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Optimizing Warehouse Management System Selection for Agricultural Third-Party Logistics Providers: A CRITIC–CoCoSo Decision-Making Framework

Aijun Shang[1,*]

1 Yulin Vocational and Technical College, Yulin 719000, China.

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ABSTRACT

Agricultural supply chains rely heavily on warehouses to manage the receipt, storage, picking, packing, and distribution of products to their final destinations. Warehouse management becomes particularly demanding in the agricultural context because product availability is strongly influenced by seasonality, supply is received from multiple sources, and reliable information concerning inventory levels and product movement must be maintained. In response to these operational requirements, agricultural Third-Party Logistics (3PL) providers may adopt a Warehouse Management System (WMS) to facilitate the coordination of warehouse processes and enhance overall operational performance. Nevertheless, determining the most appropriate WMS remains a complex decision-making problem. This study therefore developed a systematic evaluation framework to support agricultural 3PL providers in selecting a WMS that is compatible with their operational requirements. The framework employed the Criteria Importance Through Intercriteria Correlation (CRITIC) method to establish the relative importance of nine evaluation criteria, followed by the Combined Compromise Solution (CoCoSo) method to assess and rank six alternative WMS solutions. The criteria considered in the evaluation comprised API access, barcode support, pricing, mobile compatibility, trial availability, integration with other systems, user-friendly interface, scalability, and data security. According to the CRITIC weighting results, trial availability emerged as the most influential criterion, receiving a weight of 0.154, while barcode support obtained the lowest weight of 0.068. The subsequent CoCoSo evaluation identified A4 as the leading alternative, achieving a final score of 2.7414. The remaining alternatives were ordered as A1, A2, A6, A3, and A5. The resulting framework offers agricultural 3PL providers a systematic basis for evaluating and prioritising WMS alternatives in accordance with their specific operational and technological requirements.

1. Introduction

Within the contemporary business environment, agricultural 3PL providers commonly interact with Enterprise Resource Planning (ERP) systems to organise information and coordinate logistics-

* *Corresponding author.*
E-mail address: 918746392@qq.com

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related activities. When appropriately designed and implemented, an ERP system can facilitate the integration of processes across different areas of an organisation. Nevertheless, ERP adoption can require substantial financial investment and considerable implementation time. These requirements can create particular difficulties for smaller agricultural logistics providers whose financial capacity may be insufficient to support a comprehensive ERP implementation. As a result, such organisations may continue to depend on conventional approaches, including paper-based records and Excel spreadsheets, to retain essential information, operational data, and business documents.

Reliance on these methods can restrict information accessibility and adversely influence operational efficiency and overall business performance. Effective collaboration between agricultural 3PL providers and farmers, agricultural enterprises, distributors, and other supply-chain partners consequently depends on reliable and efficient mechanisms for exchanging information. At the wider food-system level, the interaction and coordination of farmers, small and medium-sized enterprises, consumers, and institutional stakeholders have likewise been recognised as significant components of the socio-technical transformation of agricultural and food supply chains [1]. The continued use of outdated information-storage practices can, however, hinder such data exchange and create difficulties in maintaining consistent and accessible information. Whereas ERP implementation is generally intended to enhance and integrate business processes throughout an organisation, smaller companies may have a more immediate requirement to improve the movement and accessibility of operational data. Consequently, specialised and comparatively affordable technologies have emerged that address data-sharing requirements without requiring organisations to undertake a full-scale ERP implementation [2].

Warehouse management represents a particularly important area in which effective information exchange is required. A WMS provides functions for collecting, storing, processing, and sharing warehouse-related information, making it relevant to agricultural 3PL providers that handle products originating from numerous small suppliers. These providers must accommodate fluctuations in product volumes associated with agricultural seasonality while maintaining accurate and timely visibility of inventory. In addition, where agricultural products require controlled temperatures, warehouse information may need to be linked with cold-chain monitoring systems to provide a more comprehensive view of product conditions throughout storage and transportation. Research concerning cold-chain logistics has highlighted the value of integrated information management and real-time monitoring across both transportation and storage processes [3]. More effective information flow can enable agricultural 3PL providers to identify operational requirements earlier, limit delays, and avoid maintaining unnecessarily high levels of safety stock. Warehouse activities involving both information and physical product flows can be organised through several technological configurations.

Providers that already operate an ERP system may incorporate dedicated warehouse-management functionality into their existing platform, whereas organisations without such infrastructure may opt for an independent WMS. The integration of a WMS module into an ERP environment can be particularly advantageous where an ERP system has already been established, as it allows warehouse activities to be connected with wider organisational processes. At the same time, a WMS does not necessarily require an ERP system and can operate as an independent solution. Inter-organisational compatibility can become more complicated when agricultural producers, logistics providers, distributors, and other supply-chain participants employ different ERP platforms. Under these circumstances, the WMS can provide the central environment for managing warehouse activities, while ERP systems continue to support broader enterprise-level processes [2].

