International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2025.0272
e ISSN: 2584-2854
Volume: 03
Issue: 05 May 2025
Page No: 1697 - 1711

Utilization of Construction 4.0 Technologies in Small-Scale Supply Chain Management: An Approach for Enhancing Productivity

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Abstract
This study explores the implementation of Construction 4.0 technologies in small-scale construction supply chain management through a web-based application. Developed using the MERN stack, the platform enhances material tracking, inventory management, order forecasting, and credit management. A 30-day trial involving small-scale contractors and suppliers demonstrated significant improvements in workflow efficiency, communication, and financial tracking. The system streamlines operations, reduces manual errors, and enhances decision-making, contributing to higher productivity and transparency. This research highlights the potential of digital transformation in small-scale construction projects and paves the way for further advancements in supply chain management.
Keywords: *Construction 4.0, Supply Chain Management, Web-Based Application, Digital Transformation, Workflow Efficiency, Inventory Management.*

1. Introduction

The construction industry has long been characterized by its reliance on traditional methods, particularly in small-scale construction firms. These firms, which often operate with limited resources, face persistent challenges in supply chain management due to inefficiencies, waste generation, and a lack of productivity. Despite the transformative potential of digital technologies, such as those encompassed by Construction 4.0, small-scale construction businesses lag behind in digital adoption. This digital divide exacerbates their challenges, leaving them at a competitive disadvantage in an increasingly dynamic and demanding market. Construction 4.0 refers to the integration of advanced technologies, such as the Internet of Things (IoT), Building Information Modeling (BIM), cloud computing, and automation, to revolutionize traditional construction processes. These innovations promise significant benefits, including enhanced supply chain visibility, reduced material waste, improved project timelines, and cost optimization. However, small-scale construction firms often struggle with adopting these technologies due to barriers such as high implementation costs, lack of awareness, and insufficient technical expertise. This review aims to bridge the knowledge gap by exploring the applicability of Construction 4.0 technologies to the supply chain management of small-scale construction firms. Through a comprehensive literature survey, key barriers to the adoption of digital tools have been identified, highlighting the need for tailored solutions to meet the unique needs of these firms. To further investigate current practices, a questionnaire survey will be conducted targeting engineers and suppliers within the small-scale construction supply chain. The findings will guide the development of a user-friendly web-based application designed to address specific challenges and streamline supply chain operations. By leveraging digital transformation through Construction 4.0 technologies, this study seeks to empower small-scale construction firms to overcome operational inefficiencies, reduce costs, and enhance their competitive positioning. This

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review sets the foundation for a practical, scalable solution that aligns with the evolving demands of the construction industry. [1]

1.1. SCM: The Role in Construction

Supply Chain Management (SCM), initially developed for the manufacturing industry, plays a critical role in managing business processes systematically to enhance quality, reduce time, and boost profitability (Wisner et al., 2011). In contrast, the adoption of SCM practices within the construction sector remains fragmented and limited. Akintoye et al. (2000) highlighted in their study that the interactions between clients, suppliers, and contractors are predominantly centered around procurement and production planning. This indicates that SCM has only been partially integrated into the construction industry in the UK. Additionally, Vrijhoef and Koskela (2000) emphasized the significance of SCM in construction, identifying four primary roles it serves. These roles are determined by the focus of industry challenges, whether related to the broader supply chain, the construction site, or both, as illustrated in (Figure 1)

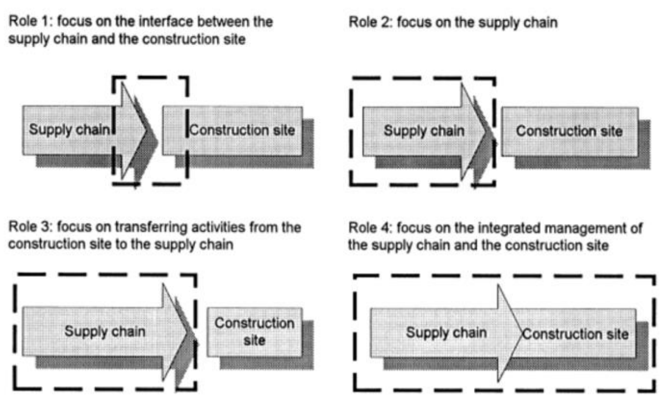

Figure 1 Supply Chain Management Role in Construction (Vrijhoef and Kosksela, 2000)

1.2. Construction Supply Chain Characteristics

Construction supply chains (CSC) in small-scale projects are inherently complex, despite their relatively smaller scope compared to large-scale endeavors. This complexity is driven by the diverse range of materials and the numerous stakeholders, including suppliers and subcontractors, that must collaborate to complete the project. As small-scale projects often rely on a mix of first-tier, second-tier, and other subcontractor tiers, the supply chain becomes intricate, requiring significant coordination. While smaller projects may involve fewer resources than large ones, the challenges of planning, organizing, and fostering collaboration among stakeholders remain equally significant. The relationship between project scope and supply chain complexity is also evident in small-scale construction. As the scope grows, even modestly, more materials, manpower, and parties become necessary, adding to the coordination burden. For example, small construction firms often interact with multiple suppliers and subcontractors annually, necessitating efficient supply chain management to minimize delays and costs. However, limited resources and reliance on traditional practices often impede the adoption of streamlined processes, intensifying challenges for small firms.

