CHAPTER 101

Optimization of Last-Mile Delivery in Construction Projects: Improving Efficiency Through Routing Algorithms and Technology Integration

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ABSTRACT

Cost overruns and project delays caused on by ineffective supply chains and last-mile logistics are a common problem in the construction industry that this paper seeks to address. The primary goal of this research is to be helpful in enhancing project outcomes while attempting to optimize logistical operations by identifying latest tactics and technologies. This research uses a combination of simulations, literature reviews, and analysis of methods such as the Vehicle Routing Problem (VRP) algorithm, GPS integration, and Just-In-Time (JIT) delivery systems. Simulations costs and efficiency and efficacy of proposed solutions in smoothing delivery routes, saving fuel costs, and reducing stoppages. The report indicates that last-mile logistics are significantly enhanced by the application of GPS technology, use of VRP algorithms, and JIT delivery systems. Such techniques reduce on-site handling and storage costs due to streamlined route planning, real-time decision-making, and timely material delivery. The results depict reduced project schedule delays, cost overruns, and improved supply chain performance. This research is a valuable contribution to the construction industry with its comprehensive approach to last-mile logistics optimization, practical benefits of utilizing modern logistics techniques, and practical recommendations for industry adoption. These findings give construction managers useful strategies to streamline logistics and minimize delays and cost overruns, which enhances operational effectiveness and project success.

Keywords: Construction logistics optimization; Just-in-time delivery (JIT); GPS integration; Vehicle routing problem algorithm (VRP); Last-mile delivery.

1.0 Introduction

The prompt and effective transportation of supplies and machinery to the job site is crucial to the construction sector. This includes multiple stages like procurement, loading, dispatch, transportation, tracking, site delivery, unloading, inspection, on-site management, etc. Due to population growth and urbanization, the final step of logistics or transportation is becoming increasingly important which is also called last-mile delivery stated in (Demir *et al.*, 2022).

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DOI: 10.17492/JPI/NICMAR/2507101 *ISBN: 978-93-49790-54-4*

This stage involves multiple challenges like congestion, limited site access, and specific time for delivery due to space or security constraints on the construction site leading to delays, increased costs, and disruptions to the project schedule. To mitigate these challenges, technologies like GPS, VRP, and JIT delivery systems have become important tools for improving last-mile logistics. So, Improving and optimizing the route assigned to vehicles of the fleet, it highly possible to reduce time and cost overruns. (Calabrò *et al.*, 2020). Real-time tracking of individual vehicle locations along with real-time status visibility is available using a global positioning system (Michaelides *et al.*, n.d.). Using (VRP) vehicle routing problem algorithms helps optimize routes and delivery paths to avoid traffic and congestion (Calabrò *et al.*, 2020). Just-In-Time (JIT) is a material management system that aims to reduce inventory and ensure the materials are available when they are required on time which helps in increasing productivity, quality, and efficiency, decreasing inventory cost, etc (Ozalp *et al.*, 2010)

Urban building sites are most likely to be located in densely populated areas with narrow streets and restricted site access. This is further exacerbated by the increasing number of delivery trucks, resulting in longer delivery times and congestion (Bakogianni & Malindretos, 2021). To reduce disruptions, city governments also establish narrow delivery windows, meaning construction logistics managers must plan material arrival very carefully. Since conventional routing models rely on static plans that do not include actual-time considerations like traffic, weather, or site-based restrictions, inefficient routing worsens the last-mile delivery. This leads to inefficient routing, raising operating costs and delivery times. Research has indicated that using AI-based dynamic routing models can greatly improve productivity by lowering delivery times and fuel usage (Casado-Vara *et al.*, 2020).

2.0 Literature Review

2.1 Last-mile delivery and its challenges

Logistics refers to the organized movement of products from the origin to distribution points and finally to consumers. A specially located warehouse near the customer location is the source of last-mile delivery, with a short drive to the final destination. The effectiveness of this process is utmost, as it has a direct impact on customer satisfaction, operating costs, and overall supply chain efficiency (Sorooshian *et al.*, 2022a). Urbanization and online shopping have further contributed to the complexity of last-mile delivery, making it necessary for sophisticated logistics solutions such as real-time tracking, route optimization, and autonomous delivery mechanisms to enhance efficiency and minimize delays (Batan *et al.*, 2020). Last-mile delivery can simply be said to begin from a previously determined warehouse near the customer's address, which travels a few miles to reach its intended recipient. (Sorooshian *et al.*, 2022b)

