

## Article

# An Industrial Blockchain-Based Multi-Criteria Decision Framework for Global Freight Management in Agricultural Supply Chains

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**Abstract:** In view of increasing supply chain disruption events, for example the China–United States trade war, the COVID-19 pandemic, and the Russia–Ukraine war, the complexity and dynamicity of global freight management keeps increasing. To build a resilient and sustainable supply chain, industrial practitioners are eager to systematically revamp the freight management decision process related to the selection of carriers, shipping lanes, and third-party logistics service providers. Therefore, this study aims at strengthening decision-making capabilities for global freight management, in which an industrial blockchain-based global freight decision framework (IB-GFDF) is proposed to incorporate consortium blockchain technology with the Bayesian best-worst method. Through the blockchain technology, pairwise comparisons can be conducted over the international freight network in a decentralized and immutable manner, and thus, a secure and commonly agreed-on pairwise comparison dataset is acquired. Subsequently, the pairwise comparison dataset with multi-stakeholder opinions is analyzed using the Bayesian best-worst method in order to prioritize the selection decision criteria related to carriers, shipping lanes, and 3PL service providers for global freight management. To verify the methodological feasibility, a case study of an Australian agricultural supply chain firm was conducted to support the development end-to-end (E2E) supply chain solutions originated from Australia. It was found that port infrastructure, ports of call and communication effectiveness were the major criteria for the selection decision, which can be emphasized in future global freight collaboration. In addition, an immutable and append-only record of pairwise comparisons can be established to support the visibility of time-varying stakeholders' preferences.

**Keywords:** global freight management; agricultural supply chain; consortium blockchain; best-worst method; decision framework

**MSC:** 90-08; 90B50; 90B90



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## 1. Introduction

Agricultural supply chain management (ASCM) involves managing material, information and financial flows among supply chain actors such as farmers, distributors, and end customers. Compared with the typical supply chain management, ASCM is complicated to deal with, involving conflicting objectives and multiple dependencies for agricultural products in fragmented inbound and outbound networks [1]. Appropriate decisions should be made at the right time and right place based on digital technologies and analytics to maximize the customer value. According to a recent report from the Food and Agriculture Organization [2], the global food and agricultural trade in 2020 reached nearly USD 1500 billion, and countries tend to formulate various trade clusters due to the geographic proximity and economic integration.

Global agricultural trade is subject to economic growth, urbanization, technological advancements, and trade policies, which is deemed to further increase in near future. Under the globalization of business activities, agricultural products are sold not only to domestic markets but also overseas markets. Recently, the regional comprehensive economic partnership (RCEP) [3], which is a free trade agreement, was initiated and promoted in November 2020 to facilitate international trade between the Association of Southeast Asian Nations (ASEAN) and five major trade partners (i.e., Australia, China, Japan, Korea, and New Zealand). The agreement aims at lowering tariffs and reducing protectionism as an alternative measure to the comprehensive and progressive agreement for trans-pacific partnership (CPTPP) [4]. Under the RCEP, the trade of agricultural goods is conducted in a broader market with faster growth rates. Since most of the agricultural products are time- and temperature-sensitive and perishable in nature, the formulation of an optimal, or even just appropriate, global freight management strategy becomes complicated. As illustrated in Figure 1, global freight management plays an important role in handling the import and export operations of agricultural products across different borders internationally. Throughout the whole ASC, the global freight management is the core between two distribution centers at different geographic locations [5]. Cargoes are consigned to a specific third-party logistics (3PL) company for freight forwarding, while a contracted carrier is responsible for determining the suitable shipping lane and shipping solution. Since the current free trade agreement provides an attractive incentive to facilitate the trade of agricultural products, market competition has become fiercer and more complicated than before. Consequently, the development of an effective global freight management strategy has drawn considerable attention for most supply chain firms, where ASCM processes under the RCEP should be further smoothed with the aid of state-of-the-art technologies. In short, two research questions are raised in the context of the global freight management in the contemporary ASC environment as follows:

- (a) What are the essential decision criteria of global freight management in ASCs?
- (b) How can global freight management decisions be effectively made in the peer-to-peer freight network?