Vrijhoef (1998) studied construction supply chains in residential building projects and identified several key characteristics that also apply to small-scale CSCs:

- **Converging Supply Chain:** Small-scale construction supply chains are converging in nature, meaning all materials, documentation, and resources must be delivered to the site by suppliers and subcontractors under the main contractor's supervision. This creates a centralized flow of resources to serve a single or limited group of end users.
- **Make-to-Order Supply Chain:** Like large projects, small-scale construction is client-driven, with the end user initiating the project. This often leads to the client being directly involved in key decisions throughout the construction process.
- **Fragmented Supply Chain:** The fragmentation in small-scale projects is pronounced due to the involvement of multiple, often temporary, participants. Contractors, suppliers, and other stakeholders operate at different stages of the project, frequently resulting in unclear authority and divided responsibilities.

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- **Temporary Supply Chain:** Small-scale construction supply chains are highly transient. Once a project concludes, the teams and suppliers involved are usually dismissed. This short-term nature can lead to inefficiencies, such as inconsistent performance or gaps in knowledge transfer across projects.

Muya et al. (1999) identified additional features that are particularly relevant to small-scale construction supply chains:

- **Primary Supply Chain:** Delivers core materials and components such as raw materials, sub-assemblies, and basic equipment required for project completion.
- **Support Chain:** Provides essential resources, such as tools and minor equipment, that simplify construction processes. Small firms often rely heavily on these chains due to limited in-house resources.
- **Human Resource Supply Chain:** Ensures the availability of skilled labor and supervisory staff, which is crucial for maintaining efficiency in smaller projects where teams are lean.

In small-scale construction, these supply chain elements face unique challenges. Limited digitalization and dependence on traditional methods exacerbate inefficiencies, including material wastage and coordination delays. Additionally, the temporary and fragmented nature of small-scale supply chains makes collaboration and communication between stakeholders particularly challenging.

1.3. Small-Scale Construction Supply Chains and Construction Industry Problems

The construction industry, particularly in the context of small-scale construction supply chain (CSC) management, faces numerous challenges that significantly hinder its efficiency and growth. Yeo and Ning (2002) identified several persistent problems, including budget overruns, project delays, low profit margins, and frequent legal disputes. Vrijhoef and Koskela (2000) further attributed these issues to the narrow and short-term focus often applied to the control of construction supply chains, which exacerbates inefficiencies and waste. These issues are often more pronounced in small-scale construction due to limited resources and fragmented supply chain practices. From a demand-supply perspective, Cox, Ireland, and Townsend (2006) categorized construction industry challenges into demand-related issues, supply-related issues, and common challenges. These problems are equally relevant and often more impactful in the small-scale sector due to its constrained operations and reliance on traditional methods:

1.4. Demand-Related Issues in Small-Scale CSCs

- **Inappropriate Selection Criteria:** Small-scale projects often award contracts based solely on the lowest price, ignoring the overall value offered by contractors. This practice can result in substandard quality, reduced trust, resistance to necessary design changes, and additional claims for unforeseen costs.
- **Discontinuous and Low Demand:** Economic downturns or unstable markets disproportionately impact small-scale construction firms, leading to sporadic demand for services and financial instability. This limits their ability to sustain long-term operations or invest in process improvements.
- **Inappropriate Allocation of Risk:** Risk distribution in small-scale projects is often skewed, with clients shifting disproportionate responsibilities onto contractors. This creates financial and operational strains on small firms.
- **Frequent Changes in Specification:** Clients frequently altering project specifications mid-construction pose significant challenges to small-scale firms, often leading to cost overruns and delays due to limited flexibility and resources.
- **Public Image:** Small-scale firms struggle to attract skilled professionals due to perceptions of low job security, limited career advancement, and poor working conditions within the construction industry.
- **Inefficient Construction Methods:** Small firms often face difficulties integrating design and construction processes effectively,

e ISSN: 2584-2854
Volume: 03
Issue: 05 May 2025
Page No: 1697 - 1711

leading to inefficiencies and reduced buildability. This is especially common in sectors like residential housing, where outdated practices persist.

- **Poor Quality:** A lack of stringent entry regulations allows inexperienced firms to compete in the small-scale construction market, undermining quality and tarnishing the reputation of the sector as a whole. Common Issues in Small-Scale CSCs
- **Fragmented Industry Structure:** The reliance on multiple layers of subcontractors, many of whom lack proper training or experience, leads to fragmentation. Small-scale projects often suffer from poorly coordinated workflows and unmet specifications due to unqualified subcontractors being involved.
- **Adversarial Culture:** Adversarial relationships between clients, contractors, and subcontractors are common in small-scale construction. These tensions hinder collaboration, reduce trust, and impede the adoption of modern procurement practices.
- **Inadequate Investment in Training:** Limited budgets in small-scale firms often mean minimal investment in staff training or research and development. This leads to stagnation and a lack of innovation, further reducing competitiveness.
- **Poor Management:** Ineffective project and site management are critical issues in small-scale construction. With fewer resources and less oversight, small firms frequently experience delays, cost overruns, and reduced productivity.