The role of a WMS extends beyond the routine coordination of warehouse activities, as its implementation can enhance both the efficiency and responsiveness of business processes within agricultural 3PL operations. Through real-time inventory monitoring and accurate identification of product locations, a WMS can strengthen operational control while reducing the likelihood of handling and information errors. Such capabilities are especially pertinent to agricultural 3PL providers, which frequently deal with products originating from multiple producers, substantial fluctuations in inventory quantities, and continuous inbound and outbound product movements. These operational characteristics make the choice of an appropriate WMS an important strategic decision.

Available WMS alternatives therefore need to be examined systematically to determine whether their functional and technological capabilities correspond with the requirements of agricultural 3PL operations. The evaluation is not straightforward, however, because WMS selection requires the simultaneous consideration of several criteria that may differ in their units of measurement, relative significance, and contribution to the overall decision. To address this issue, this paper developed a decision-making framework combining the Criteria Importance Through Intercriteria Correlation (CRITIC) and Combined Compromise Solution (CoCoSo) methods to evaluate and select WMS alternatives for agricultural 3PL providers using predefined evaluation criteria.

The remainder of this paper is organised as follows. Section 2 examines the underlying problem and reviews relevant literature addressing warehousing, WMS implementation, and WMS selection within the 3PL context. Section 3 describes the principal characteristics of the WMS alternatives considered in the study and details the agricultural 3PL case study, evaluation criteria, methodological approach, and obtained results. Section 4 concludes the paper and identifies potential directions for future research.

2. Problem Analysis and Related Literature

2.1 The Role of Warehousing in the Agricultural Supply Chain

Warehousing constitutes a fundamental stage within the agricultural supply chain, providing a location where products are held before they undergo additional processing, enter distribution channels, or reach the market. Although warehousing is primarily associated with the physical retention of goods, its scope also encompasses the maintenance of associated inventory records and transaction-related information within digital databases. Its importance in agricultural logistics arises from the involvement of numerous producers, variations in harvesting periods, and changes in market requirements that influence when and where products must be distributed. Consequently, effective storage and distribution practices can generate substantial benefits for agricultural producers, 3PL providers, distributors, and retailers. These benefits can be characterised by the following features [2]:

Continuity of Supply – Warehousing creates an intermediate inventory buffer linking agricultural production with processing and distribution activities, thereby helping to sustain the availability of products. This buffering function is particularly significant because agricultural operations are influenced by harvest periods, seasonal supply patterns, processing requirements, and transportation constraints. A delay occurring at any point may consequently interfere with subsequent logistics activities. While the Just-In-Time (JIT) philosophy is intended to avoid unnecessary inventory accumulation, agricultural 3PL providers still require suitably determined buffer stocks to accommodate variations in supply and demand. An interruption in one part of the agricultural supply chain can subsequently propagate across other stages, potentially intensifying fluctuations through the bullwhip effect.

Time Utility – Warehousing separates the timing of production from the timing of consumption by retaining products until they are required. Since future demand cannot generally be forecast with complete accuracy, agricultural 3PL providers maintain inventories to preserve service levels and respond to customer requirements without unnecessary delays. This function becomes especially important for seasonal commodities such as rice, tomatoes, and bananas, whose production is concentrated within particular harvesting periods. Consumer requirements for these products, however, may continue throughout the year, making suitable storage arrangements and effective inventory control necessary.

Storage of Excess Inventory – Agricultural products that are not required immediately following harvesting or processing do not necessarily have to be disposed of. Where appropriate storage conditions are available, such products can remain in inventory until a corresponding demand occurs. Maintaining surplus products in this manner can limit avoidable losses and promote more effective utilisation of available resources.

Price Stabilization – The timing of agricultural production frequently differs from the timing of market demand. Warehousing provides an opportunity to retain products following harvest and subsequently release them in response to prevailing demand conditions. By regulating the timing of product availability, this function can moderate the consequences of temporary oversupply and support greater stability in both product availability and market prices.

Risk Minimization – Warehousing assumes particular importance when agricultural products are perishable and susceptible to deterioration. Appropriate temperature, humidity, and other environmental conditions can help preserve product quality and extend usable shelf life. Although a WMS does not itself establish or control these physical storage conditions, it can facilitate product identification, inventory rotation, location allocation, and documentation of relevant warehouse information. By supporting these activities, a WMS can assist agricultural 3PL providers in limiting spoilage and mitigating risks associated with product quality.

Packaging and Sorting – Agricultural warehouses can incorporate dedicated facilities or work areas for activities including sorting, grading, inspection, packaging, labelling, and preparing products for subsequent distribution. Coordinating these functions within the warehouse can streamline logistics activities while enabling agricultural 3PL providers to accommodate the differing requirements of producers, distributors, retailers, and other customers.