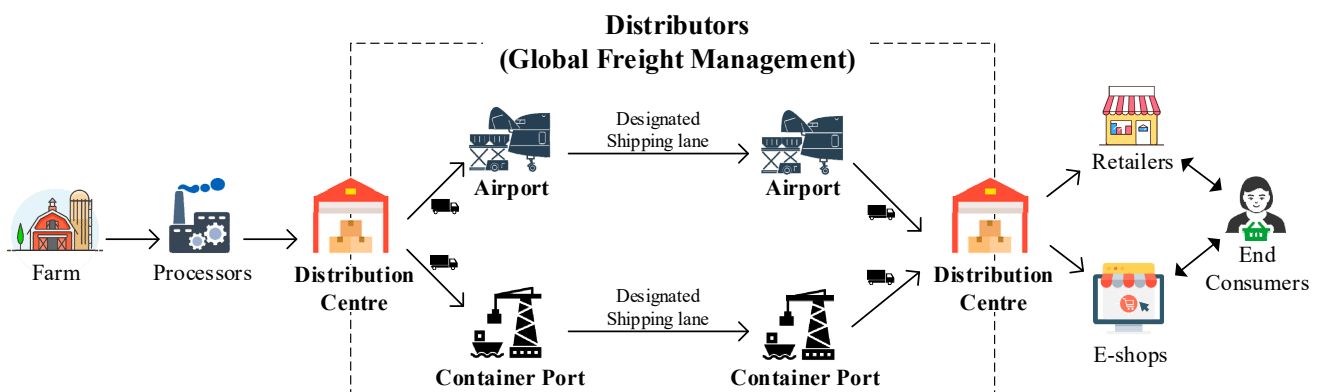


Figure 1. Graphical illustration of the global freight management for agricultural supply chains.

In view of the above questions, this study aims to address the challenges about selection decision in the context of global freight management through considering the recent advances in information and communication technologies and decision analytics approaches. In this study, an industrial blockchain-based global freight decision framework (IB-GFDF) is proposed integrating the consortium blockchain and the group-decision-based best-worst method (one of the multi-criteria decision-making methods). In general, blockchain is an enabling and promising technology to facilitate shared and immutable data management across an entire computer network [6]. Through the use of consortium blockchain, a peer-to-peer (P2P) freight network was built for the permissioned enterprises in the ASCM such that the data exchange and transmission within the network become

decentralized and secure. Rather than centralization of the freight and shipment information, the blockchain-based framework can effectively reach the consensus on the selection decisions for carrier, shipping lane and 3PL company among a number of decision makers in the P2P freight network. Additionally, the decentralized infrastructure provides secure and immutable data management for the pairwise comparison process across the network. Updated pairwise comparisons are then used to determine the most appropriate carrier, shipping lane, and 3PL company in the global freight management by means of Bayesian best-worst method. To be specific, this is a probabilistic group decision-making approach, where opinions from multiple decision makers can be effectively analyzed to obtain the overall decision [7]. To examine the feasibility of the proposed framework, a case study in an Australian ASC firm is conducted, where improving its global freight management practice is the focus. With the aid of the proposed framework, the formulation of pairwise comparisons is relatively fair where stakeholders in the P2P freight network can participate via blockchain technology in a decentralized manner. Therefore, the selection strategy and result of the carrier, shipping lane, and 3PL company can be justified and trusted in the entire P2P freight network.

The contribution and novelty of this study are summarized in the below two facets. Firstly, the essential decision criteria of the global freight management in ASCs are determined through reviewing the extant literature in aspects of carriers, shipping lanes, and 3PL service providers. The sub-criteria of the above three aspects are also identified to drive the multi-criteria decision analytics process for the global freight management, which is valuable for supporting the development of end-to-end supply chain solutions. Secondly, the industrial blockchain is incorporated into the multi-criteria decision framework of the global freight management, which create a new synergy between blockchain technology and the multi-criteria decision-making (MCDM) approach, namely Bayesian best-worst method in this study, to obtain decentralized and immutable data management over the peer-to-peer freight network. Such a framework is regarded to be novel in the MCDM research in facilitating the pairwise comparison process for group-based decision making. Overall, this study contributes not only research and industrial development of the business process in global freight management but also a methodological enhancement in the context of MCDM.

This paper is organized as follows. Section 1 is the introduction. In Section 2, related literature is reviewed to describe the trends in global freight management, blockchain technology, and MCDM approaches. Section 3 presents the decision criteria of the global freight management in the existing business process of the ASCM, while the formulation of the IB-GFDF in the P2P freight network is described. A case study in an Australian firm is presented in Section 4. Section 5 focuses on implications to the research of business process management based on this study, as well as the comparative analysis. Finally, Section 6 draws the conclusion and recommendations for future work.