1.5. Supply Chain Management Benefits in Small-Scale Construction Supply Chain

Modern approaches to procurement in small-scale construction are increasingly emphasizing integrated supply chains. This approach promotes collaboration and alignment of objectives among all participants in the supply chain, resulting in greater goal congruence and added value for the client. Traditionally, the relationship between small-scale contractors and clients was defined by rigid contracts with predetermined prices and specifications. In this conventional model, clients had limited involvement, contractors often lacked motivation to prioritize client interests, and coordination between contractors and designers was minimal, typically managed through separate agreements. In contrast, adopting integrated supply chain methods within small-scale construction allows Supply Chain Management (SCM) to be more effectively implemented, overcoming the limitations of traditional practices. The benefits of integrated supply chains for small-scale construction firms include:

Streamlined processes reduce material waste and operational inefficiencies, which are critical for small-scale firms operating on tighter budgets.

Improved collaboration and transparency provide greater certainty in project costs, reducing financial and operational risks for smaller projects.

- **Value for Clients:** Integrated approaches ensure better communication and alignment, delivering higher-quality outcomes and improving client satisfaction.
- **Facilitation of Long-Term Planning:** Collaborative relationships enable small firms to engage in more effective project scheduling and resource allocation.
- **Opportunities for Repeat Business:** Satisfied clients are more likely to return for future projects, fostering stability and growth for small-scale firms.

By adopting an integrated supply chain model, small-scale construction firms can improve their service delivery. Clients and end users benefit from timely project completion, reduced costs, and minimized defects, which enhances confidence in the construction process and the industry as a whole. Additionally, Erikson (2010) noted that integrated supply chains offer small construction firms better control over their operations, further aiding in cost reduction and process efficiency.

1.6. The Need of Information Sharing in Construction Supply Chains

In small-scale construction projects, the supply chain can be viewed as comprising two distinct processes: the supply process and the construction process (Friblick 2000; Thunberg 2016). These processes

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Page No: 1697 - 1711

operate on different principles. The construction process, typically following an engineer-to-order (ETO) logic, focuses on designing and executing the project. It involves key actors such as the project developer, who initiates the project, and the main contractor, who organizes and executes it. Small-scale construction projects often involve multiple subcontractors, reflecting the fragmented nature of the industry (Dubois and Gadde 2002; Miller, Packham, and Thomas 2002). Conversely, the supply process often operates under varying production logics, such as make-to-order (MTO), assemble-to-order (ATO), or make-to-stock (MTS) (Hicks, McGovern, and Earl 2000). This diversity adds complexity to small-scale projects, where main contractors must carefully manage lead times and ensure that materials are delivered on schedule to avoid delays. For example, MTO and ATO suppliers typically require more detailed planning due to their longer lead times, whereas MTS suppliers, with inventory readily available, often result in less transport efficiency due to frequent small deliveries (Ying, Tookey, and Seadon 2018). In small-scale construction, coordination between the supply chain actors and the construction site remains challenging. Main contractors are responsible for integrating these processes, yet planning efforts are often skewed towards on-site production rather than supply chain optimization (Ko, Azambuja, and Felix Lee 2016). The fragmented and temporary nature of small-scale construction exacerbates these issues, making effective collaboration and information sharing among stakeholders more difficult (Modig 2007; Dainty, Moore, and Murray 2006). [2]

Key obstacles to efficient small-scale supply chain management include:

- **Limited Information Sharing:** Information on project progress, inventory levels, and delivery schedules is often not effectively communicated between contractors and suppliers, leading to misaligned operations and inefficiencies (Fellows 2009; Shin et al. 2011).
- **Temporary Relationships:** Short-term partnerships in small-scale projects hinder the development of trust and collaboration, making it difficult to build long-term efficiencies (Meng 2012).
- **Manual Processes:** Due to the low level of digitalization in small-scale construction, much of the information flow relies on manual collection and communication, increasing the likelihood of errors and delays (Ko, Azambuja, and Felix Lee 2016).
- **Fragmented Purchasing Practices:** Strategic purchasing decisions are often separated from on-site operational purchasing, leading to inconsistencies in material availability and delayed deliveries (Thunberg and Fredriksson 2018). (Figure 2)

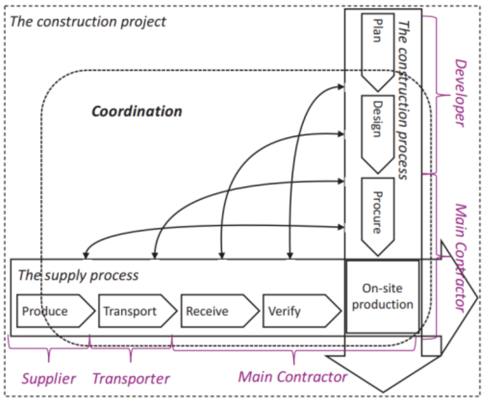

Figure 2 Relationship Between a Construction Project, and its Construction Process and Supply Process, Adapted from Friblick (2000) and Thunberg (2016)

The unique challenges of small-scale construction demand a more integrated approach to supply chain management. Main contractors must foster better coordination with suppliers, including sharing real-time information on project progress, inventory levels, and logistical needs. Effective use of digital tools can mitigate many of these challenges by streamlining communication and enhancing supply chain visibility. Despite these challenges, small-scale construction offers significant opportunities to improve supply chain performance through better collaboration and integration. As Akintoye (1995) highlighted, understanding suppliers' needs and tailoring delivery schedules based on the specific demands of the project are critical to minimizing

