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TECHNOLOGY-ENABLED REVERSE LOGISTICS FOR COST-EFFICIENT DEPLOYMENT OF DIGITAL LEARNING INFRASTRUCTURE: EVIDENCE FROM BUILDING PROJECTS IN ABUJA, NIGERIA

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Abstract

The expansion of open and distance learning (ODL) in developing contexts depends heavily on the efficient deployment of digital learning infrastructure, including mobile devices, low-bandwidth connectivity equipment, and virtual lab tools. Effective management of reverse logistics (RL),the backward flow of materials involving transportation, warehousing, handling, and cost control,is critical to containing costs during infrastructure rollout. This study evaluates the cost implications of RL activities in building projects within Abuja, Nigeria, and explores how technology-enabled solutions can enhance cost performance. Primary data were collected from 25 construction professionals at active building project sites using a structured questionnaire. Descriptive statistics were used to profile cost intensity across five RL activity dimensions: transportation, warehousing, material handling, time management, and cost management. Results indicate that transportation is the most cost-intensive RL activity (60% of responses in the high-cost category of N1 million and above), followed by warehousing and material handling (48% each). Cost management also shows notable intensity (44% high-cost), while time management is largely perceived as low-cost (64% low-cost; 8% high-cost). These cost pressures can be mitigated through digital logistics platforms, route optimisation software, real-time inventory tracking systems, and data-driven cost-monitoring tools . The findings indicate that RL cost exposure in Abuja projects is driven primarily by the physical logistics requirements of reverse flows, movement, consolidation, storage, and handling, rather than administrative effort alone.The study concludes that integrating technology into reverse logistics operations is essential for achieving cost-efficient deployment of digital learning infrastructure. The findings offer practical insights for ODL institutions, policymakers, and project managers seeking to scale technology-enhanced learning in resource-constrained environments.

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Keywords: Reverse logistics, technology-enabled logistics, digital learning infrastructure, cost performance, distance learning, Abuja, Nigeria.

Introduction

Reverse logistics involves planning, executing, and monitoring the movement of materials, parts, and finished products back from where they are used to points of recovery, reuse, recycling, remanufacturing, or proper disposal (de Brito and Dekker, 2004). Within construction, RL is gaining relevance to circular-economy objectives as it helps extract remaining value from demolition and construction waste, eases pressure on landfills, and enhances resource efficiency across a project's lifespan. Scholarship shows that attention to RL in construction has grown significantly in recent years. However, putting it into practice is still difficult due to fragmented supply chains, underdeveloped markets for recovered materials, poor data visibility, and the lack of RL considerations in project planning and control processes (Chen *et al.,* 2024; Huang *et al.,*

2025). While RL is already well established in manufacturing and retail, its adoption in construction is still behind. This gap matters because construction is unique, it deals with bulky materials, multiple scattered sites, unpredictable quantities of returns, and short-term project setups, all of which can drive up the cost of managing reverse flows.

Chileshe *et al.* (2016) also noted that RL adoption in construction remains low. In Nigeria specifically, research on RL is scarce. Existing Nigerian studies have mainly examined how RL connects to economic performance (Somuyiwa and Adebayo, 2014), environmental sustainability (Oko and Nkannebe, 2013), and waste management (Amole *et al.,* 2018). More recent work on the circular economy and waste reduction points to rising awareness of material recovery and efficient resource use (Unegbue *et al.,* 2025). Despite this, there is still little empirical data on how RL activities affect costs at the level of individual construction projects.

Recent advances in digital logistics technologies, including route optimisation software, radio-frequency identification (RFID) tracking, cloud-based inventory management systems, and real-time cost monitoring dashboards, offer new opportunities to address the cost challenges associated with reverse logistics (Govindan *et al.,* 2015; Namweseza *et al.,* 2024). These technologies enable project managers to improve visibility into reverse material flows, consolidate shipments more efficiently, reduce handling delays, and track expenditures with greater precision (Sun *et al.,* 2024; Amir *et al.,* 2025). In the context of distance learning infrastructure deployment, such technology-enabled reverse logistics systems are particularly valuable. The rapid scaling of mobile learning devices, low-bandwidth connectivity equipment, and virtual lab tools across dispersed locations requires robust reverse flows to recover, refurbish, and redeploy assets cost-effectively (Chen *et al.,* 2024). Without technological support, the logistical costs of managing these reverse flows may undermine the sustainability of digital education initiatives (Huang *et al.,* 2025).

The intersection of reverse logistics technology and distance learning infrastructure is an emerging area of inquiry. As open and distance learning (ODL) institutions increasingly adopt blended and fully online models, the demand for physical learning devices, connectivity hardware, and simulation tools has grown substantially (Unegbue *et al.,* 2025). Efficiently managing the lifecycle of these assets, from initial distribution to recovery, repair, and redeployment, requires reverse logistics systems that are both cost-effective and technologically sophisticated (Aguirre Rodríguez *et al.,* 2024). This study contributes to this gap by examining the cost dimensions of RL activities in construction projects, which share similar logistical characteristics with large-scale digital infrastructure deployment, and by exploring the potential for technology to enhance cost performance (Chileshe *et al.,* 2016; Hassan and Osman, 2025).

