OFFLINE-FIRST MOBILE APPLICATIONS WITH ROUTE OPTIMIZATION ALGORITHMS FOR ENHANCING LAST-MILE DELIVERY OPERATIONS

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Abstract

The rise of online shopping has made last-mile delivery more challenging, especially in poor regions without reliable internet. This study evaluates offline-first mobile apps and route optimisation algorithms for last-mile logistics reliability, precision, and efficiency. Responses were collected from 35 logistics experts through a Google Forms survey and secondary data were gathered from scholarly publications and case studies for this mixed-methods study. Drivers were asked about communication, route optimisation, offline apps, and documentation routines. Prioritising offline operations increases operational reliability in low-connectivity regions, gathers and reports BOL faster, and optimises routing, lowering fuel costs and trip time. Despite these improvements, offline sync, documentation, and app usability concerns existed. Logistics organizations seeking scalable and cost-effective delivery solutions can profit from the findings, which are consistent with previous literature and bring novelty through mixed-method validation. Increase map accuracy, offline conflict resolution, AI-powered voice help, safety alarms, and predictive routing. Modern logistics and last-mile deliveries may benefit from offline-first apps.

Keywords: Offline-first mobile applications, Last-mile delivery, Route optimization, Logistics technology, Bills of Lading (BOL).

1. Introduction

Over the past decade, online shopping has grown rapidly, making last-mile delivery important but difficult for global supply chains [1]. Consumers expect fast, transparent, and reliable delivery; therefore, logistics companies must make it easier and more precise. Optimizing the final mile of delivery is crucial to an organization's competitiveness because it accounts for a considerable amount of logistical costs [2]. Digital logistics projects have increased in response to these expectations. Delivery operations increasingly use algorithm-driven route planning, real-time tracking, and mobile technology. Drivers may check delivery manifests, track routes, document delivery, and communicate with dispatchers using their mobile apps. Mobile apps do various logistical tasks beyond navigation. Smartphones and tablets let drivers plan routes, coordinate deliveries, document, and track processes [3]. These mobile solutions improve field employee-central dispatch team collaboration by offering real-time delivery insights and decision-making. Despite digitization's benefits, the increasing quantity of internet-connected devices makes driving in undeveloped or inaccessible areas nearly impossible [4]. Inconsistent network coverage impairs last-mile delivery system efficiency, communication, and data synchronization.

Drivers can't acquire real-time delivery updates due to poor cell networks [5]. Dispatchers cannot track routes, predict delivery times, or respond to interruptions due to visibility concerns. Without traffic and route updates, mobile apps affect operational expenses, fuel consumption, and travel time. Drivers' photographs and forms slow down Bills of Lading and other document processing. Time delays in billing, financial flow, and dispatch affect transportation firms. These restrictions have changed offline-first mobile app distribution and offline commodities outperform cloud software.

Local device storage lets drivers access goods manifests, route planning, and delivery details [6]. Network difficulties do not affect remote distribution and record BOL quickly with offline apps. After reconnecting to the main system, drivers can sign, take pictures, and check delivery [7]. Administrative efficiency, faster payments and invoices, and more accurate data. Offline route optimization software help in places with poor internet [8].

Since it maintains route data and optimization algorithms locally, the program can provide smart routing, delivery sequencing, and estimated journey lengths without an internet connection. Mobile solutions that favour offline processing can speed up the sending of BOLs and proofs of delivery for billing teams and dispatchers. Logistics companies' offline-first smartphone apps address connectivity, paperwork, and routing issues. Last-mile deliveries, driver productivity, and operational transparency improve with route optimization and offline power. This mixed-methods study uses primary survey data and secondary literature to evaluate these technologies in modern delivery operations.

1.1 Research Aim & Objectives

- To evaluate how offline-first mobile apps improve last-mile delivery efficiency
- To analyze effectiveness of route optimization algorithms
- To assess user experience (using Google Form results)
- To integrate literature insights into real-world needs

1.2 Research Questions

1. How do offline-first mobile applications impact last-mile delivery operations?
2. What is the role of route optimization algorithms in improving delivery performance?

3. What benefits and challenges do drivers experience while using such applications?
4. How does offline capability influence data accuracy, timeliness, and payment cycles?

2. Literature Review

2.1 Last-Mile Delivery Challenges

The final stage of delivery is often challenging and costly. Inconvenient road closures, heavy rush-hour traffic, and unforeseen traffic jams force drivers to waste petrol as they take fuel-consuming detours through congested areas [9].