## 2. Literature Review

In this section, literature in the aspects of (i) global freight management in the ASCM, (ii) evolution of blockchain technology, and (iii) multi-criteria decision-making applications is reviewed.

### 2.1. Global Freight Management in the ASCM

International supply chains for agricultural products involve a number of stakeholders, namely farmers, exporters, carriers, logistics service providers, importers, wholesalers, retailers, consumers, and governments. All stakeholders have their own business logic, preferences, behavioral patterns, and operational requirements. Additionally, different jurisdictional rules and laws on customs regulate the interactions of the stakeholders and freight operations in the global agricultural supply chain [8]. Since agricultural products are perishable and time- and temperature-sensitive in nature, product quality is dynamic along the entire ASCM, which is subject to a quality deterioration process through chemical

and biochemical reactions [9]. Shelf life was developed as an indicator to quantify the quality of perishables handled in supply chains, describing a period of time the product remains acceptable for consumers.

Recent research studies on global freight management focus on the following aspects: (i) inventory tracking and traceability [10], (ii) horizontal collaboration [11], and (iii) operational reliability [12]. Firstly, having detailed information about origin, shelf life, and list of ingredients about food products is important to most end consumers, while an effective inventory tracking system helps producers, distributors, and retailers with the end-to-end monitoring of products. It facilitates product traceability along the whole supply chain, and consumer confidence is therefore effectively built as a core business competitive edge. Secondly, inventory tracking and traceability and horizontal collaborations in transportation, warehousing, and inventory management throughout the entire supply chain have been the focus of some previous studies. The research on the reduction of operational and overhead costs has focused on achieving sustainable and competitive supply chain goals. For example, partnerships among ASCM actors can be leveraged to develop new shared infrastructure, such as food processing and cold storage facilities, and to improve the reliability and off-season supply of regional food. Such a partnership also enables the creation of a shared vehicle fleet that can support efficient vehicle utilization, backhauling, and on-time deliveries to customers. Thirdly, operational reliability is a key to the success of the global freight management to prevent the failure of or disruption to supply chain activities, in which supply chain risk and resilience management strategies are therefore actively investigated [13]. To better control resources and strengthen the flexibility in ASCM, logistics outsourcing has emerged since logistics operations are regarded as non-core business functions to most companies. Therefore, 3PL service providers occur to enhance the effectiveness and efficiency of the supply chains [14].

## 2.2. Evolution of Blockchain Technology

In order to develop a blockchain-based decision framework, the foundation of blockchain technology is reviewed. Blockchain was first explored through the establishment of a peer-to-peer electronic cash system in 2008 [15]. Generally speaking, blockchain is defined as a database system in which data stored in blocks are chained together and distributed in the P2P network. There are three generations of blockchain technology, from blockchain 1.0 to blockchain 3.0, where blockchain 1.0 generally refers to the cryptocurrency built by using the fundamental blockchain mechanism, for example Bitcoin [16]. When Ethereum was founded in 2013, the era of blockchain 2.0 came to incorporate smart contracts to develop more financial applications other than cryptocurrency, and the system autonomy and intelligence greatly improved [17]. Since blockchain technology has become relatively mature, a number of industrial applications, such as supply chain traceability and health care management, have been developed to establish trust and consensus in business models [6,18]. This recent era is named blockchain 3.0, where applications are designed and developed on the consortium blockchain mechanism. In the field of logistics and supply chain management, Orji et al. reported that blockchain is vital for facilitating cooperation between supply chain members due to its security, transparency, and traceability [19]. Influences on ASCM objectives, including cost, product quality, risk mitigation, sustainability, flexibility, and efficiency have been found [20]. To apply the blockchain technology in ASCs, Kamble et al. examined the relationships among adoption enablers and identified that traceability, auditability, and immutability were the top three reasons for blockchain implementation [21]. Since blockchain development is still at the preliminary stage, Mirabelli and Solina advocated formulating more blockchain use cases and evaluating the corresponding impacts on ASCs [22]. Beyond the blockchain-driven financial services, future blockchain implementation can be extended to identity management, supply chain traceability, health care, and so on [23]. Consequently, there is room to further explore the potential of consortium blockchain in global freight management so as to provide not only trust development but also reliable decision making in the business network.