Financing – Agricultural products retained in storage continue to represent an economic asset until their eventual sale. In certain countries, warehouse operators may provide financing against the value of goods deposited in their facilities. Such arrangements can provide agricultural producers and other supply-chain participants with an additional source of liquidity while the stored products remain within the warehouse.

2.2 WMS Implementation

Agricultural 3PL providers can adopt different approaches to WMS implementation according to factors such as their operational size, product portfolio, supplier network, and available financial and technological capabilities. Regardless of the selected approach, several fundamental implementation activities require careful consideration. Among these, adequate preparation is particularly important for establishing the conditions necessary for successful implementation [4]:

Assemble an Implementation Team – Effective WMS implementation requires the involvement of a suitably skilled and appropriately structured team. The implementation group should comprise personnel such as a project manager, warehouse manager, database administrator, engineer, and WMS specialist. Within an agricultural 3PL environment, team members should additionally possess a clear understanding of product movement, seasonal warehouse requirements, supplier interactions, and inventory-control processes. The intended objectives of implementing the WMS should remain clearly defined and continuously considered throughout this stage.

Develop Management Plans and Best Practices – Following formation of the implementation team, a comprehensive plan should be developed to define the activities required for implementation and anticipate possible operational difficulties. This plan should address the estimation of implementation expenditure, preparation and approval of the budget, distribution of allocated funds across implementation activities, creation of data backups, employee training, system deployment, and subsequent assessment of implementation outcomes. Ineffective communication between the agricultural 3PL provider and its suppliers, customers, employees, and technology partners represents a significant potential source of implementation failure. Accordingly, effective coordination, clear communication channels, and timely access to required resources should be established throughout the process.

Forecast Implementation Costs and Budget – The implementation budget should account for major expenditure categories, including system maintenance, WMS training, additional employee working hours, insurance, and necessary hardware. Agricultural 3PL providers should also consider allocating resources for subsequent system development. Such provisions may be required when training further employees, introducing additional system modules, or accommodating growth in suppliers, product volumes, and warehouse locations.

Prepare Data Backups – Comprehensive backups of existing inventory, supplier, customer, and transaction records should be established before implementation activities progress. Maintaining these copies provides protection against data loss and supports continuity of warehouse operations if technical or implementation-related problems occur.

User Training – Employees require appropriate instruction to use the WMS effectively. Regular training programmes commonly extend over three to five days and can be organised according to employee shifts, enabling personnel to acquire practical experience, practise system functions, and resolve areas of uncertainty. Training may be delivered through online courses, instructional materials, vendor-supported programmes, or practical sessions conducted directly within the company warehouse. The training content should reflect the specific activities undertaken by the agricultural 3PL provider, including receiving products, identifying items, assigning storage locations, picking orders, and dispatching goods.

Plan Launch Steps – WMS deployment should be supported by a detailed implementation plan covering the preparation of personnel, equipment, data, financial resources, and other necessary components. Each planned activity should undergo verification to determine whether the organisation is adequately prepared to address unexpected implementation issues. The process should include confirming required system capabilities, performing system tests, establishing assessment criteria for the initial operating period, developing the deployment strategy, evaluating network performance, and verifying the integrity of backup data. In addition, the selected WMS should undergo testing under both routine and seasonal operating conditions representative of the agricultural warehouse.

System Launch – During system deployment, the implementation team should maintain close oversight of WMS performance and minimise disruption to ongoing warehouse activities. System operation should be checked regularly to confirm the accuracy of inventory records, reliability of transaction processing, and satisfactory overall system performance.

Implementation Success Review – Issues associated with implementation commonly emerge during the early period of system operation. Effective preparation and appropriate budget allocation can improve implementation outcomes by controlling expenditure and ensuring that employees possess the knowledge required to operate the WMS. For agricultural 3PL providers, the post-implementation assessment should additionally determine whether the WMS can accommodate fluctuations in product volumes, interactions with multiple suppliers, real-time inventory visibility, and the timely execution of warehouse activities.

2.3 Advantages of Implementing a WMS

A WMS can contribute to lower operating expenditure by improving the productivity of warehouse activities. By transferring many record-keeping tasks from manual paperwork to digital processes, the system can reduce the administrative burden placed on warehouse personnel. Automated data processing also helps limit the occurrence of recording errors and enables discrepancies to be detected at an earlier stage. These capabilities are particularly valuable for agricultural 3PL providers that must coordinate products originating from multiple suppliers while accommodating fluctuations in inventory levels. Greater process efficiency can consequently improve service quality while supporting reductions in operating costs. The principal benefits associated with WMS implementation include [5; 6]:

Reduced Operational Costs – Effective WMS implementation can improve the allocation and utilisation of both warehouse labour and available storage space, thereby limiting unnecessary resource consumption and operational waste. The system can also assist in determining suitable storage locations for agricultural products, packaging materials, and warehouse equipment, enabling available space to be used more effectively.