Delivery planning is impeded, customers are irritated, and resources are wasted due to missing or erroneous ETAs. Problems with connectivity or other technical issues prevent location updates from going through, leaving huge gaps in visibility that make it hard to follow a driver's progress.

Dispatchers can't provide drivers advice, change routes, or communicate with clients without access to real-time data [10]. Paper-based operations are inefficient because bills of lading, delivery confirmations, and proof-of-delivery documents require human signatures. Manual labor might cause missing paperwork and late payments. E-commerce and hyperlocal delivery have raised customer expectations for speedy, reliable service with accurate tracking [11]. Logistics companies use digital technologies to speed last-mile delivery, clarify orders, and reduce delays.

2.2 Logistics Mobile Computing Evolution

Manual operations are digitalized for faster, more accurate, and reliable delivery. The palm of our hand can now track deliveries, signatures, barcodes, and even autos [12]. These improve real-time field compatibility of office logistics management systems. Cloud-based dispatching tools are another logistics digitalization milestone. Central dashboards let dispatchers change routes, delivery directions, and driver behavior. All users having the latest cloud data speeds up responses to customer demands and route disruptions and improves decision-making [13]. Drivers and dispatch teams can instantly communicate via mobile apps, expediting crisis response. Last-mile delivery productivity and precision require a move from paper-based to mobile operations.

2.3 Offline-First Mobile Application Architecture

As a strategic answer to logistics connectivity concerns, offline-first mobile architectures have emerged [14]. Unlike cloud-based apps, offline-first apps process and store data locally. Local caching enables drivers to access delivery details, route maps, and previous data regardless of network capacity. This keeps the workflow going without internet.

Data must be synchronized when offline-first apps reconnect [15]. Integrate locally stored changes with the central server for data consistency during synchronization. Strong synchronization systems must handle conflicts, duplication, and timestamp validation. Offline-first applications safeguard data from network outages, incomplete uploads, partially captured documents, and route modifications.

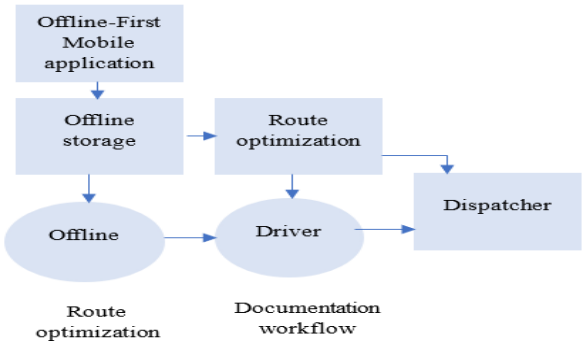


Figure 1 Offline-First Mobile Application Architecture

Security and data validation are essential for offline-first systems [16]. Because the device temporarily holds key logistics data, encryption and caching are essential. Validation criteria should also be implemented to ensure that synchronisation delivers complete and accurate data.

2.4 Drone-Based Final-Mile Delivery in Offline-First Logistics Systems

Drone delivery has become a popular last-mile logistics solution, especially in rural, underdeveloped areas. Traffic, poor road networks, and physical impediments can be avoided with drone transportation [17]. When connected to smartphone apps that favor offline use, drone operations can continue seamlessly in areas with poor connectivity. Connections can be restored to sync flight trajectories, delivery coordinates, cargo details, and confirmation records with central systems. This strategy ensures data consistency and delivery. Route-optimizing algorithms can improve drone deployment by locating the ideal takeoffs, routes, and swapping positions for ground vehicles and aerial units. Electric drones save fuel and carbon emissions therefore they help the environment. Despite payload and regulation limits, hybrid delivery methods using ground vehicles and drones can improve last-mile delivery efficiency and resilience.

2.5 Route Optimization Algorithms

Delivering efficiently in the last mile generally requires route optimisation. Several algorithms find the most efficient vehicle routes based on distance, traffic, and delivery. Traditional algorithms like A* (A-star) and Dijkstra's Algorithm calculate shortest paths. These methods find optimal routes in graph-based road networks.

Genetic algorithms and VRP technologies help logistics systems handle complex multi-stop routing scenarios. VRP-based algorithms consider truck capacity, delivery time, and route constraints. Logistics environments where elements can change at any time require real-time route adjustments [18]. Route optimization algorithms can automatically recalculate the best route using real-time traffic and road closure data. Offline-first apps calculate routing directions

locally and update when the device reconnects to the network.