### 2.3. Multi-Criteria Decision-Making Applications

Multi-criteria decision-making (MCDM) methodology is a sub-field of operations research proposed for evaluating conflicting criteria and sub-criteria in decision making [24]. There are a wide range of MCDM methods, such as analytical hierarchy (AHP), best-worst method (BWM), and grey relational analysis (GRA). Generally speaking, BWM is a pairwise-comparison-based MCDM approach that weighs decision-making criteria for aiding the decision-making process [25]. Instead of completing a full pairwise comparison matrix like AHP, two vectors, namely, the best to others and others to the worst, are considered in the optimization model for minimizing the anchoring bias of decision makers. Among existing MCDM approaches, BWM is considered in this study because it outperforms the AHP method in terms of ease of pairwise comparisons and measurement consistency. Extensive applications in the context of logistics and supply chain management based on BWM are exploited, such as sustainability assessment [26], performance indication [27], and port management [28]. For the pairwise comparisons, Saaty's scale from 1 to 9 is adopted to compare the extent of importance between two independent criteria. In global freight management, a group decision-making process is preferred for synthesizing different decision makers' opinions, and therefore the Bayesian best-worst method incorporating probabilistic opinions is relatively promising and appropriate (Mohammadi and Rezaei, 2020). Recently, the Bayesian BWM has been applied in a wide range of decision-making problems, such as risk assessments of health, safety, and the environment in textile production [29] and the prioritization of new product development projects [30]. Its capacity to simultaneously analyze the pairwise comparisons from a group of decision makers has been proven. The application of the Bayesian BWM could be extended to global freight management in this study.

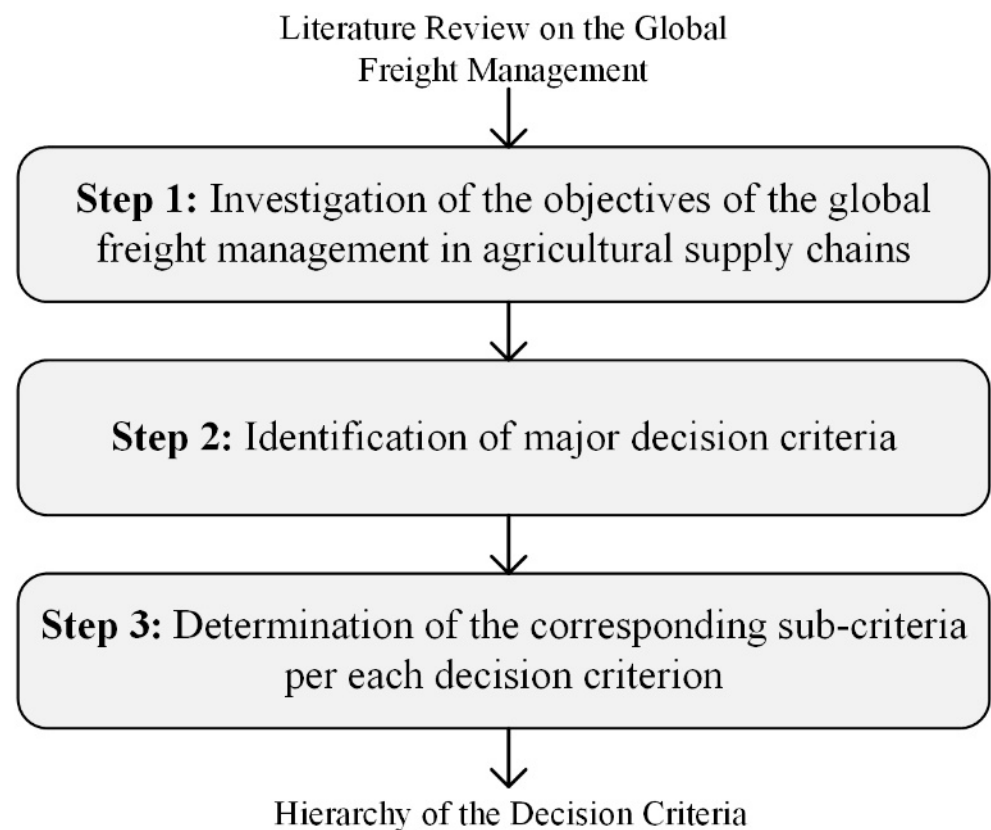
In summary, the importance of global freight management in ASCs has become even more apparent due to globalization, particularly in the free trade agreements on the RCEP. A wide range of factors, including carriers, shipping lanes, and 3PL service providers, should be taken into consideration in global freight-related decisions. Due to the presence of consortium blockchain, there is room to formulate a mutually trusted and secure platform for conducting pairwise comparisons in the MCDM methods, and therefore a commonly-agreed strategy on global freight management can be established.