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Page No: 1697 - 1711

disruptions and ensuring efficient project execution. Future research should focus on exploring innovative solutions for information sharing and digital adoption tailored specifically to the needs of small-scale construction supply chains. [3-4]

1.7. Industry 4.0 in the Construction Industry

Industry 4.0 represents the fourth industrial revolution, encompassing digitization and automation across various sectors, including manufacturing and construction. Although primarily applied in manufacturing, Industry 4.0 is steadily transforming the construction industry, presenting both opportunities and challenges, particularly in small-scale construction supply chain management (SCM). Small-scale construction projects face unique obstacles, such as highly fragmented supply chains involving multiple small and medium-sized enterprises (SMEs), resource constraints, and project-specific complexities. These factors often result in inefficiencies, delays, and limited adoption of advanced technologies. However, the integration of Industry 4.0 concepts offers solutions to address these challenges effectively. Building Information Modeling (BIM) is one of the central technologies driving digital transformation in construction. For small-scale projects, BIM facilitates better visualization, collaboration, and resource optimization. By leveraging cloud-based platforms, contractors and suppliers can coordinate more effectively, reducing delays and preventing rework. Automation and robotics also play a crucial role in improving productivity and reducing labor costs. Technologies such as robotic bricklayers and 3D concrete printers, while often associated with large-scale projects, can be adapted for smaller projects to enhance efficiency and lower costs. The Internet of Things (IoT) and RFID technology offer affordable solutions for real-time tracking of materials and equipment. These technologies enhance transparency, minimize delays, and streamline inventory management. Similarly, cloud computing and mobile applications provide practical tools for project tracking, communication, and data sharing among stakeholders, ensuring smoother coordination and decision-making. Augmented Reality (AR) and Virtual Reality (VR) further enhance project planning and client engagement. AR can assist in on-site inspections and quality control, while VR allows clients to visualize designs early, reducing the likelihood of changes during construction. Wearable technologies such as smart helmets and glasses also improve safety and communication on-site, making them valuable even for small projects. The benefits of adopting Industry 4.0 technologies in small-scale construction SCM are significant. Cost savings can be achieved through automation, prefabrication, and better inventory management. Improved coordination between contractors and suppliers reduces waste and delays, while digital tools enable more accurate scheduling and resource allocation. Additionally, these technologies enhance safety and client satisfaction, ultimately fostering more efficient and reliable construction processes. Despite these advantages, implementing Industry 4.0 in small-scale construction requires careful planning and phased adoption. SMEs can start with accessible tools such as mobile apps or cloud-based platforms before exploring advanced technologies like robotics or big data analytics. Collaboration among contractors and suppliers can also help share costs and resources, making these innovations more feasible. In summary, while small-scale construction projects face distinct challenges, Industry 4.0 offers transformative potential to streamline supply chain management, improve productivity, and enhance overall project outcomes. By adopting scalable and cost-effective solutions, small-scale construction firms can effectively embrace digital transformation and address the inefficiencies inherent in their operations.

2. Problem Statement

Phishing websites are malicious platforms designed to deceive users into revealing sensitive information such as passwords, credit card numbers, or personal identification by imitating trusted websites. The rapid growth and evolving techniques of phishing attacks have made traditional, rule-based detection methods insufficient, as they often fail to identify new or subtly modified threats in time. This project addresses the need for a smarter, faster solution by developing a machine learning-based model that can automatically detect phishing websites with high accuracy. The system analyzes a range of features extracted from URLs and web page behavior, such as the length of the URL, presence of suspicious characters (e.g., "@" or "-"), use of HTTPS and SSL certificates, age of the domain, redirection patterns, and more. These features are then used to train and evaluate various classification algorithms—including Decision Tree, Random Forest, Support Vector Machine (SVM), and Gradient Boosted Decision Trees (GBDT)—to identify which model performs best. By leveraging these intelligent models, the proposed system can recognize both known and emerging phishing threats, enabling real-time protection for users and significantly reducing their exposure to cyberattacks. [5]

3. Scope and Objective

The objective of this project is to design and implement an intelligent phishing website detection system using machine learning techniques, aimed at enhancing user protection against online scams. The project involves collecting and preprocessing a comprehensive, labeled dataset consisting of both phishing and legitimate websites. Key features—such as url length, presence of special characters, use of https, domain age, redirection patterns, and ssl certificate validity—are extracted to help distinguish between safe and malicious websites. These features are then used to train and evaluate multiple machines learning algorithms, including decision tree, random forest, support vector machine (svm), and gradient boosted decision trees (gbdt), to determine the most accurate and reliable model. The scope also includes assessing model performance using metrics like accuracy, precision, recall, and f1-score to ensure robustness and reliability. The ultimate goal is to develop a scalable, real-time detection system that can be integrated into browsers or security platforms, offering users an automated and efficient way to identify phishing threats. Additionally, the project sets the foundation for future improvements such as real-time updates, adaptive learning from new phishing patterns, and broader integration with cybersecurity tools. [6]

