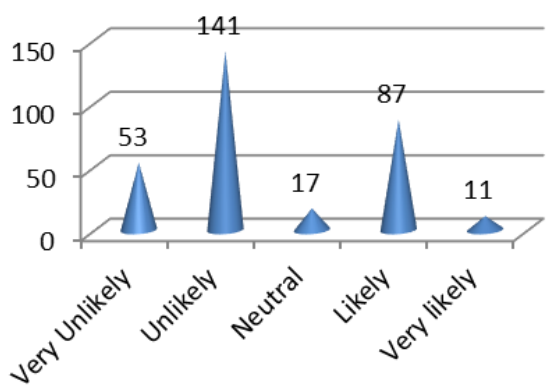
3. Methodology

In appraising drivers' attitude towards road accidents victim, Survey method was adopted to carry out this research and data were collected through primary sources, which consisted of questionnaire administration in line with the objectives of the study, interview and observation. Questionnaires were administered to five groups of people involved in giving first aids to road accident victims as well as survival of road accident victims. These included, transport operators, Commuters, Law enforcement agent, health practitioners and accident victims to obtain information as regards examine the behavior of drivers towards accident in the study area. A total of three hundred and sixteen (316) questionnaires were administered since the population is an infinite population while three hundred and nine (309) questionnaires were returned and analysed. A multi-stage sampling technique was employed. Respondents were stratify into five (5) strata namely: transport operators, Commuters, Law enforcement agent, health practitioners and accident victims, snowball sampling technique was also used to administered questionnaires to the respondents. Both descriptive and SERVQUAL were used to analysis the data collected.

4. Results and Discussion

Figure 1 revealed that, 53 (17.2%) of respondents said they were very unlikely to assist road accident victims, 141 (45.6%) of respondents said they were unlikely to assist road accident victims, 17 (7.7%) of respondents said they could not decide whether they will assist or not road accident victims, 87 (28.2%) respondents said they were likely to assist road accident victims while the remaining respondents said they were very likely to assist road accidents victims. This indicate that majority of respondents were unlikely to assist road accident victims due to mob action.

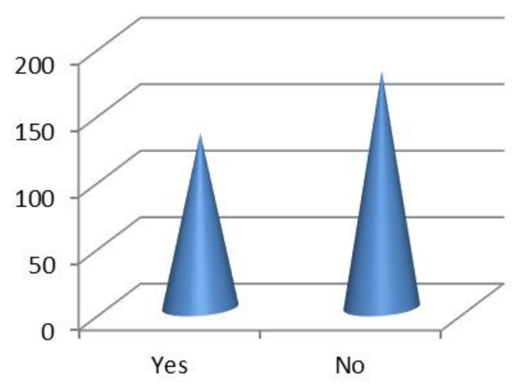
Figure 1. Assist to Road Accident Victims



Source: Authors' field survey (2025)

The data in figure 2 shows a significant inclination towards "No" responses, suggesting that more individuals have not assisted road accident victims. This could imply potential social or structural barriers that discourage people from offering assistance during road accidents.

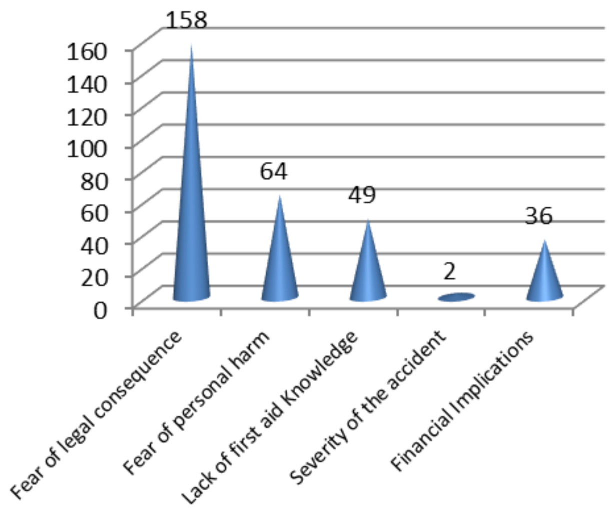
Figure 2. Have you ever assisted a road accident victim



Source: Authors' field survey (2025)

Figure 3 shows that, 158 (51.1%) of the respondents' said fear of legal consequence prevent drivers from providing assistance to accident victims, 64 (20.7%) of the respondents' said fear of mob action prevent drivers from providing assistance to accident victims, 49 (15.9) of the respondents' said lack of first aid knowledge prevent drivers from providing assistance to accident victims, 2 (0.6%) of the respondents' severity of the accident prevent drivers from providing assistance to accident victims while the remaining of the respondents' said prevent drivers from providing assistance to accident victims. This implies that, majority of respondents refuse to assist accident victims due to the fear of being arrested and detain by police officers.

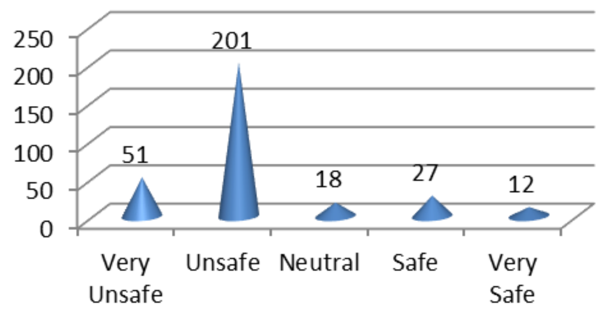
Figure 3. Perceived barriers that prevent drivers from providing assistance to accident victims



Source: Authors' field survey (2025)

Figure 4 revealed that, 51 (16.5%) of respondents was of opinion that their very unsafe to stop to assist accident victims, 201 (65.0%) of respondents was of opinion that their unsafe to stop to assist accident victims, 18 (5.8%) of respondents was of opinion that their neutral whether to stop or not to assist accident victims, 27 (8.7%) of respondents was of opinion that their safe to stop to assist accident victims while the remaining of respondents was of opinion that their very safe to stop to assist accident victims. This implies that, drivers were of the opinion that they are not safe due to mob action and legal consequences which characterize the process.