The last mile delivery (LMD) segment that ends the supply chain involves the conveyance of construction materials from the warehouse or distribution center to the construction site. To finish the project within the specified time and reasonable cost, the last part

DOI: 10.17492/JPI/NICMAR/2507101 *ISBN: 978-93-49790-54-4*

of the supply chain is crucial (Mbhele & Rambaran, 2021). Because construction projects usually depend on timely scheduling, supply chain delays at the last mile may result in significant project delay, higher cost, and inefficiencies (Mangiaracina *et al.*, 2019). Because of constraints like heavy traffic, site-restricted access, and difficult delivery schedules, LMD is a complex but critical element of construction logistics. (Galkin *et al.*, 2019b). The use of the advance technologies, such as Just-In-Time (JIT) inventory management, GPS navigation, and artificial intelligence (AI) route optimization, has been the primary way of enhancing LMD efficiency.

This final leg of the supply chain is crucial for ensuring timely project completion and cost efficiency. (Galkin *et al.*, 2019a). The complexity of LMD stems from the need to meet customer expectations for speed, timeliness, accuracy, and individual delivery precision (Sorooshian *et al.*, 2022b). LMD involves many individual deliveries, typically in highly congested urban areas where parking and access restrictions add to the complexity of the task, compared to bulk shipments transported over long distances by efficient logistical networks. Logistics companies are using technology-based solutions, such as AI-based route planning, real-time tracking, and automated delivery systems, to counter these challenges (Galkin *et al.*, 2019b). To determine the most effective delivery routes for delivery vehicles, machine learning-based route optimization technologies analyze historic delivery patterns and real-time traffic information. (Oloko, 2025).

2.2 Vehicle routing problem algorithm (VRP)

The term “VRP” denotes a broad class of problems. It is stated by Dantzig and Ramser in 1959 that it is one most difficult optimization problems, more than 40 years back. It aims at developing the best routes possible for an inventory of cars that is meant to service a particular set of clients (Bell & McMullen, 2004). The objective of the problem is to serve all the requirements of a group of customers with minimum possible truck route costs, which starts and ends at the same depot. (Santillán *et al.*, 2012a).

Numerous Variants of VRP for Optimization of Logistics Management Problems Based on computational knowledge, VRP typically is a standard NP-hard problem; that is to say, it is impossible to find the optimal solution. Heuristics methods were applied to most real-world vehicle routing problems (Santillán *et al.*, 2012b). Practical Applications of VRP can be applied to a number of practical situations depending on the nature of the activity undertaken such as collection and distribution whilst considering following constraints: vehicle capacity, multiple depots. It has been reported that the effective cost minimization of those issues could successfully yield significant savings in the tune of 5% to 20% of the total cost of the products (Cattaruzza *et al.*, 2017). All the routes should begin and end at the depot. Every point may only be visited once, and only one vehicle per location could be used, and the capacity cannot be over exceeded by the vehicle (Belka & Godlewski, 2021). Real-world applications vary depending on operational specifics. Examples include pickup and delivery scenarios, incorporating factors like

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

vehicle capacity and multiple depots. (Santillán *et al.*, 2012a)

2.3 Just in time delivery (JIT)

Just In Time (JIT) delivery, a concept originating from the Toyota Production System, aims to provide the necessary materials at the precise time and in the exact quantity needed for each stage of a process. The ultimate objective is to eliminate waste, such as excessive wait times and large inventories, by minimizing storage and handling, thereby streamlining operations. (Tommelein & Li, 1999) It is called "Just-In-Time" (JIT) because materials arriving on a construction site will be transported directly to their intended installation sites and subsequently installed immediately, thus not disrupting the process because they are not put into laydown or staging. The Toyota Production System, also known as the lean manufacturing paradigm in English, was established by Japanese engineers and forms the foundation of the concept of Just-In-Time. The basic idea of Just-In-Time manufacturing is the delivery of all materials at the right time and in the right quantities at every step of the production process (Ozalp *et al.*, 2010).