As firms decrease their environmental effect and operating expenses, fuel- and energy-efficient routing strategies are becoming [19]. Telematics-GIS integration increases mapping, route estimate, and decision assistance, improving route optimisation algorithms.

2.6 BOL-capable mobile document capture

Mobile document capture has revolutionized paper logistics. Drivers can use phone apps to take photos of Bills of Lading (BOL), proof-of-delivery documents, and shipment receipts [20]. Eliminating paper documentation reduces missing, illegible, and incomplete paperwork problems. Images are converted into computer-readable text by OCR, improving documentation.

OCR reduces data entry errors and time by extracting delivery details. Better BOL capture speeds and accuracy lower payment processing time. By submitting delivery confirmations and documentation instantaneously, logistics companies may start invoicing and avoid cash flow delays.

Portable office supplies Logistics companies improve productivity, customer satisfaction, and financial correctness by reducing paperwork errors and ensuring timely submission [21].

2.7 Role of Alerts and Communication in Driver Safety

Communication is essential for driver and operational safety. Drivers can track road dangers, automobile issues, and the best delivery route with an app [22]. These signals help drivers make fair decisions, reducing delays and risks. Drivers who can call dispatchers for technical assistance or route changes work better together. Dispatchers can change automobile routes, provide backup support, and notify consumers of delays while sending or receiving information. People can use incident reporting systems to inform the police about accidents, blocked entrances, and dangerous road conditions and this makes the roadways safer. These solutions enable logistics organizations maintain track of safety records, deal with risks, act promptly, and meet the rules.

2.8 Synthesis and Research Gap

For efficient last-mile delivery, the literature suggests using digital documentation systems, route optimization algorithms, and mobile technology. Studies also suggest that offline-first mobile designs reduce network issues and enable ongoing operations. However, current research rarely incorporates technical perspectives with mixed-method driver input. Few studies analyse delivery operations from both perspectives, instead focussing on system architecture or operational efficiency.

There is few research on offline-first mobile apps in rural, mountainous, or infrastructure-limited areas, where truck drivers commonly experience sporadic connectivity. Due to this knowledge gap, empirical investigations of user experiences and operational outcomes in real delivery scenarios are needed in addition to technological research of offline-first systems. This mixed-methods study will evaluate offline-first mobile apps in last-mile logistics to fill that gap. Primary survey data and secondary literature will inform the evaluation.

3. Method

3.1. Research Design

This quantitative and qualitative study examines how offline-first mobile apps and route optimisation algorithms effect last-mile delivery. A Google Form survey of logistics and driver employees supplied quantitative data, while research papers and case studies provided qualitative data. Data triangulation guarantees that statistical trends, theoretical views, and practical case evidence affect conclusions. Hybrid methods capture daily users' subjective experiences and offline-first apps' measurable operational benefits.

3.2 Primary Data Collection

Logistics managers, truck drivers, and delivery drivers were asked to fill out Google Forms for this study. There are 12 questions that cover SEO, offline features, communication, documentation, and making users satisfied. The question was a multiple-choice question, and a closed-ended question. Offline-first delivery app data is useful, even though the sample size is only 35 people.

3.3 Data Analysis

Survey trends were found using Excel sums, percentages, and frequency distributions. Bar charts showed documentation, route optimization, and connectivity concerns. Grouping open-ended comments by theme caused sync issues, reduced work, convenience of use, and map interface modifications. A mixed-method study found that statistics and context affect user experiences.

3.4 Secondary Data

Secondary data came from logistics technology study, peer-reviewed scientific publications, conference papers, and market assessments of last-mile delivery innovations. It was observed at how digital logistics change, offline-first system designs, computational route optimization, and mobile documentation tools work. These questions set survey results in a philosophical context.

Secondary data and primary replies were used to compare real-world user experiences with well-established research conclusions, showing agreement and disagreement. This literature-based component made the study reliable and complete.