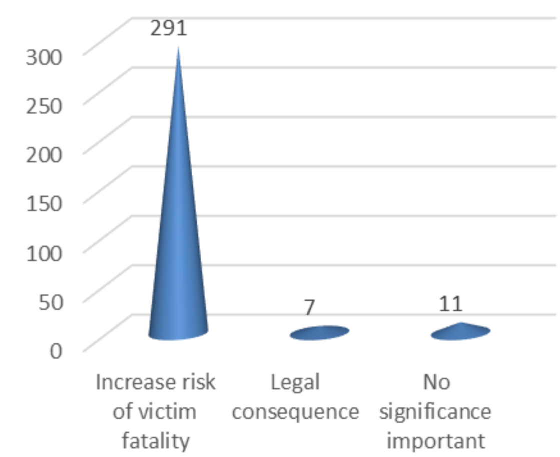
Figure 4. How safe is stopping to assist accident victims



Source: Authors' field survey (2025)

Figure 5 shows that, 291 (94.2%) of respondents said consequence of not assisting accident victims increased risk of victim fatality, 7 (2.3%) of respondents said consequence of not assisting accident victims legal implications and 11 (2.3%) of respondents said there is no important significance of not assisting accident victims. This implies that, majority of accident might not result to death if prompt action were taken to rescue the victim.

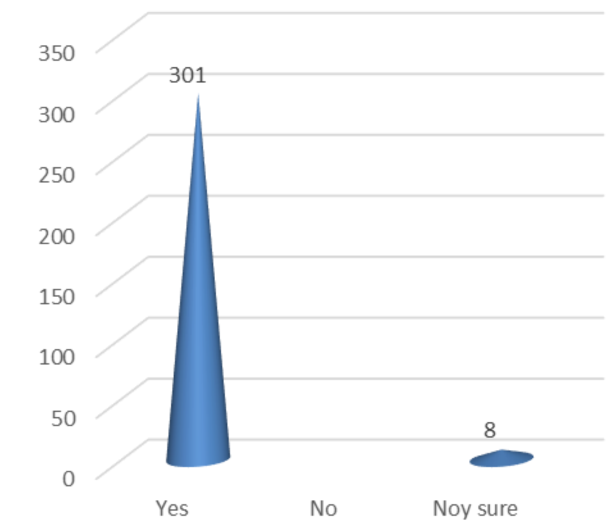
Figure 5. Consequence of not assisting accident victim



Source: Authors' field survey (2025)

Figure 6 revealed that, 301 (97.4%) of drivers said there should be legal protection for drivers who attempt to provide first aid to accident victim while the remaining respondents are not sure whether there should be legal protection for drivers who attempt to provide first aid to accident victim. This indicates that, if there would be legal protection for drivers making an attempt to safe accident victims, drivers would be willing to rescue road accident victim.

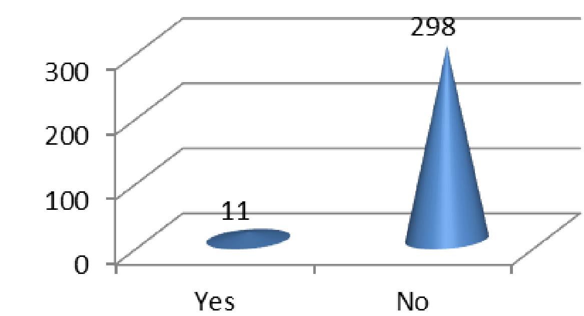
Figure 6. Legal Protections to provide first aid for accident victim



Source: Authors' field survey (2025)

Figure 7 shows that, 11 (3.6%) of respondents said they did received formal training on first aid training and 298 (96.4%) of respondents said they did received formal training on first aid training. This implies that, those that could have been a life safe could not do so due to the fact that they did not receive first aid training.

Figure 7. Formal training in first aid by drivers



Source: Authors' field survey (2025)

It can be deduced that there is a gap result between the perceived and expected services for empathy. Table 1 shows that the significance value of empathy (0.000) is less than 0.05 at 95% level of significance, thus the null hypothesis is rejected under this variable.

The size of a lower-case "j" will give the point size by measuring the distance from the top of an ascender to the bottom of a descender.

Table 1. Drivers Perception of rescuing Road Accident Victims

		Mean	SD	Mean difference	t-value	p-value
Reliability	Perceived	6.02	1.01	-0.084	1.142	0.244
	Expected	6.10	1.12			
Responsive	Perceived	5.79	1.21	-0.559	5.476	0.358
	Expected	6.25	1.01			
Assurance	Perceived	6.02	1.04	0.037	0.562	0.612
	Expected	5.98	1.20			
Empathy	Perceived	5.88	0.98	-0.205	2.808	0.000
	Expected	6.09	1.15			
Tangibility	Perceived	5.56	1.02	-0.298	3.482	0.217
	Expected	5.59	1.25			

Significance at p-value < 0.05

Source: Authors' computation (2025).

5. Conclusions

The findings reveal that the majority of respondents are unlikely to assist road accident victims, primarily due to fears of mob action and legal consequences. The lack of first aid training and legal protection further discourages drivers from providing assistance, despite the significant impact their help could have in reducing victim fatalities. Most drivers feel unsafe stopping to assist accident victims, underscoring a critical gap in public safety perception. It was recommended that the introducing and enforcing laws that protect individuals who assist road accident victims from legal liabilities and potential mob action.

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Assessing the Effects of Road Conditions on Police Response in Nigeria

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Abstract The quick response of the police to emergency calls can save lives and property. However, one key factor that affects police emergency response time, with limited focus in the literature, is the effect of the poor condition of the road. Thus, this study aims to examine the effect of poor road conditions on the response of the Nigeria Police to emergency calls in Ijebu-North Local Government Area (INLGA), Ogun State, Nigeria. The study is based on the range concept of the Central Place Theory. Data on the locational coordinates of three (3) police stations, sixty-five (65) identified settlements, and road networks in INLGA were obtained from topographic maps. The p-median and maximal covering location models were used for data analysis. The study showed that the average emergency travel time of the police can be reduced by 33.01% if the poor roads, in the study area, are improved. It was also shown that emergency response time, by the police, to the farthest settlement can be reduced by 55.47 percent if the poor roads are fixed. The study also revealed that 27.7 percent of all settlements can be covered by the police within five minutes under the actual condition of the roads, and this can be increased to 30.77 percent assuming all roads are in good condition. The study further revealed that total coverage of settlements can be achieved within 45 minutes under the actual road condition and within 20 minutes if the roads' condition is improved. The study demonstrated that the response of the police to emergency calls will be improved if the poor roads are fixed; consequently, citizens' protection and the state of security in the Country will improve.