4. Methodology

The project methodology is structured into several well-defined stages to systematically develop an effective phishing website detection system. It begins with data collection, which is the foundation of the model. A comprehensive dataset is gathered from trusted sources such as open repositories, cybersecurity databases, and real-time phishing feeds. This dataset includes labeled entries of both phishing and legitimate websites, each associated with a variety of attributes that describe their behavior and structure. Following data collection, the data preprocessing phase ensures the dataset is clean and consistent. This involves removing duplicate or irrelevant records, handling missing values, and transforming categorical data into numerical format suitable for machine learning models. Important steps like normalization or standardization of data are performed to bring all features to a uniform scale, improving model performance. Additionally, the dataset is split into training and testing subsets to allow for unbiased evaluation of model accuracy. Once the data is prepared, feature selection and extraction is carried out to identify the most informative attributes that contribute significantly to detecting phishing websites. These features typically include URL-based indicators (like length, use of hyphens, presence of '@' symbol), domain information (age, registration length), presence of SSL certificates, use of HTTP vs HTTPS, and other behavioral patterns such as number of redirections or iframe usage. Dimensionality reduction techniques may also be applied to eliminate redundant or less useful features, improving both the speed and accuracy of training. In the model building phase, several machine learning algorithms are implemented and trained using the processed dataset. Common classifiers such as Decision Tree, Random Forest, Support Vector Machine (SVM), and Gradient Boosted Decision Trees (GBDT) are selected based on their performance in classification tasks. Each model is trained on the training data and then tested against the unseen test data to evaluate how well it can generalize to new cases. The evaluation phase is crucial to comparing model performance. Key evaluation metrics include accuracy (overall correctness), precision (true positives vs. predicted positives), recall (true positives vs. actual positives), and F1-score (harmonic mean of precision and recall). These metrics help determine which model

e ISSN: 2584-2854
Volume: 03
Issue: 05 May 2025
Page No: 1697 - 1711

strikes the best balance between detecting phishing websites and minimizing false alarms. Cross-validation may also be used for a more robust assessment of model performance. Once the best-performing model is identified, the project proceeds to the deployment and future enhancement phase. The model can be integrated into web browsers, email filters, or standalone applications to provide real-time phishing detection. Additionally, a feedback mechanism can be introduced to retrain the model periodically with new data, helping it adapt to evolving phishing tactics. Future improvements may also include deep learning integration, user interface development, and real-time alert systems. [7]

5. Pilot Study

Before conducting the full-scale questionnaire survey, a pilot study was carried out to test the clarity, relevance, and effectiveness of the survey questions designed to assess user experience and feedback on the phishing detection system. The pilot involved a small group of selected participants, including IT professionals, students, and individuals with basic internet usage experience, to reflect the diversity of the target user base. The purpose was to ensure that the questions were easily understandable, logically sequenced, and capable of capturing meaningful responses related to system usability, accuracy, trust, and ease of integration. Feedback from the pilot study revealed minor ambiguities in question phrasing and helped refine certain terminologies to avoid misinterpretation. Additionally, the time required to complete the survey was evaluated to ensure it was reasonable and user-friendly. The insights gained from this preliminary phase were crucial in validating the content and structure of the questionnaire, ensuring that the final version would effectively gather reliable and insightful data during the main study. [8]

6. Validation

Validation of the questionnaire through a pilot study played a critical role in ensuring the effectiveness, clarity, and reliability of the survey instrument used in this project. The primary goal of validation was to confirm that each question was clearly understood by respondents, was free from bias or confusion, and effectively aligned with the objectives of the study. During the pilot phase, the questionnaire was administered to a small group of participants who closely represented the target audience, including both technical and non-technical users. Their feedback helped the research team assess whether the questions captured relevant insights about user experience, satisfaction, and perceptions of the phishing detection system. Key issues identified during validation included the use of overly technical terms that were not easily understood by non-specialist users, vague multiple-choice options, and an unclear sequence that caused hesitation among respondents. As a result, several important changes were made: technical jargon was replaced with simpler language, redundant or overlapping answer choices were restructured for clarity, and the flow of questions was revised to follow a more logical and user-friendly progression. These enhancements ensured that respondents could answer questions accurately and comfortably, thus improving the overall quality and validity of the data collected during the main survey. [9]

7. 30 Days Evaluation

The 30-day evaluation phase was a critical part of the project, aimed at testing the real-world effectiveness of the phishing detection system and gathering user feedback through a structured survey. During this period, the system was deployed among a selected group of users who interacted with it under normal usage conditions. These participants included students, working professionals, and general internet users, allowing for a diverse and representative sample. Throughout the evaluation, users were asked to use the system to identify and verify websites, while the system's performance was monitored in terms of detection accuracy, speed, and usability. At the end of the 30-day period, a detailed questionnaire survey was distributed to all participants to collect their feedback. The survey focused on key areas such as user satisfaction, system ease of use, accuracy of phishing detection, clarity of alerts, and overall trust in the system. Responses were collected on a Likert scale along with open-ended comments to capture both quantitative and qualitative insights. The feedback revealed a high level of user satisfaction, particularly with the system's ability to detect

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Issue: 05 May 2025
Page No: 1697 - 1711

suspicious sites quickly and intuitively. However, some users suggested additional features like mobile compatibility, real-time browser alerts, and customizable security levels. The survey results were instrumental in validating the practical value of the system and highlighting areas for future enhancement, ultimately confirming that the tool had strong potential for real-world application and user acceptance. [10-13]