Improved Inventory Visibility – Real-time visibility of inventory represents a central capability of a WMS. Through technologies such as barcodes, serial numbers, and RFID tags, the system can maintain up-to-date records of stock movements. Agricultural 3PL providers can use these technologies to document when products enter the warehouse, monitor their movement throughout the facility, and identify transfers between different storage locations. Such visibility supports more accurate inventory control and facilitates timely access to stock information.

Continuous Improvement – A WMS can evolve alongside changes in warehouse operations and organisational requirements. As WMS providers introduce additional functions and capabilities, agricultural 3PL providers can adapt their systems to accommodate changes in operational scale, supplier arrangements, product quantities, and customer expectations. This flexibility enables the warehouse-management environment to remain aligned with changing business conditions.

Improved Security – WMS platforms commonly assign individual login credentials to employees, allowing transactions to be associated with specific users. This creates an electronic audit trail through which warehouse activities can be traced to the personnel responsible for them. Such traceability strengthens accountability and can help prevent or identify theft, unauthorised modifications, and inaccuracies in inventory records.

Higher Employee Motivation – An effectively configured WMS can create a more structured working environment by simplifying workflows and reducing reliance on repetitive manual documentation. Clearly defined procedures and rapid access to relevant warehouse information can ease operational pressures on employees and support more consistent decisions during routine activities. Consequently, improved organisation and reduced administrative workload may contribute to a more positive employee experience.

Stronger Relationships with Customers and Suppliers – Improvements in warehouse coordination can benefit both suppliers and customers of agricultural 3PL providers. Suppliers may experience reduced waiting periods during product receipt and at warehouse docks, while customers can benefit from deliveries that are more accurate and timely. Consistent service performance can subsequently strengthen relationships between agricultural 3PL providers and their producers, processors, distributors, retailers, and other business partners.

2.4 Disadvantages of Implementing a WMS

The principal limitation associated with WMS implementation concerns the substantial expenditure required at the outset. While the price of radio-frequency (RF) devices has declined over the years, the acquisition of such equipment can still represent a considerable financial burden for small and medium-sized agricultural 3PL providers. In addition to hardware expenditure, specialised WMS software and the training required to prepare employees for system operation may constitute a greater proportion of the overall investment than the hardware itself. Implementation may also necessitate modifications to existing warehouse layouts so that physical operations are compatible with the requirements of the WMS. Furthermore, effective WMS adoption depends on the establishment and consistent application of standardised procedures and controls. This requirement can become particularly challenging when an agricultural 3PL provider receives products from numerous small suppliers that employ different documentation practices and information systems. Other significant limitations include [5]:

Multiple IT Partnerships – Agricultural 3PL providers that require dedicated technological support for separate business functions may have to coordinate with several IT partners. When a technical problem occurs, determining which provider is responsible can delay diagnosis and corrective action. Clearly assigning individual business processes to their respective systems is therefore necessary to establish responsibility and facilitate troubleshooting. Effective technical support from each IT provider is also important for determining the origin of system-related problems and resolving them efficiently.

Multiple Databases – A WMS may have to exchange and coordinate information originating from several databases, including records associated with suppliers, products, customers, inventory, and transportation. Managing information distributed across these systems can make data retrieval and reconciliation more complex and may require personnel to perform manual comparisons. Such manual procedures increase the possibility of discrepancies and errors, potentially resulting in decisions being made using incomplete or inaccurate information. Contemporary software applications can partially alleviate this limitation by facilitating information exchange and interoperability between otherwise separate platforms.

2.5 Literature Review

The literature review encompasses studies that investigate WMS from both general and 3PL perspectives. Collectively, these investigations provide the methodological and operational foundation for examining WMS selection within agricultural 3PL operations. One study [7] examined the contribution of WMS implementation to business continuity by integrating and coordinating different systems responsible for essential warehouse functions. Since warehouses represent central nodes for operational activities, their effective management is important for improving overall efficiency. The study examined fundamental warehouse characteristics and alternative approaches to WMS implementation, demonstrating that WMS adoption can facilitate warehouse processes, reduce operational errors, and strengthen customer relationships and service quality. These capabilities are similarly applicable to agricultural 3PL providers that must coordinate inventory and information originating from multiple suppliers.

The integration of artificial intelligence and robotics into sustainable WMS has also been examined, particularly in relation to strengthening the economic resilience of supply chains [8]. The findings indicated that these technologies can contribute to error reduction, enhance inventory-management activities, and improve organisational responsiveness to variations in market demand. Such considerations are particularly relevant within agricultural logistics, where product quantities and storage requirements can fluctuate across different periods. In temperature-sensitive logistics, a framework for monitoring temperature conditions during transportation and storage emphasised the importance of sensor technologies, the Internet of Things, and integrated information management in cold-chain operations [3]. Similarly, the use of WMS data together with Big Data analysis has been investigated as a means of improving order-picking activities [9].