Keywords Emergency Service, Police, Maximal Covering Location Problem, Network Analysis, Road Condition

JEL H54, R41, R42

1. Introduction

The police is one of the three primary emergency services that can be summoned directly by the public. Others are the fire and emergency medical services. The police is an organization for maintaining law and order. It is a civil organization whose members are given special legal powers by the government and whose task is to maintain public order and to solve and prevent crimes [1]. Timely response by the police to emergency calls is very crucial and can save lives and property.

A common measurement in benchmarking the efficacy of emergency services is response time. It is the amount of time it takes an emergency service from the receipt of a call to arrive at the scene of an incident. Some factors can prevent the police from achieving a targeted response time. These factors include the condition of the police vehicle, the ability to use technology to find addresses, traffic congestion in urban areas, the condition of the roads, etc. There is limited research on the effect of poor road conditions on police emergency services in developing countries. The effect of road conditions on emergency service delivery can be impactful in many developing countries. Roads in some regions of such countries are known to be in a poor state, particularly in rural areas. It was observed that poor roads in Nigeria significantly delay the movement of security operatives to crisis scenes, particularly in remote and insecure regions where timely intervention is essential to prevent loss of life and property. [2], [3].

There are few studies on the response time of emergency services in African countries [4]. Most of the available studies focused on the response time of emergency medical service (EMS). Limited attention has been paid to how poor road conditions directly affect police response time. Thus, this study will examine the effect of road conditions on the emergency response time of the police, using Ijebu North local government area in Ogun state, Nigeria as a case.

2. Literature: Emergency Service Location Planning

The Central Place Theory (CPT) is fundamental to explaining the location of services. The CPT explains the size, numbers, and spacing of central places (in this case, police stations) supplying goods/services to the surrounding population [5]. The range concept of the CPT specifies that there is a distance from the provider of a service beyond which the service will become irrelevant to the consumer. The range

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concept is particularly relevant to explaining the maximal service distance in emergency service planning. There is always a distance or time that will render an emergency service irrelevant. Thus, the guiding principle in assessing the delivery capability of the police emergency service is to minimize the distance between police stations and the people and properties they are supposed to protect. The assessment of the locations of police stations vis-à-vis the people they are to protect can be carried out using the location-allocation models. The location-allocation (L-A) models are designed to find the location for facilities (e.g. police stations) and at the same time allocate demand or users to them in a way to achieve stated goals such as minimizing distance or time travelled. Location-allocation methods can be used to solve a variety of problems such as finding location for new facilities, find location for additional facilities. Location-allocation methods can also be used to find locations for new facilities to replace badly located ones (re-organization problem) and to determine a minimum number of facilities that are needed to service a population distribution. The p-median of the L-A modelling is to locate a given number of facilities (e.g. police stations) and allocates demand nodes (e.g. settlements) to the facilities to minimize the total distance or time between the facilities and the consumers.

In planning the location of emergency services, location-allocation methods are used to find locations of facilities to deliver services in an emergency within a given response time. The coverage models, of the L-A modelling approach are commonly used to solve emergency facility location problems because they aim to maximize coverage of the population within a 'maximal service distance'. The maximal service distance is the distance of the farthest user of a service from a facility or service. This distance can be translated to the response time for service delivery. Response time is a common performance measure and is a critical factor in the measurement of the effectiveness of emergency services [6]. It is the amount of time it takes an emergency service from the receipt of a call to arrive at the scene of an incident. A limit on response time is imposed to ensure that no more than a specified time will elapse before an emergency service will get to the location of the emergency event [7]. Safety of lives and properties can be more assured where the total response time of the police is at the minimum as discussed below.

The total response time of a police emergency service is calculated from the time the call for service is answered by a call taker to the time the first police officer arrives on scene. The total response time consists of the call process time, the dispatch time and the dispatch to arrival time. The total response time depends on many factors such as: regulations guiding police operations, the discipline of police officers, speed allowed for emergency vehicles, traffic situation in cities, the state of disrepair of the roads, etc. Emergency response has been noted to be best if it arrives quickly to minimize the impact of the disaster [8]. Response time of the police varies from one country to another, particularly between the developed world and the developing countries. Response time of the police is usually fixed by the government or her regulatory agency, because police service is a type of public service as discussed below.

Police services are public sector-oriented services. They are provided by the government as a public service, funded through taxes. Public service is a service that is found in the public domain because it can only be profitably produced by the government or its parastatals due to their attributes [9]. The objectives in the provision of public goods or service are to ensure equal availability of the services and to maximise societal benefit, while minimizing cost and use resources in the most rational way possible [10]. Pure public goods are characterized by three main properties of (1) non-excludability, (2) joint supply and (3) non-rejectability. Non-excludability or non-exclusion principle implies that if a good is provided for an individual it is impossible to hold it back from any other person. Joint supply, non-rivalrous or shared consumption implies that once a good is made available it is equally available to all other persons at the same time at no extra costs [11]. Finally, the third property of non-rejectability implies that once a good is provided, it must be fully used up by all [10]. Given the three principles, pure public goods are not actually common in reality. Services provided by the police are an example. Once a police station is established, an individual cannot be excluded from using the service; it is also always equally available to everybody and the protection and maintenance of order provided by the police is for everybody in the society.

3. Methods

The study area, type, and methods of data collection and data analysis techniques are discussed in this section.