In alignment with contemporary discussions on technology and innovation in distance learning (Chen *et al.,* 2024; Huang *et al.,* 2025), this study recognises that reverse logistics cannot be treated as a purely operational concern. Rather, it must be integrated with digital tools such as route optimisation algorithms, real-time tracking systems, and data-driven cost management platforms. These technologies have been shown to reduce cost intensities in transportation, warehousing, and material handling across various supply chain contexts (Govindan *et al.,* 2015; Sun *et al.,* 2024). By extending these insights to the domain of distance learning infrastructure, this study provides empirical evidence from Abuja, Nigeria, on how technology-enabled reverse logistics can support cost-efficient scaling of digital education.

Against this background, this study examines the cost implications of reverse logistics activities on construction project management throughout a project lifecycle in Abuja, Nigeria.

By focusing on transportation, warehousing, material handling, time management, and cost management (Bello *et al.,* 2026). The study also explores technology-enabled approaches that can help address the identified cost pressures and support cost-efficient deployment of digital learning infrastructure. The study was guided by the following research questions: (1) What are the perceived cost implications of transportation, warehousing, material handling, time management, and cost management as reverse logistics activities in building projects in Abuja? (2) What technology-enabled approaches can be applied to improve the cost performance of reverse logistics activities in building projects in Abuja?

Materials and Methods

A descriptive survey research design was adopted to examine how construction professionals perceive the cost implications of reverse logistics activities in building projects. The research population comprised active building construction projects within the Abuja Municipal Area Council (AMAC), executed under private-sector, government, and NGO ownership (Bello *et al.,* 2026). Purposive sampling was used because the study required respondents with direct, informed experience of project delivery and reverse material-flow decisions. The sampling process proceeded in four steps: first, active building projects within AMAC were identified; second, projects were screened to confirm that they were active and fell within the stated ownership categories; third, projects were further screened for accessibility and the availability of construction professionals directly involved in project delivery and material-flow decisions; and fourth, 25 projects that met these criteria were purposively selected. One knowledgeable professional was targeted from each selected project, resulting in a sample of 25 respondents. The final sample size therefore reflects the number of eligible and accessible project sites selected through the stated purposive criteria rather than a statistical sample-size formula.

The sole data-collection instrument was a structured questionnaire titled "Structured Questionnaire on the Cost Implications of Reverse Logistics Activities in Construction Project Management." The questionnaire comprised two main sections. Section A captured relevant respondent and project characteristics, while Section B obtained respondents' assessments of the cost implications of five reverse logistics activity dimensions: transportation, warehousing, material handling, time management, and cost management. Responses were classified into three cost bands: low (<₦500,000), medium (₦500,000–₦1,000,000), and high (₦1,000,000 and above). Before field administration, the questionnaire was subjected to expert review for clarity, relevance, content coverage, and alignment with the study objectives. It was also trial-tested with a small group of construction professionals who were not included in the final sample, and feedback from the trial test was used to refine ambiguous wording and confirm the suitability of the response categories. A total of 25 valid responses were obtained and analysed using descriptive statistics, specifically frequencies and percentages, to summarise the perceived cost intensity of RL activities.

Results

Cost implications of reverse logistics activities on construction project management.

Table 1 summarizes how respondents perceived the cost implications across five dimensions of reverse logistics. Transportation emerged as the costliest activity, with 60% of respondents rating it as high-cost, while 12% rated it medium-cost and 28% rated it low-cost. This indicates

that moving materials back from sites is a major cost driver in Abuja projects, likely due to scattered pickup schedules, several handling stages, and limited chances to consolidate routes. Warehousing and material handling also showed high-cost burdens, with 48% of respondents categorizing each as high-cost. This suggests that temporary storage, sorting, safeguarding, loading, unloading, and moving recovered materials within sites create significant financial pressure on projects. Cost management was also seen as expensive, with 44% of responses placing it in the high-cost category. This reflects that tracking, coordinating, and controlling RL-related expenses demands considerable resources on their own. By contrast, time management was largely viewed as low-cost. About 64% of respondents rated it low-cost, with just 8% rating it high-cost.

Discussion

These results show that in the study area, the main cost challenges of reverse logistics stem from physical operations rather than administrative coordination (Bello *et al.,* 2026). This finding matches recent studies which argue that RL in construction is still limited by fragmented supply chains, poor recovery infrastructure, and the failure to integrate reverse-flow requirements into project planning (Chen *et al.,* 2024; Huang *et al.,* 2025). The strong emphasis on transportation, warehousing, and material handling in this study is also in line with wider RL research, which highlights that the quality of logistics information, formalized processes, and operational flexibility are key to improving both cost efficiency and supply chain performance (Namweseza *et al.,* 2024). For project management, the takeaway is straightforward: RL needs to be built into the early stages of planning, procurement, site logistics, and storage layout. This way, decisions about material returns and recovery are not treated as costly last-minute fixes. Practical steps such as improved route planning, segregation of materials on site, proper design of temporary storage, and consolidating recoverable items can help cut unnecessary costs and make RL interventions more financially viable in construction projects.