The challenges encountered by 3PL companies when selecting WMS solutions for improved customer-service performance have been examined through a dedicated literature review [10]. Another study developed a decision-support tool to assist 3PL managers in determining appropriate WMS customization [11]. This investigation considered several difficulties, including the cost associated with information sharing, restricted visibility of client data, and uncertainty surrounding the quantification of return on investment from WMS functions. Such concerns may be especially significant for agricultural 3PL providers because they commonly coordinate activities involving multiple producers and customers. Factors associated with successful WMS implementation have also been investigated [12]. Based on company project documentation, the study identified several benefits resulting from systematic evaluation and monitoring of implementation activities, including real-time inventory management, reduced inventory mishandling, more efficient returns processing, faster product delivery, and enhanced customer satisfaction. A WMS evaluation model based on fuzzy MCDM techniques was subsequently proposed [13]. The use of hybrid MCDM approaches has likewise been demonstrated in other warehouse and logistics decision problems. One study integrated SWARA and ARAS to establish criterion weights and prioritise alternative warehouse locations [14], while another applied fuzzy FARE and ADAM to assess alternatives associated with last-mile delivery [15].

Further research has examined the relationship between WMS and 3PL operations [16]. Inventory management in e-commerce operations conducted by a 3PL provider has also been investigated, with the findings indicating that improved inventory management could be achieved through more effective location management and automated storage processes [17]. In addition, the outcomes of WMS implementation within a 3PL company have been examined [18]. Managerial perceptions concerning WMS have been investigated through a survey-based study [19]. The findings suggested that WMS and RF technology can reduce operational errors, save time, accelerate warehouse activities, and facilitate stronger supplier integration. Improved integration can consequently contribute to reducing both shortages and excessive inventory while supporting more timely deliveries.

In another study, SWARA and MARCOS were combined to evaluate crowd logistics platforms according to cost efficiency, delivery speed, reliability, sustainability, flexibility, and customer-support quality [20]. A 3PL-provider selection model based on CRITIC and additive ratio assessment (ARAS) was proposed in [21]. Another model integrated fuzzy Analytical Hierarchy Process (AHP) and CoCoSo to evaluate and select sustainable 3PL providers [22]. Similarly, a framework combining the Best-Worst Method (BWM) and CoCoSo was developed to select a 3PL provider for last-mile delivery [23]. Within the agricultural domain, PROMETHEE was applied to rank regional agricultural technology competitiveness, with sensitivity analysis and rank-correlation measures subsequently used to examine ranking stability [24]. This study demonstrates the applicability of multi-criteria ranking techniques to agricultural technology decisions involving multiple technological dimensions.

The existing literature has consequently addressed WMS implementation, WMS selection within general 3PL operations, warehouse and delivery decisions, logistics-platform assessment, agricultural technology evaluation, and the application of MCDM techniques to logistics-provider selection. Research concerning circular food systems has additionally emphasised socio-technical coordination among farmers, enterprises, consumers, and institutional actors, while highlighting the challenges associated with fragmented supply-chain structures [1]. Nevertheless, comparatively limited attention has been directed towards combining objective criterion weighting with compromise-based ranking for WMS selection specifically within agricultural 3PL operations. This represents an important research gap because agricultural 3PL providers must manage multiple suppliers, accommodate seasonal fluctuations in inventory volumes, and coordinate product and information flows among diverse supply-chain participants. The present study addresses this gap by integrating CRITIC and CoCoSo to establish criterion weights and rank alternative WMS solutions for an agricultural 3PL provider.

3. WMS Selection for an Agricultural 3PL Provider: Case Study

This study examines the selection of a WMS for an agricultural 3PL provider whose warehouse activities encompass product receiving, storage, inventory recording, order picking, and dispatch. The provider handles agricultural products obtained from multiple producers, while its operational requirements vary according to fluctuations in product volumes, supplier arrangements, and customer orders. The evaluation is specifically concerned with the information-management and operational capabilities offered by WMS solutions. Physical equipment responsible for controlling warehouse temperature and humidity falls outside the scope of the assessment. All WMS alternatives considered in the study are Internet-accessible, and their principal functions and available options are presented below.

3.1 Potential WMS Solutions

The six candidate WMS solutions were identified on the basis of their accessibility and their capacity to address the principal information-management and warehouse-operational requirements of the agricultural 3PL provider. The assessment considered capabilities related to data exchange, inventory identification, mobile accessibility, system integration, usability, scalability, and data security. To maintain commercial confidentiality, the systems examined in this study are designated as WMS1–WMS6.

WMS1 offers comprehensive API access together with barcode processing, mobile accessibility, and a trial option. Its pricing is positioned within the average range. However, the information available on its website does not specify whether dedicated support for 3PL operations is provided. The system is available only in English. WMS2 enables information to be exported in PDF, XML, and Excel formats and includes barcode-management functionality. Its subscription cost varies between €68 and €125 per user per month. Although mobile access is indicated on the provider's website, no trial version is available. The system supports 3PL operations and provides language options in Danish, English, and French.