3.1. The Study Area

Ijebu North local government area (INLGA) in Ogun State is the study area for this work. It was chosen because of the presence of the three types of roads of varying conditions in the local government area. INLGA is approximately located between latitude 6055" and 70 N and between longitude 3045" and 4005"E. The total land area of Ijebu North local government area is about 967 square km. There are sixty-five identified settlements. The study area consists of urban and rural areas. The three urban centres are Ijebu-Igbo (headquarters of INLGA), Ago-Iwoye and Oru/Awa (see figure 1a). The population size of Ijebu North local government area grew from 148,342 (1991 population census) to 280,520 (2006 population census) - an increase of 89.1%. Public facilities are mostly concentrated in urban areas compared to rural areas. Thus, the three police stations are in the three urban centres (See figure 1b). The dominant modes of transport are roads. There are three types of roads in the local government area. The first type is the major road. It is owned and maintained by the Federal government. The major roads usually run across a state to another state. The two major roads in INLGA are the Ilishan/Ijebu-Igbo/Ikire Road and the Ijebu-Ode/Ibadan Road. The second type of road is the secondary road.

Figure 1a. Nigeria and Ogun State Showing the Study Area

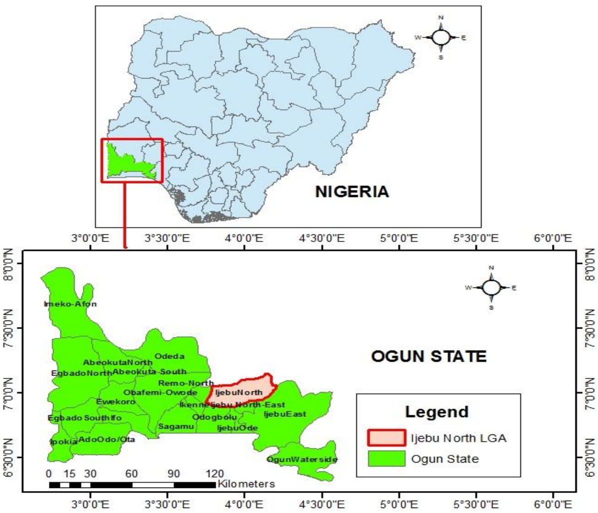
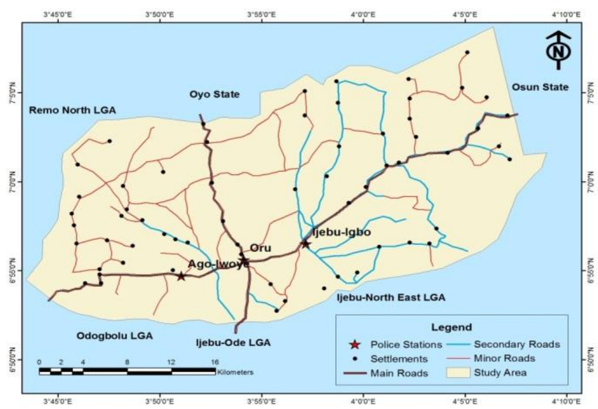


Figure 1b. The Study Area: Ijebu North Local Government Area, Ogun State, Nigeria.



It is owned and maintained by state governments. The third type of road is the local or minor road. The minor roads are owned and maintained by the local governments. Some of the minor roads are former foot/cycle paths that were made motorable, but are mostly not tarred. The above-listed characteristics of Ijebu North local government area made the area theoretically suitable for examining issues about road condition and its effect on service delivery in a regional setting.

3.2. Data for the Study

The data used for the location-allocation modelling in this study consist of the coordinates of the location of the facilities (police stations), the demand points (settlements) and the road networks that facilitate interaction between the demand points and the facilities. The coordinates of the location of the three police stations and the sixty-five settlements in Ijebu North local government area (INLGA) were obtained from a digitized topographic map of the area. The roads from the digitized map of INLGA were used to build the origin-destination matrix for the interactions in the location-allocation modelling.

3.3. Methods of Analyses

The p-median and the maximal covering location models of the location-allocation methods were used to model the interactions between the police stations and the settlements in Ijebu North local government area. The analysis was carried out using the Network Analyst of ArcGIS v10.5. This study is about emergency service delivery by the police, and it is assumed that police emergency vehicles will move freely on good roads. However, since it is not all the roads in INLGA that are good, this study tried to factored the effect of the present state of the roads in the interaction modelling. The approach used is based on the observation that, in the study area, attention is paid more to the major and secondary roads by the Federal and state governments, respectively. The minor roads that are to be maintained by the local government are mostly neglected in INLGA. In this study, the major and secondary roads were assumed to be good. They are all tarred roads and are always getting attention from the Federal and state governments, while the minor roads are neglected. Thus, the minor roads are modelled with an impedance factor of three, that is. It is assumed that it will take thrice the time one will used on a major or secondary road to traverse the same distance on a minor local government road. Thus, to factor in the impedance on the minor roads, the time spent was multiplied by three.

The p-median model of the location-allocation methods was used to find the optimal service pattern from the three police stations to all sixty-five settlements in the study area by allocating each police station to the nearest settlements. The optimal allocation pattern will yield the minimum total and average travel time between the police stations and the settlements.

The maximal covering location model of the location-allocation methods was used to find the proportion of the settlements that could be optimally covered within a given response time. The model was used to compute a table of options in a "what-if-analysis" by generating statistics for different proportions of settlements that can be covered within different response time to emergency by the police.

4. Results and Discussion

The discussions of the findings of this study are in two parts. The first part is the result of the application of the p-median model to optimally allocate the three police stations in the study area to the nearest settlements under two conditions: (1) actual/observed road conditions (major and secondary roads are good and minor roads are poor) and (2) under the assumption that all the roads are good. The second part of the discussion of findings is the result of the application of the maximal covering location model. The model was used to find the proportion of settlements that could be optimally covered under a given response time.

The results of the application of the p-median model to optimally allocate the three police stations to the nearest settlements are shown in Table 1. It is shown that the time it will take the police to attend to an emergency call from the farthest settlement, travelling on the roads in their present condition, is 41.66 minutes. This will occur where a call from Owode-bale is directed to Ago-Iwoye police station (being the nearest police station to the settlement). Assuming that all the roads are in good condition, the longest time would have been 18.55 minutes, this is also between Ago-Iwoye police station and Owode-bale. Thus, a reduction of 55.47 percent in emergency response time, by the police, to the farthest settlement can be achieved by fixing the roads.