Traditional construction logistics involve heavy handling, storage, and transportation, which is fuel- and emission-heavy (Bookbinder & Dilts, 1989). JIT reduces carbon footprints, maximizes fleet utilization, and reduces transportation frequency through material delivery optimization. In addition, since materials are less likely to be damaged or wasted through over-ordering, waste creation is reduced when material storage on site is reduced (Bookbinder & Dilts, 1989). Since the supply chain relies on correct scheduling, even an interruption-be it in the form of tardy transport, lack of availability of suppliers, or unforeseen changes in project timelines-can prove calamitous (Tezel *et al.*, 2020). Companies must spend money on real-time monitoring software, maintain cordial relations with suppliers, and construct contingency plans to minimize such threats. These are overcome through good communication, team planning, and project management on computer platforms (Dallasega, 2018).

Traditional procurement practices must be modified in order to make JIT delivery in the construction industry possible. Contractors must change to a more responsive and demand-driven approach rather than buying in bulk and stocking resources for later use. This includes collaboration with suppliers to maintain quick response times, the use of data analysis to accurately forecast material needs, and simplifying logistics networks to provide just-in-time delivery (Ng *et al.*, 2009). With real-time visibility into inventory, material flow, and any interruptions, next-generation technologies like IoT-based sensors, GPS tracking, and AI-based predictive analytics further facilitate JIT deployment (Michaelides *et al.*, 2010).

2.4 Potential of GPS technology integration

In the latest periods, ICTs have emerged as critical enablers of coordinating and synchronizing geographically dispersed manufacturers, suppliers, and logistics providers within global supply chains (Brusselaers *et al.*, 2022). Mass diffusion and widespread deployment of ICTs has significantly increased the complexity of technological solutions that can be offered to

DOI: 10.17492/JPI/NICMAR/2507101 *ISBN: 978-93-49790-54-4*

complex systems of supply chains because of the explosion of mobile technologies (Bányai, 2018). Advanced internet solutions that deploy in conjunction with mobile technologies, such as GPS, GPRS, and GIS, really improve the transparency and accuracy of the information on the location and traceability of shipments as well as the current status of deliveries to supply chain partners (Michaelides *et al.*, 2010). These advances have improved efficiency and responsiveness through real-time data sharing, predictive analytics, and automated logistics process management. Businesses can integrate cloud-enabled supply chain management tools whereby they gain immediate visibility into inventory levels, order tracking, and transport plans, thus reducing delays and improving decision-making.

Enhanced risk management, demand forecasting, and route planning capabilities of ICT are further enhanced by a mix of AI and machine learning, which helps strengthen supply chain operations (Giuffrida *et al.*, 2022). These technologies help to mitigate disruptions from unforeseen elements such as weather, traffic jams, and geopolitical events (Ozalp *et al.*, 2010). These developments have promoted efficiency and responsiveness by making possible real-time exchange of information, predictive analytics, and logistics operations automation. Cloud supply chain management software that enables companies to access at a moment's notice inventory levels, order status, and transport schedules can be incorporated (Michaelides *et al.*, 2010). With the fusion of AI and machine learning further developing ICT capabilities, the improvement of supply chain operations' risk management, demand forecasting, and route planning also ensues (Bányai, 2018).

These technologies alleviate disruptions generated by unforeseen conditions like weather, traffic, and geopolitical action. Besides that, through offering unalterable transaction records, blockchain technology is transforming supply chain transparency and security and guaranteeing stakeholder accountability and trust. Smart contracts reduce administrative costs and fraud risks through enabling automatic transactions and conformity checks. Firms can build more dynamic and robust supply chains that can respond to fast-paced market evolution and rising customer expectations by leveraging ICTs (Özarık *et al.*, 2024). According to many researchers, real-time monitoring of physical objects greatly improves logistics efficiency, cost, and customer satisfaction (Bányai, 2018).

3.0 Research Methodology

The aim is to study the ways in which advanced technologies and routing algorithms are able to make last-mile delivery more efficient for the construction projects. In order to do so, a structured, multi-phase approach is applied, as below.

3.1 Research design

The study uses the qualitative approach to explore last-mile delivery challenges in construction, with phases for identifying issues through interviews and literature (Exploratory

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

Phase) and validating solutions through surveys (Validation Phase).

3.2 Data collection

Data was gathered using primary sources through questionnaires, targeting construction project managers, supply chain coordinators, and logistics professionals with 60 volunteers from different companies via purposive sampling.

3.3 Data analysis techniques

The data was analyzed using comprehensive strategic evaluation of last-mile delivery optimization by using Descriptive Analysis to summarize problems and trends, Statistical Analysis of the primary data and SWOT Analysis to assess the effectiveness of VRP algorithms, GPS, and JIT in routing optimization.