WMS3 incorporates Electronic Data Interchange (EDI) for data export and also provides barcode functionality and mobile access. Its stated cost is $200 per user per month. The solution offers extensive functionality for 3PL operations, although a trial version is not provided. English is the sole supported language. WMS4 offers advanced data-export functionality through EDI, MS SQL, and

Oracle. Barcode processing and mobile accessibility are also supported, together with functionality for 3PL operations. The provider does not disclose pricing information on its website, and no trial version is available. In terms of language coverage, the system supports Chinese, English, French, German, Italian, Japanese, Korean, Portuguese, Russian, Spanish, Swedish, Turkish, and Vietnamese.

WMS5 provides users with access to an API development team and is designed to accommodate multiple languages, companies, and locations. Its reported price is [the author must verify the correct amount and pricing unit]. Both mobile access and a trial version are available, whereas barcode handling is not supported. The solution may be applicable to 3PL operations, although explicit information confirming dedicated 3PL support is not provided. WMS6 does not include dedicated export tools but supports barcode handling and offers mobile access. Its pricing is not publicly specified; however, available records report a range of $1,000–$50,000. The author should clarify whether this figure denotes a one-time implementation charge, an annual subscription, or another pricing arrangement. Although explicit 3PL support is not stated, the system is considered potentially applicable to 3PL operations. It supports multiple languages, including Finnish.

The comparison indicates considerable variation among the six WMS alternatives with respect to data-exchange capabilities, barcode functionality, pricing, mobile accessibility, trial availability, 3PL support, and language coverage. Since none of the alternatives demonstrates superior performance across all dimensions, selecting the most appropriate solution requires a systematic MCDM approach that can evaluate the alternatives against the specific operational and technological requirements of the agricultural 3PL provider.

3.2 Criteria for Selecting a WMS

The selection of the most appropriate WMS solution was based on findings derived from the literature review and the analysis of operational data obtained from the agricultural 3PL provider. These findings resulted in the establishment of nine criteria for assessing the six WMS alternatives. The criteria were formulated to capture the provider’s key requirements relating to information management, warehouse operations, financial considerations, and system development. Following the definition of each criterion and its corresponding measurement scale, an initial decision matrix was constructed, as shown in Table 1.

Table 1
Data used for Ranking the WMS Alternatives

WMS Solution	C1	C2	C3	C4	C5	C6	C7	C8	C9
WMS1	5	5	2	5	5	5	2	2	2
WMS2	5	5	3	1	1	5	3	2	3
WMS3	1	5	1	5	1	1	2	3	3
WMS4	1	5	1	5	1	5	3	3	3
WMS5	5	1	1	1	5	1	2	2	2

API Access (C1) measures the availability of an open API that enables the agricultural 3PL provider to transfer supplier, inventory, order, and transportation data between the WMS and other business applications. A value of 5 is allocated when an open API is provided for integration with ERP systems, e-commerce platforms, IoT devices, or other software applications. A value of 1 is assigned when API functionality is either unavailable or not documented. Barcode Support (C2) examines the capability of the WMS to employ barcode technology for identifying, scanning, and monitoring agricultural products and associated inventory. A score of 5 is given to systems that support barcode scanning throughout product receipt, storage, picking, and dispatch processes. A score of 1 applies when barcode functionality is absent or no information regarding this capability is provided.

Pricing (C3) reflects the monthly expenditure per user in relation to the specified market-price categories. This criterion is particularly relevant to small and medium-sized agricultural 3PL providers, which may operate under financial constraints when implementing information systems. A monthly price below €100 per user is categorised as low-cost and assigned a score of 3. Prices between €100 and €500 per user per month are considered medium and receive a score of 2. A price above €500 per user per month is classified as high and receives a score of 1. Mobile Version (C4) evaluates whether warehouse personnel can operate or access the WMS through a mobile application or responsive web interface while performing activities at receiving, storage, picking, and dispatch locations. Systems providing mobile access receive a score of 5, whereas those without such functionality receive a score of 1.

Trial Version (C5) determines whether the agricultural 3PL provider has an opportunity to evaluate the WMS before committing to its purchase. Trial access enables the provider to assess the suitability of the system in relation to existing warehouse procedures, employees, equipment, and data requirements. A free trial is assigned a score of 5, while the absence of a trial option results in a score of 1. Integration with Other Systems (C6) assesses the ability of the WMS to establish connections with ERP, TMS, CRM, and other organisational systems. Effective integration facilitates the exchange of information among agricultural producers, the 3PL provider, transport operators, distributors, and customers. A system possessing the required integration capabilities receives a score of 5, whereas a system lacking these capabilities receives a score of 1.