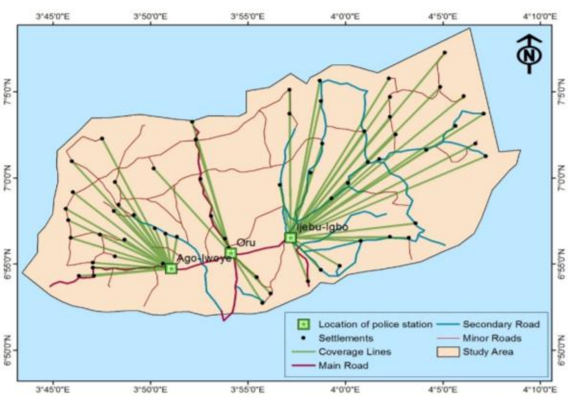
Table 1. Statistics of Police Service Delivery on Actual and Assumed Good Road Conditions

Statistics	**Dispatch-to-Arrival Time (in Minutes)**		
	Actual Roads Conditions	**Assuming All Roads are Good**	**Percent Change**
Number of settlements to be served	65	65	
Maximum time between a police station and a settlement	41.66	18.55	55.47
Average time between police stations and all settlements	12.75	8.54	33.01
Standard deviation of the time between police stations and settlements	11.36	5.18	

Source: Computed with the Minimize Impedance Module in Network Analyst of ArcGIS v10.5

Note: The response time in this study refers to the time between dispatches from the station to arrival at the scene of the emergency.

Figure 2. Total Coverage of Settlements by Police Service on Actual Road Condition



The average time it will take dispatches from the three police stations to all settlements in Ijebu North local government area (INLGA), on the present road condition is 12.75 minutes. This time will be reduced to 8.54 minutes if all roads within the local government area are good. Thus, a reduction of 33.01 percent can be achieved in the average response time by fixing the roads in INLGA.

Emergency services are usually benchmarked based on a fixed response time. However, there is no fixed response time for emergency service provision in Nigeria. A "what-if-analysis" was carried out on different response time for police service delivery in the study area. The analysis was carried out using maximize coverage module in Network Analyst of ArcGIS v10.5. The result of the what-if-analysis is presented in Table 2. The analysis in the table started with a maximum response time of five minutes, which is a common benchmark for most emergency services around the world. The table presents the results of the maximum response time increasing by five minutes until the response that covers all settlements in the study area. It is shown in the table that the police can cover 27.7 percent of the settlements in the study area within a maximum response time of five minutes under the present conditions of roads.

The percentage of covered settlements, within five minutes, can be increased to 30.77 if the roads are fixed. All the sixty-five settlements in the study area can be covered by the police within a maximum response time of 45 minutes under the present road conditions. This total coverage of the settlements could, however, be achieved within 20 minutes if the roads are in good condition.

4.1. Discussion

There are previous studies that have focused on road obstructions that can prevent or delay emergency service delivery in developing countries. Most of these studies are on emergency medical service (EMS) and they focused mostly on the effect of traffic congestion in urban areas and attempted to solve the problem as a traffic routing problem using real-time traffic data [12]. The suggested methods might not be applicable to solving road obstructions due to widespread state of disrepair of the roads, particularly in some developing countries. In such a situation, alternative routes are as poor as the assigned routes.

The size of a lower-case "j" will give the point size by measuring the distance from the top of an ascender to the bottom of a descender.

Table 2. Statistics of Maximal Coverage by Police Service on Actual and Assumed Good Roads Condition

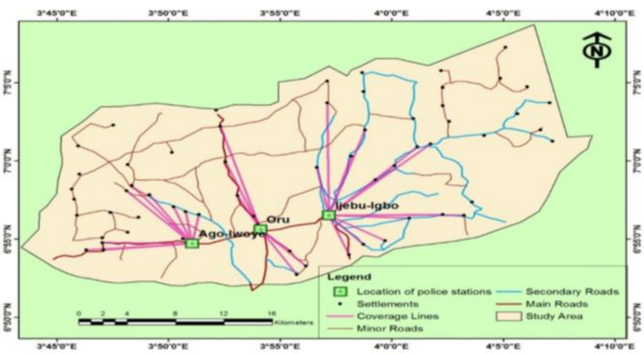
	Statistics Under Actual Condition of Roads			
Sn	Maximum response time (in minutes)	Number of settlements covered	Percent of settlements covered	Average time (in minutes)
1	5	18	27.70	2.74
2	10	36	55.38	4.87
3	15	45	69.23	6.27
4	20	51	78.46	7.50
5	25	54	86.08	8.35
6	30	56	86.15	9.00
7	35	59	90.77	10.11
8	40	62	95.38	11.40
9	45	65	100	12.75
Statistics Assuming all Roads are in Good Condition				
Sn	Maximum response time (in minutes)	Number of settlements covered	Percent of settlements covered	Average time (in minutes)
1	5	20	30.77	2.76

2	10	42	64.62	5.32
3	15	56	86.15	7.16
4	20	65	100	8.54

Source: Computed with Maximize Coverage Module in Network Analyst of ArcGIS V10.5

Figure 3. Maximal Coverage of Settlements by the Police

(A) Maximal Coverage of Settlements by Police Service on the Present Road Condition



(B) Maximal Coverage of Settlement by Police Service, Assuming all Roads are Good

Another focus of the literature on obstructions to emergency service delivery is street flooding [6], [11]. The use of some newly developed accessibility models and OpenStreetMaps to solve accessibility problem to emergency services was suggested, particularly in developing countries. The approach is described as quick and cost-effective [13].

The approaches adopted by most studies of road obstructions to emergency service delivery assumed that the conditions of the roads are uniform, apart from locations where there are obstructions. It has been shown in this study that there are different categories of roads, and speed and time used by emergency vehicles will vary according to the state of disrepair of the type of road.

It is suggested that further studies can be carried out on other factors that can affect police emergency service delivery. Researchers can look at duration and causes of delays that occur while processing incoming emergency calls by police (e.g. poor telecom signal) and while preparing emergency crews and vehicles for dispatch in developing countries.

5. Conclusions

It has been observed that poor road conditions can prevent the police from getting to an emergency scene on time to save or assist those affected [3]. This study has demonstrated that the response of the police to emergency calls will be improved if the bad roads are fixed, and thus citizens' protection and the state of security in the Country can be improved.