3.4 Validation of results

The results were validated through stakeholder feedback from logistics experts and project managers, ensuring the proposed solutions are reliable and applicable for improving last-mile construction delivery.

4.0 Data Analysis and Findings

The data analysis in this study focuses on exploring the factors that influence the adoption of better logistics technology in the construction industry. By analyzing data from surveys conducted with construction managers, the research evaluates the impact of technologies such as GPS integration, Just-In-Time (JIT) delivery systems, and Vehicle Routing Problem (VRP) algorithms. The analysis highlights significant differences in the familiarity and implementation of these technologies, and their collective role in improving logistics efficiency, reducing costs, and minimizing delays in construction projects.

Table 1: Descriptive Analysis

What is your highest qualification?	**Qualification**	**Count**	**Column N %**
	High School Diploma	17	8.30%
	Higher Secondary School Diploma	38	18.40%
	Bachelor's Degree (Engineering, Business, etc.)	47	22.80%
	Master's Degree (MBA, MTech, etc.)	98	47.60%
	Ph.D. or Doctorate	6	2.90%
Please specify your role in the construction industry.	**Role**	**Count**	**Column N %**
	Project Manager	1	0.50%
	Project Director / Senior Management	84	40.80%

DOI: 10.17492/JPI/NICMAR/2507101 *ISBN: 978-93-49790-54-4*

	Project Manager / Construction Manager	46	22.30%
	Site Manager / Site Engineer	33	16.00%
	Logistics Coordinator / Supply Chain Manager	18	8.70%
	Supplier / Vendor	22	10.70%
	Other	2	1.00%
What is your company's approximate annual turnover?	**Turnover Range**	**Count**	**Column N %**
	Less than 1 crore	2	1.00%
	1–10 crore	7	66.50%
	10–50 crore	42	20.40%
	50–100 crore	19	9.20%
	More than 100 crores	6	2.90%
How many years of experience do you have in the construction industry?	**Experience**	**Count**	**Column N %**
	Less than 2 years	83	40.30%
	2–5 years	21	10.20%
	6–10 years	69	33.50%
	More than 10 years	33	16.00%
Which age group do you belong to?	**Age Group**	**Count**	**Column N %**
	18–25 years	81	39.30%
	26–35 years	19	9.20%
	36–45 years	69	33.50%
	46–55 years	18	8.70%
	Above 55 years	19	9.20%
What type of construction projects are you primarily involved in?	**Project Type**	**Count**	**Column N %**
	Residential	82	39.80%
	Industrial	48	23.30%
	Infrastructure	40	19.40%
	Commercial	36	17.50%
	Less than 2 years	83	40.30%
	2–5 years	21	10.20%
	6–10 years	69	33.50%
	More than 10 years	33	16.00%
Which age group do you belong to?	**Age Group**	**Count**	**Column N %**
	18–25 years	81	39.30%
	26–35 years	19	9.20%
	36–45 years	69	33.50%

Source: Compiled by authors

The descriptive breakdown provides a critical analysis of respondents' attributes that provide information regarding their qualifications, job positions, company turnover, experience, age, and association with projects within the construction field. In qualifications, the respondents are predominantly comprised of those having a master's degree (47.6%) and then come those with a bachelor's degree (22.8%). Another smaller percentage hold a Higher Secondary School Diploma (18.4%), while minimal respondents have a High School Diploma (8.3%) and a Ph.D. or Doctorate (2.9%). In regard to occupation in the construction sector, most are employed as Project Director/Senior Management (40.8%), then Project Managers/ Construction Managers (22.3%) and Site Managers/Site Engineers (16%).

Less are Logistics Coordinators/Supply Chain Managers (8.7%) or Suppliers/Vendors (10.7%), with a minority (1%) listing other occupations. For business turnover, a large percentage of respondents (66.5%) indicated that their businesses have an annual turnover of 1-10 crore, and 10-50 crore was indicated by 20.4%. 50-100 crore and over 100 crore categories had lesser percentages (9.2% and 2.9%, respectively). Just 1% of businesses indicated a turnover of less than 1 crore. In terms of years of experience, the majority of the respondents (40.3%) have 2 years or less experience in the construction sector, followed by a significant percentage (33.5%) with 6-10 years of experience. 10.2% have 2-5 years of experience, and 16% have over 10 years of experience.