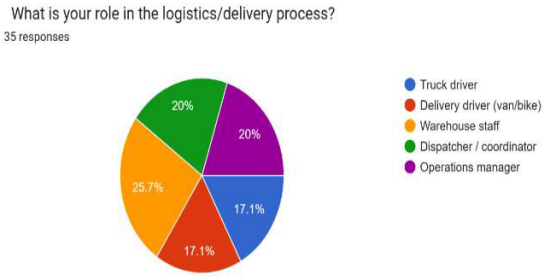
3.5 Limitations

The study has limitations despite its benefits. This survey's 35 participants are sufficient for experimental purposes, but they may not represent logistics specialists. Data also relies on people's memories and viewpoints, which may be wrong. Instead of studying algorithms or backend architecture, the study examines how offline-first apps and route optimisation effect user operations. Thus, the results may not fully

explain how the system processes data, how accurate the algorithms are, or how data synchronisation works. To present results fairly, certain limits are mentioned.

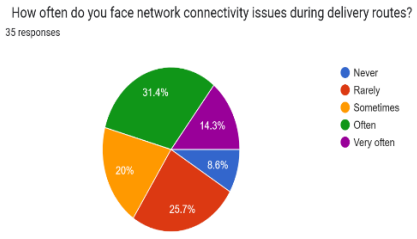
4. Results & Findings

4.1 Primary Analysis

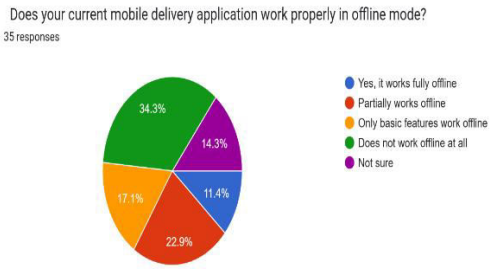


According to this survey, 25.7% of the participants are warehouse staff in the logistics/delivery process, 20% of the participants are dispatcher/coordinator in the logistics/delivery process, 20% of the participants are operations manager in the logistics/delivery process, 17.1% of the participants are truck driver in the logistics/delivery process and 17.1% of the participants are delivery driver (van/bike) in the logistics/delivery process.

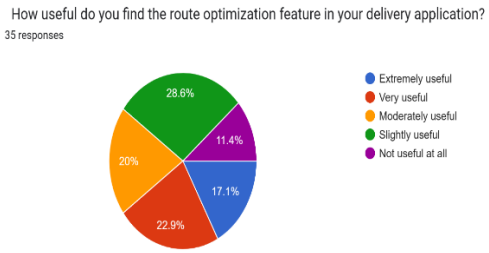
In this survey, 28.6% of the particants are 4-6 years of experience in delivey or logistics operations, 22.9% of the particants are 7-10 years of experience in delivey or logistics operations, 20% of the particants are more than 10 years of experience in delivey or logistics operations, 14.3% of the particants are less than 1 years of experience in delivey or logistics operations and 14.3% of the particants are 1-3 years of experience in delivey or logistics operations.



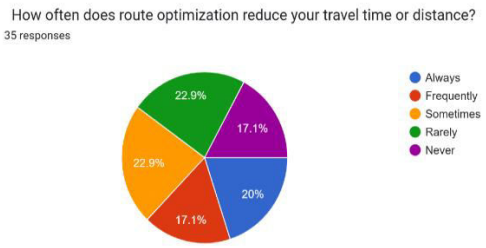
According to this survey, 31.4% of the participants often faces network connectivity issues during delivery routes, 25.7% of the participants rarely faces network connectivity issues during delivery routes, 20% of the participants sometimes faces network connectivity issues during delivery routes, 14.3% of the participants very often faces network connectivity issues during delivery routes and 8.6% of the participants never faces network connectivity issues during delivery routes.



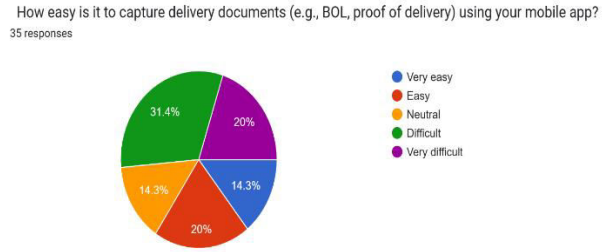
In this survey, 34.3% of the participants current mobile delivery application does not works properly in offline mode, 22.9% of the participants current mobile delivery application partially works properly in offline mode, 17.1% of the participants current mobile delivery application works properly only basic features in offline mode, 14.3%of the participants current mobile delivery application not sure work properly in offline mode and 11.4%of the participants current mobile delivery application work properly in offline mode.