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Packages and Parcels Delivery by Inter-City Informal Transport Service Operators in Ogun State, Nigeria

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Abstract The study investigates the impact of Person-to-Person (P2P) package and parcel delivery via informal public transportation in Nigeria, which dominates inter/intra-urban mobility in developing countries. A concerning trend is the unchecked dispatch of parcels through informal means, such as parks, without proper verification by drivers or their agents. To examine this, a multi-stage sampling approach was used: the population was first stratified into drivers and commuters, then snowball sampling identified those with relevant experiences, and purposive random sampling was employed for questionnaire distribution. Findings show that most drivers rely solely on senders' verbal declarations about parcel contents, enabling the smuggling of illegal substances. Respondents generally agreed that P2P package delivery negatively affects society. ANOVA results revealed a statistically significant relationship ($p = 0.000 < 0.05$), and the R-square value of 77% indicates a strong explanatory power of the model on illegal substance movement. The null hypothesis was rejected, confirming that informal parcel delivery poses societal risks. The study concludes that informal transport services facilitate smuggling and recommends that drivers conduct physical checks on parcels before transportation to mitigate the risks associated with unverified deliveries.

Keywords Package/Parcel delivery, Informal Transport, P2P delivery, Illegal goods

JEL L91, L92, R4, R41

1. Introduction

Immobility can be likened to a lifeless body in which the flow of blood through the arteries has ceased. Reviving such a body requires the supply of blood, which may be obtained either through hospitals or from relatives. The former represents a formal blood supply system, while the latter constitutes an informal source. Regardless of the source, all blood must undergo adequate screening before transfusion. Due to the high rate of emergencies in hospitals, informal blood supply has often become a necessary alternative to complement formal systems.

A similar analogy applies to urban transportation systems. Urban residents require daily mobility between their places of residence and work. However, as the effectiveness of formal public transportation systems declined, informal transport services expanded significantly, eventually accounting for over 80% of urban mobility demand in many developing cities. In countries such as Nigeria, where formal public transport systems are limited, irregular, and insufficient, informal transport modes including minibuses, tricycles, and motorcycles have become indispensable. These modes possess the flexibility to navigate difficult terrains and routes that are often inaccessible to formal transport services (Afolabi and Akinbo, 2020).

In many developing countries, informal public transport constitutes the dominant mode of inter- and intra-urban mobility, largely due to limited access to high-capacity formal public transportation (Kassa, 2014). One major distinction between informal and formal transport systems lies in regulatory compliance. Informal transport operators often lack the necessary licenses, permits, and registrations required for legal operation. Weak regulatory enforcement enables these services to fill the gaps created by inadequate formal transport provision. Consequently, several scholars describe informal public transport as a complementary system that enhances urban mobility while contributing to economic development through employment generation and contributions to gross domestic product, particularly for low-income groups (Selim, 2010).

Technically, informal transport services operate without official endorsement from public authorities. This absence of regulation implies that many vehicles and drivers do not meet established safety, fitness, or insurance standards. The sector is typically characterized by small-sized vehicles that are individually owned or leased, and often old and poorly maintained. Informal transport largely provides paratransit

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services, offering door-to-door or route-flexible operations with adaptable pricing structures. Operating in a largely laissez-faire environment, operators often working on thin profit margins frequently engage in intense and sometimes unsafe competition for passengers, parcels, and freight.

Beyond passenger transportation, informal transport operators increasingly became involved in freight and parcel delivery. Recognizing the income potential, operators expanded their services to include inter-city freight movement. This development benefited customers by enabling same-day or near-immediate delivery of parcels and goods. Consequently, the informal transport sector evolved from a purely passenger-focused system to one that also plays a significant role in parcel and freight transportation. A parcel is typically defined as a wrapped item weighing less than 75 kilograms, smaller than a Euro-pallet, and not requiring palletization. Timely parcel delivery is critical for business efficiency and long-term urban economic growth. While Business-to-Consumer (B2C) and Consumer-to-Consumer (C2C) deliveries dominate urban parcel flows, business-to-business (B2B) deliveries also account for a substantial share of urban freight activities.

The transformation of the retail environment has further reshaped logistics and transportation systems. Firms that adapted quickly to new distribution channels and delivery services have thrived, particularly those involved in last-mile B2C and C2C deliveries. Urban parcel delivery involves diverse receivers including retailers, hospitality establishments, businesses, government offices, healthcare and educational institutions, as well as individual residents, workers, and visitors each requiring distinct distribution channels and vehicle types. These variations contribute to the complexity of last-mile delivery operations.

In Nigeria, the preference for fast, accessible, and demand-responsive services has sustained the relevance of informal transport-based parcel delivery. As demand increased, the number of informal "parcel and freight caretakers" operating within motor parks also grew, effectively introducing informal warehousing functions. Drivers' responsibilities expanded beyond passenger transport to include hand-to-hand delivery of parcels and mail, with vehicle owners and owner-drivers actively participating in these activities.

Despite the absence of formal registration as courier companies, informal transport operators have continued to provide parcel delivery services to date. Notably, some registered private courier firms even incorporate informal transport operators into their logistics chains. Additionally, Person-to-Person (P2P) parcel transfers frequently occur through motor parks without adequate inspection by drivers or their representatives. This unregulated practice underscores the need for systematic research into parcel and package delivery by inter-city informal transport service operators, particularly within the context of P2P logistics.

2. Literature Review

The service industry has experienced significant growth in terms of service speed, cost efficiency, and quality, largely driven by technological advancement and evolving consumer purchasing behaviour. In response, service-oriented firms increasingly seek innovative ways to reduce operational costs and delivery times while ensuring timely product fulfillment. Consequently, delivery services have emerged as a core pillar of the service industry and have attracted growing scholarly attention in recent years (Shbool et al., 2022).

Within this context, the informal transport sector occupies a central position in Nigeria's socioeconomic landscape. Functioning largely as a Demand Responsive Transport (DRT) system, it offers flexible, real-time services at competitive prices. The resilience and operational relevance of Nigeria's informal transport sector are widely acknowledged, as over 75 percent of the urban population relies on it for both work-related and non-work-related travel. Over the decades, however, the roles performed by actors within this sector have evolved in response to changing economic conditions and service demands.