By age, the most represented respondents are in the 18-25 years age group with 39.3%. The 36-45 years group is next at 33.5%, followed by 26-35 years, 46-55 years, and over 55 years (with the last three being smaller proportions at 9.2%, 8.7%, and 9.2%, respectively). Finally, the respondents are mostly engaged in residential building projects (39.8%), followed by industrial projects (23.3%) and infrastructure projects (19.4%). The smallest portion is engaged in commercial projects (17.5%). As a whole, the descriptive analysis depicts a multifaceted pool of participants that includes different educational backgrounds, titles, experience levels, and activities within various categories of construction work. This information helps to frame understanding of the construction industry's workforce and dynamic influences that potentially contribute to last-mile delivery problems.

Table 2: Challenges in Last-mile Delivery for Construction Projects

Short Variable	t-value	df	Sig. (2-tailed	Mean Difference	95% Confidence Interval of the Difference
Last-Mile Delive Challenge	37.669	205	0	3.17	3.00 - 3.34
Impact of Delivery Delays on Timelines	30.308	205	0	1.859	1.74 - 1.98
Average Delivery Delay	33.377	205	0	2.447	2.30 - 2.59
Consequence of Delivery Inefficiencies	25.898	205	0	2.481	2.29 - 2 67
Concerns About Adopting Advanced Technologies	28.447	205	0	2.908	2.71 - 3.11

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

Source: Compiled by authors

The above table identifies major last-mile delivery challenges in construction projects. The first question, "Last-Mile Delivery Challenge," indicates a large mean difference (3.170) that participants recognize a huge challenge in last-mile delivery. The second question, "Impact of Delivery Delays on Timelines," indicates that delivery delays have a huge impact on project timelines (mean difference of 1.859), illustrating the effect on project efficiency. The third question, "Average Delivery Delay," indicates that last-mile inefficiency delays are also significant, with an average difference of 2.447, implying significant delays in deliveries. The fourth question, "Consequence of Delivery Inefficiencies," indicates that delivery inefficiencies have a discernible effect on projects (average difference of 2.481), with an effect on the outcome of projects. Finally, the question "Concerns About Adopting Advanced Technologies" identifies key concerns (mean difference of 2.908), indicating resistance or hindrances to the adoption of new technology in last-mile delivery management, which can further lead to inefficiencies. Overall, these findings emphasize that delivery issues, delays, inefficiencies, and technology adoption concerns are key problems in construction project logistics.

Table 3: ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	231.088	2	115.544	589.545	.000[b]
	Residual	39.786	203	.196		
	Total	270.874	205			
a. Dependent Variable: How many years of experience do you have in the construction indust?						
b. Predictors: (Constant), How frequently do last-mile delivery delays impact your project timelines? What is the most common last-mile delivery challenge you face in construction projects?						

Source: Compiled by authors

ANOVA results for the model that explores how last-mile delivery delays and issues impact years of experience in construction reveal a very significant relationship. The regression model accounts for a very high percentage of the variance in the dependent variable, "How many years of experience do you have in the construction industry?" The model's sum of squares equals 231.088 with 2 degrees of freedom for the predictors, and hence the mean square equals 115.544. The F-statistic of 589.545 is very high, with a p-value of 0.000, which shows that the overall model is statistically significant and that the predictors - "How often do last-mile delivery delays affect your project timelines?" and "What is the most frequent last-mile delivery issue you encounter in construction projects?" - are significant in explaining the variation in years of experience. The residual sum of squares is 39.786 with 203 degrees of freedom, indicating that although the model is a good fit, there is still some unexplained variability.

Generally, the results indicate that last-mile delivery delays and challenges have a strong impact on years of experience in the construction sector. The coefficients table provides

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

further insights into the relationship between last-mile delivery challenges, delivery delays, and years of experience in the construction sector. The constant value of -0.303 represents the expected years of experience when both predictor variables are zero. However, this value does not carry meaningful interpretative significance unless it is statistically significant. The coefficient for the variable "What is the most frequent last-mile delivery difficulty that you experience on construction projects?" is 0.251, with a standardized beta of 0.264.

Table 4: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.303	.088		-3.448	.001
	What is the most common last-mile delivery challenge you face in construction projects?	.251	.035	.264	7.245	.000
	How frequently do last mile delivery delays impact your project timelines?	.947	.048	.725	19.913	.000
a. Dependent Variable: How many years of experience do you have in the construction industry?						