8. Final Survey

8.1. Ideology on the Questionnaire Structure

The final survey in the study was designed to evaluate the effectiveness, usability, and acceptance of the newly developed web application for supply chain management compared to traditional methods. Participants were first asked to compare their overall experience using the web application versus the conventional supply chain process, allowing researchers to assess perceived improvements in efficiency and user satisfaction. The follow-up question inquired whether the application had improved their workflow, aiming to understand its practical impact on daily operations. To identify specific strengths, users were then prompted to list the top three advantages they noticed, which could include features like real-time updates, automation, or user-friendly design. Conversely, they were also asked to describe the main challenges they encountered while using the system, helping developers pinpoint usability issues or technical shortcomings. A key question asked whether participants would prefer the web application over traditional methods, providing insight into the tool's acceptance and potential for broader adoption. Finally, respondents were invited to suggest improvements or new features, ensuring user-driven development and refinement of the application. Collectively, these questions aim to gather both qualitative and quantitative feedback to guide the enhancement and potential scaling of the digital supply chain solution. [14-16]

8.2. Rating Form

As part of the evaluation process for the developed web-based supply chain management application, the study incorporated three Buyer Rating Forms and three Supplier Rating Forms. These instruments were designed to capture structured feedback from users who engaged with the application in simulated buyer and supplier roles. The Buyer Rating Forms focused on assessing the system's ability to facilitate key procurement activities, including order placement, communication efficiency, transaction tracking, and satisfaction with supplier interactions. Participants evaluated criteria such as product quality, delivery timelines, and overall user experience. Conversely, the Supplier Rating Forms aimed to evaluate the supplier-side functionalities of the application, emphasizing the ease of order reception, clarity of buyer communication, fulfillment efficiency, and workflow support. Collectively, these rating forms served as vital tools for analyzing the system's operational effectiveness from both ends of the supply chain. The dual-perspective assessment provided comprehensive insights into the application's strengths, usability, and areas requiring improvement, thereby guiding iterative design enhancements and validating the tool's practical applicability in real-world supply chain scenarios. [17]

8.3. Survey Reports

The post-simulation survey responses collected from participants offer rich qualitative insights into user perceptions of the web-based supply chain application. Participants were asked to reflect on various aspects of the system by responding to open-ended questions designed to compare it against traditional supply chain methods, assess workflow impact, identify advantages and challenges, state preferences, and suggest improvements. One of the key survey questions asked participants to compare their experience using the web application with traditional supply chain methods. Responses overwhelmingly highlighted increased efficiency, better tracking, and centralized data visibility as major improvements offered by the web application. Several users emphasized that the platform simplified what is traditionally a fragmented and manual process by integrating various steps—from order creation to delivery tracking—into a streamlined, digital workflow. Respondents appreciated the real-time updates and reduced dependency on manual communication, such as email or phone calls, which

e ISSN: 2584-2854
Volume: 03
Issue: 05 May 2025
Page No: 1697 - 1711

often cause delays in traditional systems. When asked whether the application improved their workflow, most participants responded positively, indicating that the application reduced redundancies and errors, improved communication speed, and provided better access to historical data for future decision-making. One participant mentioned that “workflow was much smoother, and errors in order fulfillment were significantly reduced,” which speaks to the system’s potential for improving operational accuracy and speed. In identifying the top three advantages of the web application, the most commonly mentioned features were: Real-time order tracking and visibility, Ease of communication between buyers and suppliers, Centralized and accessible record-keeping, these responses affirm that the system's design successfully targeted and alleviated common bottlenecks in traditional supply chain operations. Conversely, participants were also asked about the biggest challenges or difficulties faced while using the application. Some users mentioned initial difficulties with navigation and system familiarity, highlighting a learning curve during the first use. A few respondents suggested that the user interface could be improved for intuitiveness. Others pointed out occasional system lag and the need for more detailed error messages when transactions failed. These issues indicate the need for user experience refinements and technical optimizations in future iterations. When asked whether they would prefer using the web application over traditional supply chain methods, the majority of participants indicated a strong preference for the web application. Their reasoning centered around time savings, clarity of transactions, and reduced communication overhead. This preference underscores the application’s ability to modernize and streamline supply chain interactions. Lastly, in response to the question about suggested improvements or additional features, participants proposed the inclusion of mobile compatibility, advanced reporting features, and alerts or reminders for pending tasks. These suggestions reflect a desire for greater flexibility, data-driven decision-making, and proactive task management, pointing toward the next stage of development. [18]

8.4. Understanding the Rating form

The post-implementation survey responses collected from participants offer a nuanced understanding of the web-based supply chain management application’s performance and user acceptance. Participants who interacted with the system in simulated buyer and supplier roles provided detailed feedback on its usability, effectiveness, and areas requiring enhancement. A consistent theme across the responses was the application’s ability to streamline traditional supply chain operations. Users reported increased efficiency in handling transactions, with significant time savings attributed to real-time order tracking, centralized communication, and automated documentation. Many participants noted that the application reduced delays and minimized miscommunication, which are common challenges in traditional supply chain systems. The application was also praised for its ability to enhance visibility across the supply chain process. Buyers expressed satisfaction with how clearly the system displayed transaction histories, delivery timelines, and product specifications. Suppliers, in turn, appreciated the structured process for receiving and fulfilling orders. (Figure 3)