Urban commercial activities and the diverse delivery requirements of goods receivers have further complicated logistics operations. City centres host a wide range of receivers, including retailers, hospitality establishments, businesses, government offices, healthcare and educational institutions, as well as individual consumers such as residents, workers, and visitors. Each category requires distinct distribution channels, vehicle types, and operational approaches depending on shipment characteristics. These variations often overlap and conflict, thereby increasing the complexity of light parcel movements and making last-mile delivery particularly challenging (Aljohani and Thompson, 2018; Dablanc and Rodrigue, 2014).

The rapid expansion of e-commerce has further transformed logistics and delivery systems. E-commerce provides micro, small, and medium-sized enterprises (MSMEs) with unprecedented access to global markets, enabling them to reach far more customers than traditional physical retail would allow. However, the effectiveness of e-commerce depends heavily on key enablers, among which logistics and delivery services are critical. These services ensure that goods purchased online reach consumers promptly and are efficiently returned when necessary (WEF, 2018). Over the past two decades, e-commerce has reshaped the retail sector, forcing traditional retailers to restructure or exit the market due to intense competition from online platforms that offer continuous accessibility, price comparison, and home delivery through digital technologies.

To meet rising urban delivery expectations, several innovative logistics strategies have been introduced. These include the establishment of delivery points and the provision of same-day delivery services aimed at reducing first-attempt delivery failures and clearing delivery backlogs (Comi and Nuzzolo, 2016). Studies have also shown that information technology has significantly influenced consumer shopping behaviour by lowering online shopping costs. Since online purchases cannot be used immediately, delivery and travel time are perceived as part of the consumer's overall cost, making fast delivery a crucial determinant of customer satisfaction and loyalty (Miyatake et al., 2016).

As competition within the retail sector intensifies—particularly during peak demand periods only firms capable of fulfilling orders and delivering parcels efficiently are likely to remain competitive (Lee and Whang, 2001). In response, many companies have adopted advanced information exchange systems to improve infrastructure utilisation and resource management. Speed has consequently become a dominant competitive strategy in the e-retail market, leading to the widespread adoption of same-day and even ultra-fast (one- to two-hour) delivery options (Savelsbergh and Woensel, 2016). Same-day delivery represents a special demand imposed by customers, often requiring the exclusive use of transport modes such as trucks, vans, motorcycles, or bicycles for individual parcels.

While large e-retailers have successfully leveraged same-day delivery to gain competitive advantage particularly through partnerships between retailers and carriers, as demonstrated in Japan there is an increasing need to develop equitable delivery systems that also support small and medium-sized enterprises (Gessner and Snodgrass, 2015; Hayashi et al., 2014). Despite the growth in e-commerce adoption and associated increases in sales, challenges persist in last-mile delivery operations. Notably, failed home deliveries have increased, prompting logistics providers to continuously refine their delivery strategies (Weltevreden, 2008; Gevaers et al., 2011).

Empirical evidence suggests that consumers place high value on delivery speed and reliability, as failed or unpredictable deliveries impose additional costs, stress, and time burdens (Goebel et al., 2012). As a result, speed and reliability have become critical factors influencing online purchasing decisions. Deliveries to retail outlets also constitute a substantial component of last-mile logistics, encompassing both chain and independent retailers. These deliveries are predominantly carried out using light commercial vehicles and light trucks, reflecting the operational demands of urban freight distribution.

2.1. Gap in Literature

Despite extensive research on last-mile delivery, e-commerce logistics, and informal transport systems, notable gaps persist. Most existing studies emphasize formal logistics providers and technologically advanced delivery models, largely within developed economies, thereby limiting their relevance to developing countries. While the informal transport sector is widely recognized for its role in passenger mobility in cities such as those in Nigeria, its growing involvement in parcel and person-to-person (P2P) delivery remains insufficiently examined. In particular, there is limited empirical evidence on the operational practices, safety implications, reliability, and regulatory challenges associated with unregistered parcel movement through informal transport networks. Moreover, current literature rarely integrates informal transport operators into discussions of urban and inter-city logistics efficiency. This lack of context-specific analysis constrains policy formulation and planning for inclusive and effective delivery systems, underscoring the need for focused empirical investigation in developing country settings.

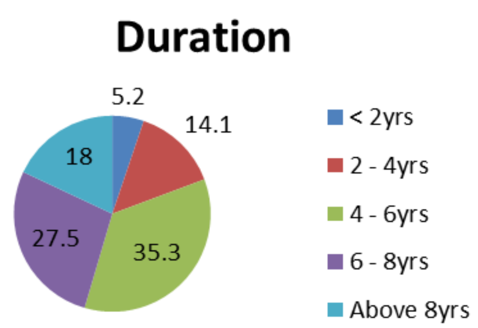
3. Methodology

The South West is the one of the six geopolitical zones of Nigeria representing both a geographic and political region of the country's southwest. It comprises six states – Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo. A sample size of three hundred and six (306) was used for this study. Multi-stage sampling technique was employed. At stage one: the population was stratified into drivers and commuters. Snowball sampling technique was employed to get information from those that experienced the incident along the route. Lastly, purposive random sampling technique was employed to administer questionnaire the respondents.

4. Results and Discussion

Figure 1 revealed that 5.2% of the respondents have been conveying/sending packages through motor packs for less than 2yrs, 14.1% of the respondents have been conveying/sending packages through motor packs between 2 – 4yrs, 35.3% of the respondents have been conveying/sending packages through motor packs between 4 – 6yrs, 27.5% of the respondents have been conveying/sending packages through motor packs between 6 – 8yrs while the remaining of the respondents have been conveying/sending packages through motor packs more than 8yrs. This indicates that majority (80.8%) of the respondents have been conveying/sending packages through motor packs between 4 – 8yrs.

Figure 1. Years of using Park to send parcels



Source: Authors field survey, 2025

Figure 2 showed that 87.6% of the respondents claimed that they confirmed the contents of the parcel while the remaining said they do not confirm the contents. This indicates that most of the drivers claimed that they have the knowledge of the contents inside the parcel.