Table 1: Cost implications of reverse logistics activities

S/N	Reverse Logistics Activities	< 500k (Low)	%	500k - 1million (Medium)	%	1million and Above (High)	%	Total
1	Warehousing	5	20	8	32	12	48	**25**
2	Transportation	7	28	3	12	15	60	**25**
3	Material Handling	8	32	5	20	12	48	**25**
4	Time Management	16	64	7	28	2	8	**25**
5	Cost Management	6	24	8	32	11	44	**25**

Source: Authors.

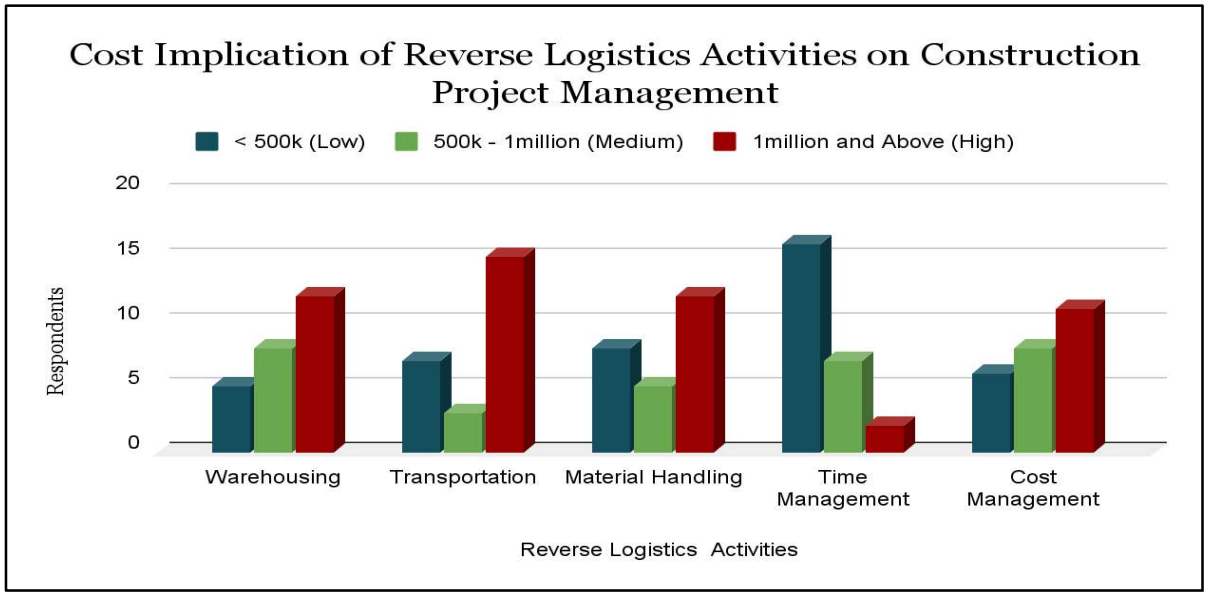


Figure 1: Cost implications of RL activities on construction project management
Source: Authors.

Conclusion

This study has shown that reverse logistics activities have clear cost implications for construction project management in Abuja, Nigeria. Among the activities examined, transportation emerged as the most cost-intensive, followed by warehousing, material handling, and cost management, while time management was perceived to impose relatively lower direct costs. The overall pattern demonstrates that the major financial burden of reverse logistics lies in the physical organisation of reverse flows, especially the collection, movement, storage, sorting, and handling of returned or recoverable materials.

The implication is that project teams cannot treat reverse logistics as an informal or incidental activity if they expect it to contribute positively to cost performance. Rather, RL requirements should be incorporated into project planning from the outset through deliberate routing plans, consolidation strategies, site layout decisions, temporary storage arrangements, and clearer cost-monitoring procedures. When these controls are absent, the benefits of material recovery and waste reduction may be offset by avoidable logistics costs. Conversely, when reverse flows are anticipated and managed systematically, RL can support both economic and environmental objectives.

This study underscores the critical role of technology in transforming reverse logistics from a cost burden into a strategic enabler. Digital tools such as route optimisation algorithms, real-time tracking systems, integrated cost management platforms, and cloud-based inventory solutions offer practical pathways to reduce the high-cost intensities observed in transportation, warehousing, and material handling.

For ODL institutions, policymakers, and project managers, investing in technology-enabled reverse logistics infrastructure is not merely an operational consideration but a prerequisite for sustainable scaling of digital learning. As distance education continues to expand across Nigeria and other developing regions, the ability to deploy, recover, and redeploy digital learning assets

efficiently will determine the long-term viability and reach of technology-enhanced learning initiatives.

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