Source: Compiled by authors

This suggests that a one-unit increase in reported last-mile delivery difficulties is associated with an increase of approximately 0.251 years in construction experience. The corresponding t-value of 7.245 and p-value of 0.000 confirm that this predictor is statistically significant. This finding implies that industry professionals with greater experience tend to report a higher awareness of last-mile delivery challenges. Similarly, the coefficient for "How often do last-mile delivery delays affect your project timelines?" is 0.947, with a standardized beta of 0.725, indicating a stronger association with years of experience.

Table 5: One-Sample Test Results for VRP, GPS, and JIT

Variable	t-Value	Sig. (2tailed	Mean Difference	95% Confidence Interval
VRP (Vehicle Routing Problem	22.98	0	1.87	1.71 - 2.03
GPS (Global Positioning System	22.08	0	2.05	1.87 - 2.23
JIT (Just-In-Time Delivery)	22.01	0	2.03	1.85 - 2.22

Source: Compiled by authors

A one-unit increase in the frequency of delivery delays corresponds to an approximate 0.947-year increase in industry experience. The t-value of 19.913 and p-value of 0.000 confirm that this predictor is also highly significant. The larger standardized beta suggests that the frequency of last-mile delivery delays has a more pronounced association with industry experience compared to general last-mile difficulties. Overall, the results indicate that both last-mile delivery challenges and the frequency of delivery delays are significantly associated with

DOI: 10.17492/JPI/NICMAR/2507101 *ISBN: 978-93-49790-54-4*

years of experience in the construction sector. However, this analysis does not establish a causal relationship but rather suggests that more experienced professionals are more likely to encounter and recognize such logistical issues. Among the two predictors, the frequency of last-mile delivery delays exhibits a stronger association with years of experience, highlighting its dominant role in last-mile logistics concerns within the construction industry.

Table 6: SWOT Analysis of Last-Mile Delivery Optimization (JIT, GPS, VRP) (Tezel *et al.*,2020)

Category	Key Factors	Implications
Strengths	Optimized Delivery Routes & Cost Savings	VRP is capable of saving up to 20% on fuel and travel time, which reduces operational expenses.
	Real-Time Visibility & Tracking	GPS incorporation increases delivery tracking and supply chain transparency.
	Reduced Material Handling & Storage Costs	JIT reduces handling and storage expenses by ensuring that materials only arrive when needed.
	Enhanced Supplier Coordination	Improved material scheduling minimizes delays and increases supplier dependability.
	Environmental & Regulatory Benefits	In compliance with green logistics regulations, VRP route optimization reduces carbon emissions.
Weaknesses	High Initial Implementation Cost	JIT logistics, GPS tracking, and VRP software all demand a large upfront cost.
	Need for Skilled Workforce & Training	VRP system adoption may be slowed by the need for employee training.
	Integration Issues with Existing Systems	Proper deployment may be delayed by incompatibilities with legacy logistical software.
	Scalability Challenges in Large Projects	Large-scale dynamic projects are difficult for VRP to handle, whereas JIT relies on precise forecasting.
Opportunities	Predictive Analytics & AI Integration	Real-time decision-making and route optimization are improved by AI-driven dynamic VRP models.
	Government Incentives for Smart Logistics	Adoption of JIT, GPS, and VRP is financially rewarded by policies which encourage smart logistics.
	Autonomous & Smart Delivery Systems	In constructing logistics, drones and automated vehicles increase last-mile efficiency.
	Expanding JIT & VRP in Construction	Equipment handling and staff scheduling are two areas where JIT principles can be applied.
Threats	Cybersecurity & Data Risks	Cloud-based VRP systems and GPS tracking are susceptible to hacking and cyberattacks.
	Unexpected External Delays	Last-mile efficiency can be impacted by weather-related delays, traffic jams, and supplier reliability problems.
	Resistance to Change	AI-based route optimization may be resisted by conventional logistics teams.
	Regulatory Uncertainty	Implementation may be impacted by legal limitations on GPS data usage and autonomous delivery.