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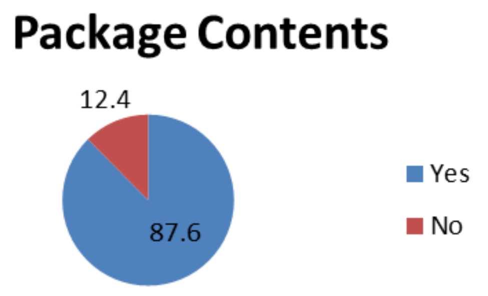
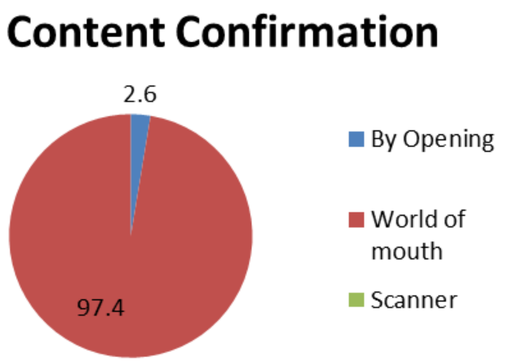
Figure 2. Contents of the Package



Source: Authors' field survey, 2025

Figure 3 revealed how the drivers confirmed the contents of the package. 2.6% of the drivers said that they confirmed by opening the parcels while 97.4% of respondents said by word of mouth from the sender. This indicates that drivers do not really have the full knowledge of the contents in the parcels.

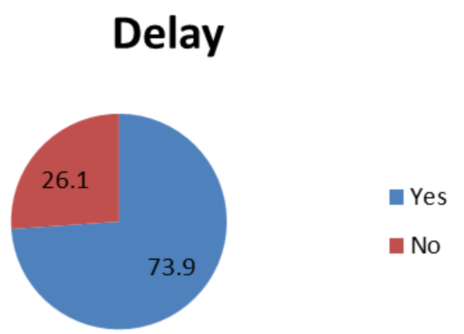
Figure 3. Methods of Confirmation.



Source: Authors' field survey, 2025

Figure 4 showed that 73.9% of the respondents said that they have been delay along the route due to package carried by commercial drivers while the remaining respondents said they have never encounter such delay due to package carried by commercial drivers.

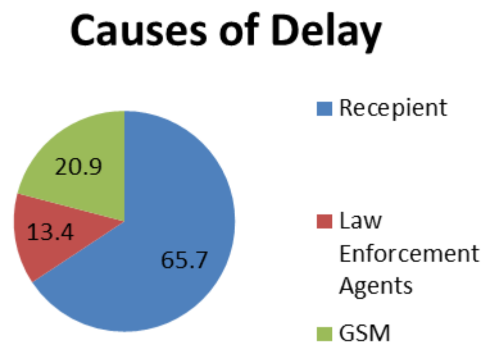
Figure 4. Delay caused by package/parcel delivery



Source: Authors' field survey, 2025

Figure 5 revealed that 65.7 of the respondents said the delay was caused by the recipients, 13.4% of the respondents said the delay was caused by law enforcement agent while the remaining of the respondents said the delay was caused by Global System Mobile (GSM). This indicates that recipients did not show up in time to collect their packages/parcels.

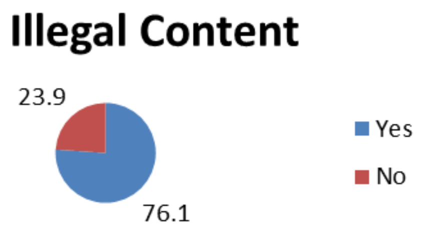
Figure 5. Causes of Delay



Source: Authors' field survey, 2025

Figure 6 showed that 56.1% of the respondents said that law enforcements agent did not found the content of the package illegal while the remaining respondents said the law enforcements agent found the content of the package illegal. This indicates that people use the process (P2P) to convey illegal substance.

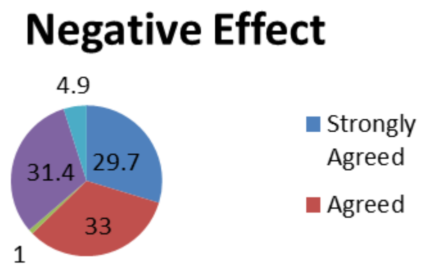
Figure 6. Illegality of the content



Source: Authors' field survey, 2025

Figure 7 revealed that 29.7% of the respondents strongly agreed that P2P conveyance of packages has negative effect in the society, 33.0% of the respondents agreed that P2P conveyance of packages has negative effect in the society, 1.0% of the respondents could not decide whether P2P conveyance of packages has negative effect in the society, 31.4% of the respondents disagreed that P2P conveyance of packages has negative effect in the society while the remaining of the respondents strongly disagreed that P2P conveyance of packages has negative effect in the society. This indicates that majority (62.7%) of the respondents agreed that P2P conveyance of packages by informal transport has negative effect in the society.

Figure 7. Negative effects of P2P package/parcel delivery



Source: Authors' field survey, 2025

Since the P-value (0.000) in the ANOVA table 1 is less than 0.05, there is a statistically significant relationship between the variables at 95.0% confidence level. The R-square statistic indicates that the model as fitted explains 77.2% of the movement of illegal substance. The adjusted R-square statistic, which is more suitable for comparing models with different numbers of independent variables, is 95%. Therefore, the null hypothesis is rejected meaning that package and parcel delivery of goods by informal transport service operators is dangerous to our society.

Table 1. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.879[a]	.772	.693	.27139

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	234.189	4	58.547	255.664	.001[a]
Residual	69.228	301	.229		
Total	303.417	305			

Source**:** Authors' Compilation, 2025

5. Conclusion and Recommendations

Informal transport services typically involve lower costs and this affordability makes it more accessible to individuals and businesses which also reduce traffic congestion. Informal transport services can be tailored to suit the unique needs of senders and recipients. However, this research concluded that, package and parcel delivery of goods by informal transport service operators create an avenue for smuggling of illegal substance within the cities. Therefore, it was recommended that drivers must make sure they ascertain the content of the package/parcel by physical examination at the park and also law enforcement agent should be provided with gadgets to examine such package/parcel without opening it.

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