## 3. Methodology

In order to address the above challenges related to the global freight management in ASCs, a research methodology consisting of the formulation of decision criteria and decision analytics framework is proposed. The aforementioned methodology can be applied to the global freight network, in which the stakeholders in different countries can share their preferences so as to derive effective end-to-end supply chain solutions. For the case study in the later section, 12 decision-making teams as the decision makers in the MCDM process who are the domain experts in the international freight business were invited in 2021 to participate the pairwise comparisons so as to examine the methodological feasibility and performance.

### 3.1. Decision Criteria of Global Freight Management in Agricultural Supply Chains

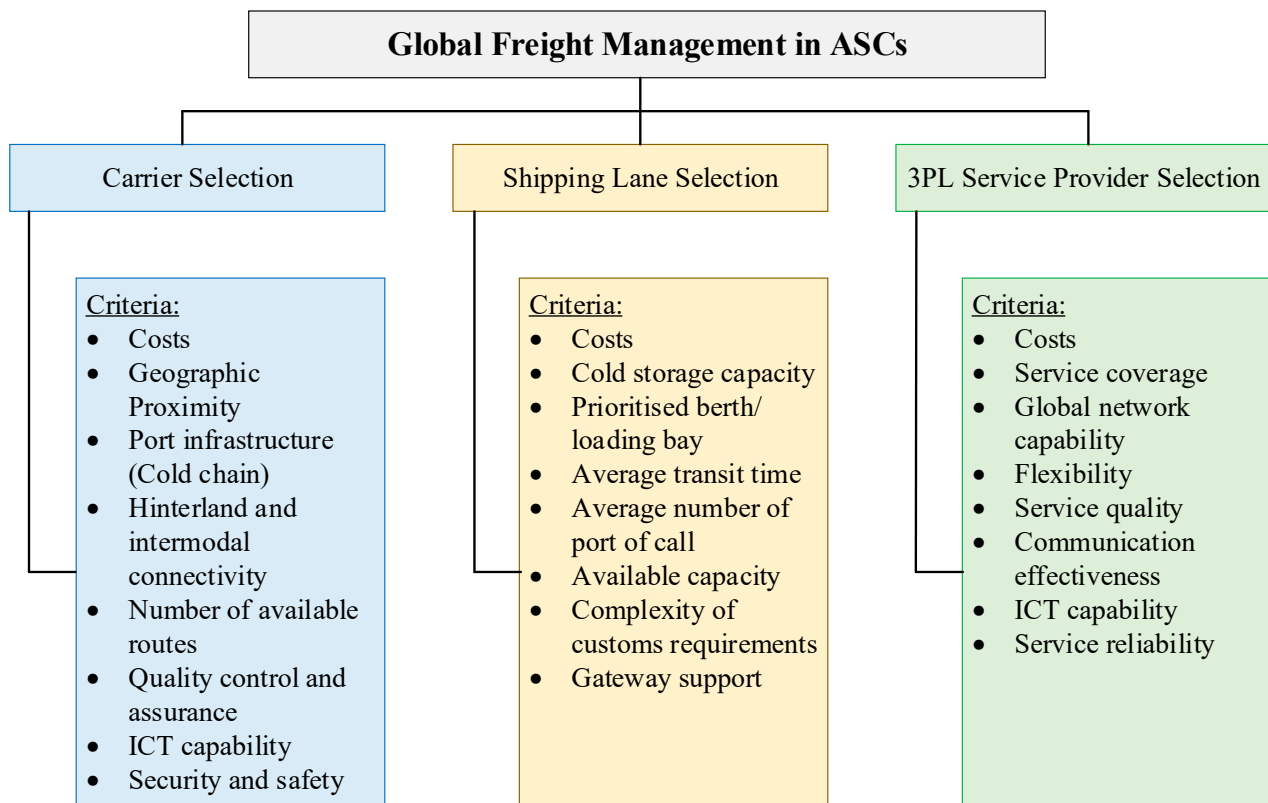
Prior to the methodological design and development to address the problems of multi-criteria global freight management, the decision criteria were determined through reviewing recent related literature to derive the size of pairwise comparisons considered in the MCDM approaches. The procedure of the criteria selection is shown in Figure 2 and summarized as follows: (i) summarizing objectives of the global freight management in ASCs (level 0), (ii) identifying major criteria (level 1) in the global freight management, and (iii) determining the sub-criteria (level 2) under each major criterion. Subsequently, a hierarchical structure of the global freight management in ASCs can be formulated to support the multi-criteria decision-making process.