Source: Compiled by authors

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

Table 5 gives the statistical findings that evaluate the efficacy of three alternative systems— Vehicle Routing Problem (VRP), Global Positioning System (GPS), and Just-in-Time (JIT) delivery systems - for optimizing delivery routes. The t-values for each of the three variables are strongly positive (22.98 for VRP, 22.08 for GPS, and 22.01 for JIT), showing strong statistical evidence that the three systems make a significant difference in the process of optimizing deliveries. The p-values (Sig. 2-tailed) for all three systems are 0.000, which is significantly less than the standard significance level of 0.05, further indicating that the results are statistically significant. The mean differences found - 1.87 for VRP, 2.05 for GPS, and 2.03 for JIT illustrate that all three systems result in a significant improvement in optimizing routes for delivery. The three systems are of similar effectiveness in cutting down inefficiencies in route planning. The 95% confidence intervals for all three mean differences (1.71-2.03 for VRP, 1.87-2.23 for GPS, and 1.85-2.22 for JIT) add to the confidence that the observed effects are not only consistent but also reliable. In summary, the evidence clearly testifies to the aim of determining the efficiency of these routing algorithms, GPS technology, and JIT delivery systems in optimizing delivery routes, as their impact on operational efficiency is evident and considerable.

5.0 Conclusion

The conclusions of this study present an exhaustive overview of the issue of last-mile delivery in construction projects and identify the efficiency of Vehicle Routing Problem (VRP) algorithm, Global Positioning System (GPS) tracking system, and Just-In-Time (JIT) delivery practices in optimizing logistics operations. The research affirms that last-mile logistics inadequacies are a major reason for initiating project delays, cost escalation, and supply chain disruption, hence the need to implement advanced technological tools to make material transport more efficient and remove inefficiencies. Statistical analysis in this research reveals that delivery delays have a significant impact on project duration, with a mean effect of 1.859 and a t-value of 30.308 ($p = 0.000$).

Similarly, delivery inefficiencies (mean = 2.481, t = 25.898, $p = 0.000$) are also reasons for increased project duration and cost overruns. The findings identify the pressing need for construction companies to enhance their logistics management practices. The results also confirm the effectiveness of advanced logistics technologies in optimizing last-mile delivery operations. The use of Vehicle Routing Problem (VRP) algorithms greatly enhances delivery efficiency, as reflected in a t-value of 22.98 and a mean difference of 1.87 ($p = 0.000$), thus highlighting that optimized route plans can reduce delays and fuel consumption. GPS tracking is a key driver of supply chain visibility, as it enables real-time monitoring of the movement of materials, thus reducing the occurrence of misplaced items and enhancing delivery accuracy (t = 22.08, mean difference = 2.05, $p = 0.000$). In addition, the JIT supply system minimizes over-storage and material handling to the bare minimum, such that resources are accessed at the point

DOI: 10.17492/JPI/NICMAR/2507101 ISBN: 978-93-49790-54-4

of need and thus increase site productivity (t = 22.01, mean difference = 2.03, p = 0.000). Regression and analysis of variance (ANOVA) analysis also indicate that experience levels have a major role in the determination of last-mile delivery inefficiencies. ANOVA results (F = 589.545, p = 0.000) indicate that increased levels of experience among industry practitioners enable them to better understand such inefficiencies and the resulting delays on project timeliness. Additionally, regression analysis indicates that delay frequency in last-mile delivery (B = 0.947, β = 0.725, p = 0.000) indicates the highest correlation with project inefficiencies and thus must be a major area of concern for construction firms.

A SWOT analysis here reveals strategic implications for maximizing last-mile delivery in construction logistics. The advantages of VRP, GPS, and JIT are cost reduction, enhanced tracking, and enhanced coordination with suppliers, all of which lead to enhanced operational efficiency and project success. Some of the weaknesses like excessive initial implementation costs, training needs, and integration issues are also highlighted in the research. Aside from these challenges, however, are opportunities in AI-based predictive analytics, government support, and autonomous delivery systems like drones that could further maximize last-mile logistics efficiency. Overall, this research illustrates how the integration of VRP, GPS tracking, and JIT delivery systems creates a substantial boost in last-mile logistics efficiency in construction projects. Despite cost, labor adaptation, and regulatory barriers associated with integration, the advantages of minimizing project delays, cost streamlining, and enhancing supply chain sustainability outweigh the constraints considerably. The research offers a strategic model for policymakers, construction managers, and logistics experts to boost last-mile delivery efficiency, making future projects more predictable, cost-efficient, and environmentally friendly. By embracing technology-based logistics management, the construction sector can overcome conventional inefficiencies, enhance project performance, and create a more robust and competitive model of operations.

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