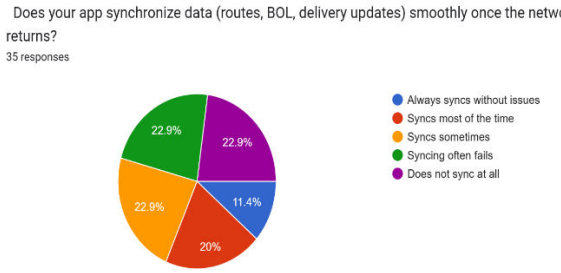
In this survey, 28.6% of the participants said that route optimization feature is slightly useful in their delivery application, 22.9% of the participants said that route optimization feature is very useful in their delivery application, 20% of the participants said that route optimization feature is moderately useful in their delivery application, 17.1% of the participants said that route optimization feature is extremely useful in their delivery application and 11.4% of the participants said that route optimization feature is not useful in their delivery application.



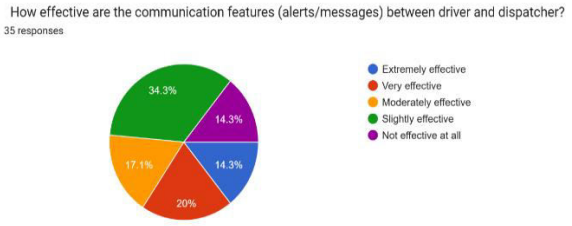
According to this survey, 22.9% of the participants said that route optimization sometimes reduces travel time or distance, 22.9% of the participants said that route optimization rarely reduces travel time or distance, 20% of the participants said that route optimization always reduce travel time or distance, 17.1% of the participants said that route optimization never reduces travel time or distance and 17.1% of the participants said that route optimization frequently reduces travel time or distance.



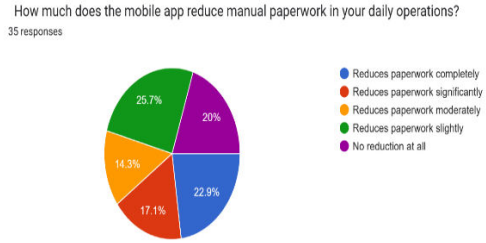
In this survey, 31.4% of the participants said that capture delivery documents (e.g., BOL, proof of delivery) are difficult while using mobile app, 20% of the participants said that capture delivery documents (e.g., BOL, proof of delivery) are easy while using mobile app, 20% of the participants said that capture delivery documents (e.g., BOL, proof of delivery) are very difficult while using mobile app, 14.3% of the participants said that capture delivery documents (e.g., BOL, proof of delivery) are neutral while using mobile app and 31.4% of the participants said that capture delivery documents (e.g., BOL, proof of delivery) are very easy while using mobile app.



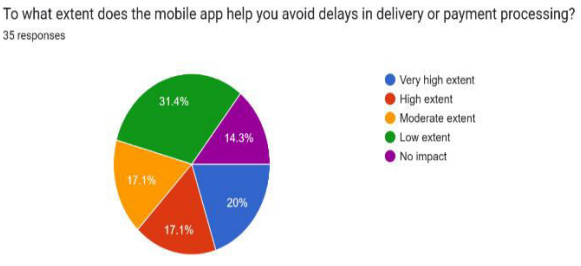
In this survey, significant synchronization issues in the app once the network returns. Only 11.4% of users report that it always syncs without issues, while 20% say it works most of the time. Another 22.9% experience syncing only sometimes, and 22.9% report that syncing often fails. 22.9% state the app does not sync at all, indicating major reliability concerns.



According to this survey, 34.3% of the participants said that communication features (alerts/messages) between driver and dispatcher are slightly effective, 20% of the participants said that communication features (alerts/messages) between driver and dispatcher are very effective, 17.1% of the participants said that communication features (alerts/messages) between driver and dispatcher are moderately effective, 14.3% of the participants said that communication features (alerts/messages) between driver and dispatcher are not effective and14.3% of the participants said that communication features (alerts/messages) between driver and dispatcher are extremely effective.

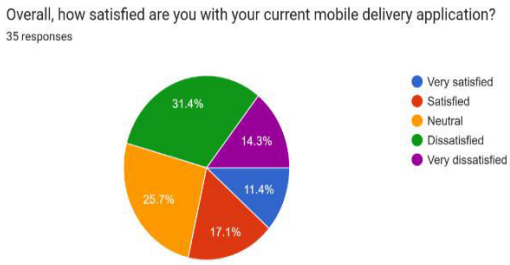


In this survey, 25.7% of the participants said that the mobile app reduces paperwork slightly in their daily operations, 22.9% of the participants said that the mobile app reduces paperwork completely in their daily operations, 20% of the participants said that the mobile app not reduces paperwork in their daily operations, 17.1% of the participants said that the mobile app reduces paperwork significantly in their daily operations and 14.3% of the participants said that the mobile app reduce paperwork moderately in their daily operations.