Avg Rating and % of Improvement - SUPPLIER			
Factors	**Avg. (Traditional**	**Avg. (Web App**	**% Improvemen**
Accurate Order Forecasting	1.7	4.7	180%
Process Efficiency & Productivity	2.0	4.7	133%
Supplier & Engineer Satisfaction	2.0	4.7	133%
Supplier Relationships (Offerings from Suppliers)	2.3	5.0	114%
Inventory Management	2.3	4.7	100%
Use of Technology for Tracking	2.3	4.7	100%
Proper Scheduling and Planning	2.7	5.0	88%
Clear Communication	2.7	5.0	88%
Waste Reduction	2.3	4.3	86%
Timely Delivery of Materials	2.7	4.7	75%
Transparency & Communication	2.7	4.7	75%
Efficient Transportation	2.3	4.0	71%
Technology Adoption & Accessibility	2.7	4.0	50%
Cost Factors	2.7	3.7	38%
Flexibility in Handling Changes	3.0	4.0	33%
Market Competitiveness & Scalability	3.0	4.0	33%

Figure 3 Average Rating and % of Improvement by Supplier

The platform’s centralized nature allowed both parties to monitor progress and resolve issues without the need for back-and-forth email threads or manual record-keeping. This clarity contributed to smoother workflows and greater confidence in task execution. Despite the overall positive reception, users highlighted several challenges. New users experienced a learning curve with the interface, noting that certain functions were not immediately intuitive. Some also reported occasional system lags

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2025.0272
e ISSN: 2584-2854
Volume: 03
Issue: 05 May 2025
Page No: 1697 - 1711

and delays in response times, suggesting the need for performance optimization. (Figure 4)

Avg Rating and % of Improvement - BUYER			
Factors	**Avg. (Traditiona**	**Avg. (Web App**	**% Improvemen**
Supplier Relationships (Offerings from Suppliers)	2.0	5.0	150%
Accurate Order Forecasting	2.0	4.3	117%
Inventory Management	2.3	4.7	100%
Supplier & Engineer Satisfaction	2.3	4.7	100%
Timely Delivery of Materials	2.7	5.0	88%
Process Efficiency & Productivity	2.3	4.3	86%
Waste Reduction	2.3	4.3	86%
Clear Communication	2.7	4.7	75%
Transparency & Communication	2.7	4.7	75%
Efficient Transportation	2.3	4.0	71%
Proper Scheduling and Planning	3.0	5.0	67%
Cost Factors	2.7	4.0	50%
Use of Technology for Tracking	3.0	4.3	44%
Flexibility in Handling Changes	3.0	4.0	33%
Technology Adoption & Accessibility	3.0	4.0	33%
Market Competitiveness & Scalability	4.0	4.3	8%

Figure 4 Average Rating and % of Improvement by Buyer

Additionally, the lack of automated alerts or notifications was cited as a limitation, particularly when users had pending tasks that could be easily overlooked without reminders. When asked to express a preference between the web-based system and traditional methods, the majority of participants favored the digital platform. Their reasons included improved speed, reduced manual errors, and better traceability. However, a few participants indicated a preference for the traditional method due to its familiarity, particularly for those less accustomed to using digital tools. This highlights the importance of onboarding and training to ensure smooth adoption across varying user skill levels. Participants also proposed several enhancements for future iterations of the application. Suggestions included the introduction of mobile compatibility to enable access on the go, real-time messaging or integrated chat features to support immediate communication, and dashboard analytics to visualize order performance trends. These recommendations reflect a user desire for greater interactivity, flexibility, and decision-making support, aligning with contemporary supply chain management expectations. In summary, the survey responses reflect a strong endorsement of the web-based application's core functionalities and its potential to modernize supply chain workflows. At the same time, user insights provided actionable directions for refining the system to improve accessibility, responsiveness, and user engagement, ensuring its broader applicability and scalability in real-world environments. [19-20]