User-Friendly Interface (C7) evaluates the extent to which warehouse personnel with varying degrees of digital experience can operate the system effectively. A system considered difficult to operate is assigned a score of 1. Where some training is necessary but the system remains reasonably manageable, a score of 2 is applied. An intuitive system with straightforward navigation receives a score of 3. Scalability (C8) measures the capability of the WMS to accommodate organisational growth and changes in operational capacity. This includes seasonal increases in agricultural product volumes, the addition of suppliers and customers, and expansion into further warehouse locations. A system that cannot accommodate substantial expansion receives a score of 1. A score of 2 is assigned when the system can accommodate a degree of growth but has identifiable limitations. A system capable of readily adapting to changing business requirements receives a score of 3. Data Security (C9) evaluates the measures available to safeguard supplier, customer, inventory, order, and transaction data. The assessment considers encryption, authentication, access control, and other security protocols supported by the system. A score of 1 represents minimal security provisions, a score of 2 denotes standard security functionality, and a score of 3 indicates the availability of advanced security measures.

Taken together, the nine criteria establish a systematic evaluation structure for assessing the six WMS alternatives against the information-management and warehouse-operational requirements of the agricultural 3PL provider. The resulting scores for each alternative are reported in Table 1 and subsequently form the input for the CRITIC–CoCoSo analysis.

3.3 Methodology

CRITIC Method

The CRITIC method was implemented through the sequential steps outlined in [25; 26].

Step 1. Construct the initial decision matrix $X = \left[x_{ij}\right]_{m\times n}$, where $m$represents the alternatives and n represents the criteria.

Step 2. Normalise the initial decision matrix using Equation (1).

$$x_{ij}^{*} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{1}$$

Step 3. Determine the weight of each criterion by considering its degree of variability, expressed through the standard deviation, together with its correlation with the remaining criteria, as presented in Equation (2).

$$w_j = \frac{C_j}{\sum_{i=1}^{m} C_i} \tag{2}$$

where C_j denotes the quantity of information contained in the jth criterion and is calculated using Equation (3).

$$C_j = \sigma_j \sum_{i=1}^{m} (1 - r_{ij}) \tag{3}$$

where $\sigma_j$denotes the standard deviation of the jth criterion, while r_{ij}denotes the correlation coefficient between the jth and ith criteria. A higher $C_j$value indicates that the corresponding criterion contains a larger amount of information and therefore receives a higher objective weight.

CoCoSo Method

The CoCoSo method was implemented through the following sequential steps [27]:

Step 1. Construct the initial decision matrix.

Step 2. Normalise the initial decision matrix using Equation (4) or Equation (5), depending on the type of criterion.

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; for\ benefit\ criterion \tag{4}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; for\ cost\ criterion \tag{5}$$

Step 3. Calculate the overall weighted comparability sequence $S_i$and the total power weight of the comparability sequence $P_i$for each alternative using Equations (6) and (7).

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \tag{6}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{7}$$

Step 4. Determine the three relative appraisal scores for the alternatives using Equations (8) – (10).

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \tag{8}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{9}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\left(\lambda \max_i S_i + (1-\lambda) \max_i P_i\right)}; 0 \leq \lambda \leq \tag{10}$$

In Equation (10), $\lambda = 0.5$ was used in this study.

Step 5. Calculate the final $k_i$value using Equation (11) and rank the alternatives in descending order. A higher $k_i$value represents a more suitable WMS solution.

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{11}$$

3.4 Results

The first stage of the proposed framework employed the CRITIC method to determine the objective weights of the nine criteria established for evaluating the WMS alternatives for the agricultural 3PL provider. The criterion weights were calculated by applying Equations (1) – (3) to the data reported in Table 1, with the resulting values presented in Table 2.

Table 2
Criterion Weights Obtained using the CRITIC Method

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9
Weight	0.15	0.068	0.094	0.106	0.154	0.106	0.1	0.121	0.101

The results indicated that trial availability (C5) obtained the highest CRITIC weight, with a value of 0.154, followed by API access (C1), which received a weight of 0.150. Barcode support (C2) had the lowest criterion weight at 0.068. These weights reflect the objective information contributed by the criteria across the six WMS alternatives and therefore do not represent the subjective preferences of the agricultural 3PL provider. Following the determination of the criterion weights, the CoCoSo method was employed to establish the ranking of the WMS alternatives. The initial decision matrix was normalised according to Equations (4) and (5), and the resulting normalised values are reported in Table 3. Subsequently, the criterion weights derived through the CRITIC method were incorporated into the normalised decision matrix. This process produced the weighted decision matrix presented in Table 4. Using the weighted decision matrix, the [missing term] value corresponding to each WMS alternative was determined through Equation (6), with the calculated results reported in Table 5.