According to this survey, 31.4% of the participants said that the mobile app help to avoid delays in delivery or payment processing at low extent, 20% of the participants said that the mobile app help to avoid delays in delivery or payment processing at very high extent, 17.1% of the participants said that the mobile app help to avoid delays in delivery or payment processing at high extent, 17.1% of the participants said that the mobile app help to avoid delays in delivery or payment processing at moderate extent and 14.3% of the

participants said that no impact in the mobile app help to avoid delays in delivery or payment processing.



In this survey, 31.4% of the participants are dissatisfied with current mobile delivery application, 25.7% of the participants are neutral with current mobile delivery application, 17.1% of the participants are satisfied with current mobile delivery application, 14.3% of the participants are very dissatisfied with current mobile delivery application and 11.4% of the participants are very satisfied with current mobile delivery application.

Overall findings

The survey revealed serious logistical and delivery operational and technological challenges. This shows that mobile delivery apps don't benefit different occupations and skills. Many people report network issues and delivery application sync issues. Route optimization and document collection were moderately useful. Most customers think the program accomplishes nothing to reduce paperwork and delays, and driver-dispatcher communication is poor. To meet logistics requirements, the existing delivery application needs considerable upgrades in reliability, offline performance, communication efficiency, and operational assistance. Most participants are dissatisfied or neutral.

4.2 Secondary Analysis

Secondary data analysis of academic papers, business journals, and logistics-related case reports contextualizes survey results and increases supply chain ecosystem understanding of mobile delivery applications.

Mobile technologies for real-time route optimization, digital proof-of-delivery, and driver-dispatcher interaction being researched in logistics and transport management. Heuristic-based vehicle routing models, Dijkstra, and A* optimise routes better for cost, delivery time, and fuel use [23]. These algorithms only work with clean, continuous internet data streaming, according to study. Poor network coverage or routes limit algorithmic performance, emphasizing the need for offline solutions.

FedEx, DHL, and UPS have hybrid offline-online systems in their case studies. These systems save routes, delivery manifests, and scans locally on devices and sync with the cloud when connected. Data loss and duplication are prevented using background synchronization, event-driven data queues, and local caching. Offline-first mobile solutions can boost driver productivity and cut downtime by 40% in highly populated or rural locations with inadequate network connections, according to academic studies. Major offline synchronisation issues persist [24]. When devices reconnect to unreliable networks, duplicate entries, failed uploads, and inaccurate timestamps are common. In delivery app usability studies, confusing system warnings, high battery usage, and complex user interfaces are examined.

Logistics workers, especially drivers and delivery managers, prefer simple, distraction-free interfaces with visual or vocal signals. Secondary sources claim logistics is relying more on digital documents. Storage bottlenecks, slow rendering, and poor camera integration sometimes reduce reliability, despite the growing use of mobile scanning and photo shooting for proof-of-delivery. Failed sync attempts, inaccurate map data, delayed route recalculations, and interface freezes during peak operations are related to the key survey results of this study. Multiple vulnerabilities were found in peer-reviewed papers, logistics software vendor analysis [25]. Real-time driver-coordinator links improve supply chain responsiveness, transparency, and delivery conflicts, according to dispatching operations communication workflow research.

Without a dependable backend infrastructure, these functions act inconsistently, slowing procedures. Secondary research suggests mobile delivery apps can improve accuracy and efficiency. They need stable offline capabilities, reliable syncing, an easy-to-use user interface, and constant system optimization to do this. Secondary sources and the main study agree that field activities in low-connectivity areas require durable mobile solutions.

5. Discussion

The study indicated that offline-first mobile apps improve drivers' operations, especially in low-network locations. These systems let drivers in rural or isolated places perform vital tasks without internet, maintaining operational continuity. Delivery documentation, route access, and proof-of-delivery are supplied. Delivery activities are not connectivity-dependent, so drivers can keep generating without delays.

Last-mile delivery efficiency improves with route optimization. Optimal routing increases time management and fuel efficiency regardless of driver happiness, according to statistics.