**Figure 2.** Procedure to formulate the decision-criteria hierarchy.

First and foremost, global freight management plays an essential role in ASCs in providing customers, including shippers and consignees, with a wide range of freight forwarding and logistics services, for example multimodal transport services, warehousing, and domestic transportation [31]. The main objective of the global freight management is to achieve economic and environmental sustainability among all stakeholders. For the end-to-end movement of goods globally, shippers initially consign the goods to 3PL/freight forwarding companies for the customization of transportation and storage services. Based on shippers' requirements, the goods are packed as cargoes for arranging freight coordination with carriers, while the best-fit shipping lane is determined for distributing the cargoes to consignees' locations. Subsequently, three major criteria in the level 1, namely carrier selection, shipping lane selection, and 3PL service provider selection, are chosen in this study.

Regarding the global freight management in agricultural supply chains (ASC), three aspects, namely carrier selection, shipping lane selection, and 3PL service provider selection, are considered for obtaining the most effective and appropriate freight solution, as depicted in Figure 3. Particularly, cross-border logistics operations between various distribution centers located in different countries are the focus of this study. In this study, selection problems of carriers, shipping lanes, and 3PL service providers are addressed, while the corresponding sub-criteria are determined through synthesizing the existing literature. By combining the criteria and sub-criteria as a whole, the multi-criteria decision-making hierarchy can be developed to effectively conduct pairwise comparisons and systematically prioritize the criteria. Therefore, the corresponding insights for the global freight management in ASCs can be summarized.



**Figure 3.** Decision criteria of the global freight management in agricultural supply chains.

For the carrier selection, costs, geographic proximity from shippers' locations to carriers, and port infrastructure are considered the basic features of carrier services [32,33]. Additionally, the hinterland and intermodal connectivity are important for handling cargoes in inland centers for gateway connection and long-distance circulation [34]. On the operational aspect, operational efficiency (e.g., lead time and throughput time) and the number of available routes are considered, and quality control and assurance should be aware of inspecting whether the carriers are technically capable of handling agricultural products in cross-border logistics operations [35]. Instead of merely providing demanded services and solutions, service quality with respect to the documentation process and customer service determines the capability of improving value for customers. Regarding the management capabilities of carriers, information and communication technology (ICT) and level of security and safety are considered for measuring enterprise system interconnectivity and risks at operations [36]. The detailed definitions of the sub-criteria for the carrier selection are listed as follows:

- Costs (C11) [in USD]: The operational costs for cargo handling offered by the carriers, for example handling charges, cost of pilotage towage, customs clearance, and warehousing cost.
- Geographic proximity (C12) [in km]: The geographic distance between ASC companies and carriers' facilities.
- Port infrastructure for cold chain (C13) [in units]: The port facilities to handle frozen, chilled, and temperature-controlled goods, for example cold storage rooms and refrigerated trucks.
- Hinterland and intermodal connectivity (C14) [in scale]: The operational smoothness from the port to the inland transportation/other transportation modes.
- Number of available routes (C15) [in units]: The flexibility of shipping routes to consign the shipments offered by the carriers.
- Quality control and assurance (C16) [in scale]: Measures to control and monitor the service quality of carriers' operations to 3PL companies and shippers so as to maintain the desired service level.

- ICT capability (C17) [in scale]: Capabilities related to applying latest information and communication technologies to facilitate communication and achieve operational excellence.
- Security and safety (C18) [in scale]: Cybersecurity and safety measures to avoid the attack and leakage on sensitive and confidential data shared among the stakeholders.

For shipping lane selections, supply chain decision makers generally consider (i) costs, (ii) cold storage capacity to satisfy environmental requirements of agricultural products, (iii) prioritized berth/loading bay to load and unload cargoes, (iv) average transit time to reach destination, (v) the average number of ports of call during the shipment journeys, (vi) available capacity to handle cargoes, (vii) complexity of customs requirements, and (viii) gateway support to facilitate inland distribution [37–39]. Differing from typical shipment lane selection, the shipping lane selected for this study should equip the capability of handling agricultural products, while designated environmental requirements are satisfied to maintain a required quality level. Since agricultural products are time- and temperature-sensitive in nature, shipment coordination for agricultural products requires additional attention to prevent shipment delay and information leakage during the supply chain. Instead of registering straightforward import and export licenses, designated importers and exporters are required to obtain the pre-shipment license and hygiene certificate following regional laws and regulations. Consequently, intermodal transportation is required to maintain the reasonable effectiveness and efficiency of the shipments internationally. The detailed definitions of the sub-criteria for the shipping lane selection are listed as follows:

- Costs (C21) [in USD]: The cost of consigning the cargoes on specific shipping lane between two ports of destinations.
- Cold storage capability (C22) [in scale]: Cold storage containers used during the freight with sufficient power supply throughout the entire period of freight.
- Prioritized berth/loading bay (C23) [in scale]: Prioritization of using the berth and loading bays to load/unload the cargoes.
- Average transit time (C24) [in hours]: The time of transporting the shipments between two destinations.
- Average number of ports of call (C25) [in units]: Average number of the intermediate stops for a ship on its scheduled shipping journey due to the cargo loading/unloading, supplies of daily commodity and fuel.
- Available capacity (C26) [in scale]: Availability to consign additional cargoes on the specific shipping lane
- Complexity of customs requirements (C27) [in scale]: Compliance with national customs requirements and regulations in various regions and countries.
- Gateway support (C28) [in scale]: The support at the gateway for the freight in-transit between transport providers as well as the customs clearance.

For the 3PL service provider selection, similar to the carrier selection, the factors of costs and ICT capability are fundamental to evaluate the business suitability, which service quality and reliability are additionally considered to maintain an acceptable service level [40,41]. Since 3PL companies play a role in connecting multiple supply chain members, such as couriers, agents, shippers, and consignees, all-round and reliable services on shipment coordination are provided. Moreover, the ability of the 3PL service providers is measured by their global network, service flexibility, and communication effectiveness, in which the corresponding competence centers are formulated to maximize the supply chain value. An extended global network for shipment coordination is advantageous to establish cost-effective and one-stop freight forwarding services. The detailed definitions of the sub-criteria for the 3PL selection are listed as follows:



- Costs (C31) [in USD]: The costs of 3PL services, including pickup, delivery, storage, coordination between shippers and consignees, documentation etc.
- Service coverage (C32) [in scale]: Coverage of 3PL services, for example freight forwarding, road transportation, and other value-added services.
- Global network capability (C33) [in scale]: Size of freight/agent network for international freight forwarding.
- Flexibility (C34) [in scale]: Flexible to fit the culture and customer freight packages based on contracted and ad hoc requirements.
- Service quality (C35) [in scale]: Service level of the 3PL services provided to the customers.
- Communication effectiveness (C36) [in scale]: Efficient and friendly communication channels for the shipment enquiries, as well as the customer support.
- ICT capability (C37) [in scale]: Capabilities on applying latest information and communication technologies to facilitate communication and achieve operational excellence.
- Service reliability (C38) [in scale]: Stability of the serviced provided by 3PL companies, which represents the trustworthiness and reliability for their services.

In summary, effective global freight management in ASCs considers three selection problems: carriers, shipping lanes, and 3PL service providers. In the past, such selection problems were solely solved by a small group of decision makers regardless of the involvement of other supply chain members, such that subjectivity in decisions and bias of the supply chain decision makers could not be avoided. By leveraging the benefits of consortium blockchain technology, an industrial blockchain for data acquisition with regard to pairwise comparisons is proposed, and therefore the group-decision-based best-worst method is then applied to make the selection decisions systematically in the global freight forwarding network.

### 3.2. Design of an Industrial Blockchain-Based Global Freight Decision Framework (IB-GFDF)

In order to determine the commonly agreed-on global freight management solution, an industrial blockchain-based global freight decision framework (IB-GFDF) was proposed in this study to consolidate the data of pairwise comparisons considering the inputs from a group of decision makers to address the problems of the carrier selection, shipping lane selection, and 3PL service provider selection. The process flow of the proposed framework is depicted in Figure 4. Regarding the global freight management in ASCs, the key stakeholders include shippers, 3PL service providers, carriers, oversea agents, and consignees. Generally speaking, shippers authorize a contracted 3PL service provider who is responsible for coordinating the shipments with carriers and overseas agents under the commonly agreed-upon Incoterms. In view of the complicated freight forwarding process, a systematic approach based on blockchain technology is suggested in this study for facilitating data acquisition and maintaining high data security and reliability due to the immutable nature of the blockchain. The entire proposed framework can be described into two major aspects, namely, (i) design a, industrial blockchain platform and (ii) conduct pairwise comparisons and Bayesian best-worst method.