Table 3
Normalized Decision Matrix

Alternatives/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	1.0000	1.0000	0.5000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000
A2	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	1.0000
A3	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000
A4	0.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
A5	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
A6	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000

Table 4
Weighted Decision Matrix

Alternatives/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.1500	0.0680	0.0470	0.1060	0.1540	0.1060	0.0000	0.0000	0.0000
A2	0.1500	0.0680	0.0000	0.0000	0.0000	0.1060	0.1000	0.0000	0.1010
A3	0.0000	0.0680	0.0940	0.1060	0.0000	0.0000	0.0000	0.1210	0.1010
A4	0.0000	0.0680	0.0940	0.1060	0.0000	0.1060	0.1000	0.1210	0.1010
A5	0.1500	0.0000	0.0940	0.0000	0.1540	0.0000	0.0000	0.0000	0.0000
A6	0.0000	0.0680	0.0000	0.1060	0.0000	0.0000	0.1000	0.1210	0.1010

Table 5
S_i Values of the WMS Alternatives

Alternatives	S_i
A1	0.6310
A2	0.5250
A3	0.4900

A4	0.6960
A5	0.3980
A6	0.4960

To calculate the $P_i$values, the exponentially weighted normalized decision matrix was obtained, as shown in Table 6. The P_i value of each WMS alternative was then calculated using Equation (7), as presented in Table 7.

Table 6
Exponentially Weighted Normalized Decision Matrix

Alternatives/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	1.0000	1.0000	0.9369	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000
A2	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	1.0000
A3	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000
A4	0.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
A5	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
A6	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000

Table 7
P_i Values of the WMS Alternatives

Alternatives	P_i
A1	5.9369
A2	5.0000
A3	5.0000
A4	7.0000
A5	3.0000
A6	5.0000

Finally, Equations (8)–(10) were applied to calculate the three appraisal scores k_{ia}, k_{ib}, and k_{ic}, as presented in Table 8. Based on the three appraisal scores, the final $k_i$values were calculated using Equation (11), and the six WMS alternatives were ranked as shown in Table 9.

Table 8
Values of k_{ia}, k_{ib}, and k_{ic}

Alternatives	k_{ia}	k_{ib}	k_{ic}
A1	0.1922	3.5644	0.8534
A2	0.1617	2.9858	0.7179
A3	0.1607	2.8978	0.7134
A4	0.2252	4.0821	1.0000
A5	0.0994	2.0000	0.4415
A6	0.1608	2.9129	0.7141

Table 9
Final Ranking of the WMS Alternatives

Alternatives	k_i	Ranking
A1	2.3728	2
A2	1.9909	3
A3	1.9498	5
A4	2.7414	1
A5	1.2915	6
A6	1.9568	4

The results ranked WMS4 (A4) as the most suitable solution for the examined agricultural 3PL provider, with a final k_ivalue of 2.7414. It was followed by WMS1 (A1), WMS2 (A2), WMS6 (A6), WMS3 (A3), and WMS5 (A5). The superior ranking of WMS4 can be attributed to its strong performance across barcode support, mobile compatibility, system integration, interface usability, scalability, and data security. These capabilities enable the agricultural 3PL provider to coordinate product and information flows involving multiple suppliers while adapting to variations in warehouse activities. However, the resulting ranking is specific to the six alternatives and nine criteria considered in this case study and should not be regarded as a universal ranking of WMS products.

4. Conclusion

This study proposed a CRITIC–CoCoSo decision-making framework for evaluating and selecting WMS alternatives for an agricultural 3PL provider. Nine criteria were considered: API access, barcode support, pricing, mobile compatibility, trial availability, integration with other systems, user-friendly interface, scalability, and data security. These criteria represented the key information-management, operational, financial, and system-development requirements of the examined agricultural logistics context. The CRITIC method was used to determine objective criterion weights based on variability and conflicting information in the initial decision matrix. Trial availability (C5) received the highest weight of 0.154, followed by API access (C1) at 0.150, while barcode support (C2) received the lowest weight of 0.068. The low weight of C2 reflects limited variation among the six alternatives rather than low operational importance. The CoCoSo analysis ranked WMS4 (A4) first, with a final score of 2.7414, followed by WMS1 (A1), WMS2 (A2), WMS6 (A6), WMS3 (A3), and WMS5 (A5). WMS4 performed particularly well in barcode support, mobile compatibility, system integration, interface usability, scalability, and data security. Based on the criteria and data used, WMS4 was therefore identified as the most suitable alternative for the examined agricultural 3PL provider.

Practically, the framework provides a transparent approach for defining criteria, determining objective weights, and ranking WMS alternatives. It can support agricultural 3PL providers in coordinating products and information from multiple suppliers while responding to changes in warehouse activity. However, the ranking is case-specific and should not be considered a universal ranking of WMS products. The study was limited to six WMS alternatives and nine criteria, with CRITIC weights based on alternative performance rather than managers' subjective preferences. The evaluation also excluded physical temperature- and humidity-control equipment. Future research could incorporate additional agricultural logistics requirements, such as batch traceability, shelf-life management, inventory rotation, cold-chain connectivity, and product-quality information. Combining CRITIC with subjective weighting methods and testing the framework across additional 3PL providers, product categories, and WMS alternatives could further strengthen its applicability and robustness.

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