8.5. Factors Affecting Productivity

The analysis of the top five factors impacting productivity, based on supplier and buyer feedback, reveals that the web-based supply chain application led to transformative improvements across all measured areas. For suppliers, the most notable advancement was in accurate order forecasting, which saw a 180% improvement as the digital system enabled real-time visibility into buyer demands and historical data trends, allowing suppliers to plan more precisely and reduce resource wastage. Process efficiency and productivity improved by 133%, with the web app streamlining routine tasks, minimizing manual intervention, and accelerating workflows. Supplier and engineer satisfaction also improved by 133%, largely due to the system's transparency, user-friendly interface, and smoother collaboration channels, which reduced miscommunication and increased operational clarity. The ability to present offerings more effectively led to a 114% improvement in supplier relationships, as buyers could easily access up-to-date catalogs and supplier capabilities, fostering stronger partnerships. Inventory management, enhanced by real-time tracking and proactive restocking alerts, improved by 100%, eliminating errors commonly found in traditional systems. From the buyer's perspective, the strongest gain—150%—was in supplier relationships, as the application allowed for clearer communication, timely updates, and easier evaluation of supplier performance. Accurate order forecasting improved by 117%, enabling better procurement planning and demand alignment. Inventory management and supplier/engineer satisfaction each improved by 100%, supported by live data integration and streamlined collaboration that helped buyers respond quickly to inventory needs and engineering requirements. Lastly, timely delivery of materials improved by 88%, as logistics coordination became more precise through the system's status tracking and automated notifications. These findings collectively demonstrate that the web application not only enhanced productivity but also strengthened coordination, reduced inefficiencies, and provided a robust digital infrastructure for more agile and responsive supply chain operations. The conclusion of this study underscores the critical role that web-based digital platforms play in enhancing the overall performance and efficiency of supply chain operations. Based on extensive comparative data from both suppliers and buyers, it is evident that the web application significantly outperforms traditional supply chain methods in several key dimensions—namely, forecasting accuracy, process efficiency, stakeholder satisfaction, relationship management, and inventory control. The research findings reveal that traditional supply chain systems, which often rely on fragmented communication, manual data handling, and delayed decision-making, introduce a range of inefficiencies and errors. These legacy methods hinder responsiveness and lead to challenges such as misaligned forecasts, excess inventory, communication breakdowns, and delayed material delivery. In contrast, the web-based system provided a centralized, real-time, and user-friendly interface that enabled seamless collaboration between stakeholders. Suppliers could more accurately predict demand, optimize resource allocation, and maintain better control over inventory. Buyers gained improved visibility into supplier capabilities, delivery schedules, and stock levels, allowing for better procurement planning and reduced operational bottlenecks. One of the most significant takeaways from the conclusion is the measurable improvement across every performance metric assessed in the study. The improvements ranged from 88% to 180% across various factors, which clearly demonstrates the web application's transformative impact rather than incremental progress. This degree of enhancement was particularly pronounced in areas such as order forecasting, supplier relationships, and process efficiency—factors that are central to supply chain success. Furthermore, the substantial gains in supplier and engineer satisfaction indicate that the digital solution not only improved operational outcomes but also enhanced the user experience and work environment. These qualitative improvements are critical because they contribute to long-term adoption, employee engagement, and continuous process refinement. Another important conclusion is the mutual benefit experienced by both buyers and suppliers. Unlike systems that may favor one stakeholder over another, the web application created a balanced ecosystem in which all participants could operate more effectively. This bilateral improvement enhances trust, collaboration, and strategic alignment between parties—key ingredients for a resilient and agile supply chain. Additionally, the ability to maintain accurate, real-time data and generate instant insights equips organizations with the flexibility needed to adapt to market fluctuations, disruptions, or evolving customer needs. Ultimately, the study concludes that the integration of web-based platforms into supply chain processes is not merely a technical upgrade but a strategic necessity in today's competitive and dynamic business environment. By moving away from traditional, reactive practices and toward proactive, data-driven systems, organizations can unlock significant performance gains, foster stronger relationships, and build more sustainable and scalable operations. The insights provided by this research contribute to the growing body of evidence supporting digital transformation in supply chain management and offer a clear roadmap for organizations seeking to modernize their practices for improved productivity, responsiveness, and stakeholder satisfaction. [23]

Conclusion

The Conclusion should contain the confirmation of the problem that has been analyzed in result and discussion section. The Conclusion should contain the confirmation of the problem that has been analyzed in result and discussion section. The Conclusion should contain the confirmation of the problem that has been analyzed in result and discussion section. [24-26]

Acknowledgements

The web application, initially developed as a project-based solution, demonstrates considerable potential to be transformed into a commercially viable and scalable business model. Specifically, it addresses a significant and often overlooked technology gap faced by small-scale construction contractors and suppliers. These stakeholders typically operate under constrained budgets and fast-paced project timelines, yet they lack access to streamlined digital tools that

can enhance coordination, visibility, and operational efficiency. By offering a simplified yet powerful alternative to expensive enterprise-level software, this platform can deliver meaningful productivity improvements tailored to the unique needs of smaller firms. To further strengthen its market readiness and usability, the application can incorporate a suite of advanced yet user-friendly features. These may include live order tracking, allowing users to monitor material shipments in real time; mobile alerts that notify stakeholders of key updates or changes; delivery photo uploads to verify and document material handovers; and urgent order flags that prioritize critical or time-sensitive requests. These enhancements would create a comprehensive, real-time supply chain experience that is particularly suited to the dynamic nature of small and medium-sized construction projects. The application's practical value has already been demonstrated through its ability to solve real-world challenges—most notably, bridging communication gaps between buyers and suppliers and ensuring reliable delivery tracking. These solutions are not only functionally effective but also highly relevant to current industry pain points. As such, the application holds strong commercial potential to be launched as a subscription-based Software-as-a-Service (SaaS) product. This model would allow users to manage multiple projects under a single account, making it a scalable and affordable solution that adapts to the operational complexity of growing contractors. Having been directly involved in the design and development of this platform, the long-term vision is to commercialize the tool in a way that empowers small contractors with essential digital capabilities—without requiring them to invest in overly complex or high-cost systems. The goal is to make modern, productivity-driven technology accessible to a segment of the industry that has traditionally been underserved by digital innovation, ultimately helping to raise efficiency, reduce delays, and improve overall project outcomes in small-scale construction operations. [27-28]

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