Offline-first systems find the optimum routes, reducing delivery time, idle travel, and detours. Operational savings are considerable.

Previous research has shown that route optimization algorithms like Dijkstra, A*, and VRP-based techniques cut delivery costs without affecting service quality. Additionally, mobile apps dramatically effect documentation and picture scanning, offline data storage, and fast BOL capture simplify delivery evidence. Faster BOL submission speeds up dispatch and payment execution, improving cash flow and billing delays. Offline-first apps decrease paper forms, enhance precision, reduce human error, and let drivers deliver.

Previous logistics mobile technology research was confirmed. Though offline-first designs and digital

documentation can boost operational efficiency, few studies have employed quantitative and qualitative user input to prove it. Uniquely, mixed-methods emphasizes these apps' practical benefits and user-centered considerations. Usability, dependability, and driving experience are as important as technical skill for field results. Results show logistical operations' practicality. Offline-first mobile apps cut costs, improve delivery, and accelerate payments.

Better, more dependable, and simpler solutions can improve driver satisfaction, motivation, and retention, enhancing labor management. Traditional cloud-based systems may fail in rural or under-connected locations, but offline-first options scale. Route optimisation with robust offline features can assist logistics companies in satisfying rising customer demands for dependability, efficiency, and cost-effectiveness.

6. Conclusion

Offline-first smartphone apps with route optimization algorithms improve last-mile delivery. These apps enhance payment, communication, and efficiency. These apps allow drivers to access delivery manifests, route planning, and proof-of-delivery documentation even in low-connectivity locations, route optimization saves time and gas. The mixed-method study confirms earlier research and highlights user-centric difficulties including synchronisation and documentation shortages. Route efficiency saves time and money, and rural distribution requires offline-first architecture. Future research may improve last-mile delivery apps with AI-based predictive routing, automatic hazard alerts, and voice-guided navigation.

7. Recommendations

The study suggests improving offline mobile delivery apps. For appropriate travel assistance in rural or complex urban areas, map accuracy must improve. If connectivity is restored, offline data conflict resolution must improve to reduce syncing mistakes and data duplication. AI-enabled voice assistance improves driver concentration and reduces app use. Bill of lading scanning with OCR and auto-validation speeds payment processing and reduces errors. By factoring in traffic, weather, and delivery priority, predictive route planning improves efficiency. Increase safety warning systems for accidents, road closures, and high-traffic zones to increase operational reliability and driver safety.

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Appendix

Survey question

1. What is your role in the logistics/delivery process?

- Truck driver
- Delivery driver (van/bike)
- Warehouse staff
- Dispatcher / coordinator
- Operations manager
- Other

2. How many years of experience do you have in delivery or logistics operations?

- Less than 1 year
- 1–3 years
- 4–6 years
- 7–10 years
- More than 10 years

3. How often do you face network connectivity issues during delivery routes?

- Never
- Rarely
- Sometimes
- Often
- Very often

4. Does your current mobile delivery application work properly in offline mode?

- Yes, it works fully offline
- Partially works offline
- Only basic features work offline
- Does not work offline at all
- Not sure

5. How useful do you find the route optimization feature in your delivery application?

- Extremely useful
- Very useful
- Moderately useful
- Slightly useful
- Not useful at all

6. How often does route optimization reduce your travel time or distance?

- Always
- Frequently
- Sometimes
- Rarely
- Never

7. How easy is it to capture delivery documents (e.g., BOL, proof of delivery) using your mobile app?

- Very easy
- Easy
- Neutral
- Difficult
- Very difficult

8. Does your app synchronize data (routes, BOL, delivery updates) smoothly once the network returns?

- Always syncs without issues
- Syncs most of the time
- Syncs sometimes
- Syncing often fails
- Does not sync at all

9. How effective are the communication features (alerts/messages) between driver and dispatcher?

- Extremely effective
- Very effective
- Moderately effective
- Slightly effective
- Not effective at all

10. How much does the mobile app reduce manual paperwork in your daily operations?

- Reduces paperwork completely
- Reduces paperwork significantly
- Reduces paperwork moderately
- Reduces paperwork slightly
- No reduction at all

11. To what extent does the mobile app help you avoid delays in delivery or payment processing?

- Very high extent
- High extent
- Moderate extent
- Low extent
- No impact

12. Overall, how satisfied are you with your current mobile delivery application?

- Very satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very dissatisfied