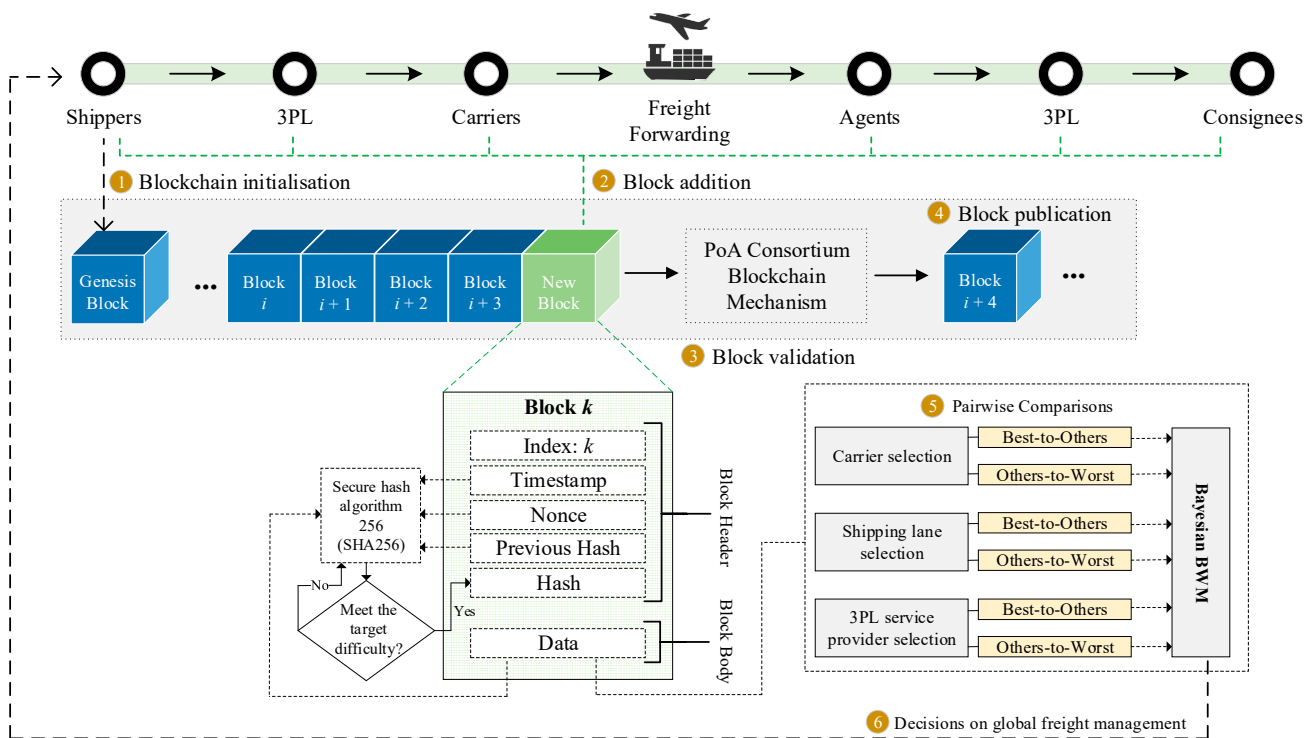


Figure 4. Schematic diagram of the IB-GFDF.

### 3.2.1. Design of an Industrial Blockchain Platform

Differing from traditional blockchain for cryptocurrency services, the industrial blockchain proposed in this framework refers to the consortium blockchain technology (also called the federated blockchain) to formulate an enterprise-wide, energy-efficient, and practical blockchain solution [42]. Instead of a permissionless blockchain solution, the entire system can be effectively governed by multiple organizations, namely, supply chain stakeholders, in the consortium/federated blockchain, which is a hybrid form of public and private blockchains. It is relatively efficient to maintain the blockchain network across various companies, but not open the entire system for the public. The core objective of this industrial blockchain is to consolidate the data of pairwise comparisons contributed by various stakeholders, and the pairwise comparisons are subsequently analyzed using Bayesian best-worst method. For the deployment of the industrial blockchain, four key applications roles are considered, including initial counterparty (i.e., shipper), counterparty, owner of the supply chain, and observer to monitor the supply chain activities. Counterparties, namely, the supply chain stakeholders, are not allowed to involve the selection decision-making process where conflicts of interest may occur. For example, stakeholders who are playing the role of carriers in the supply chain network cannot be involved in the carrier selection decision. As shown in Figure 3, the block structure is proposed that contains block index, timestamp, nonce, previous hash, current hash, and data, where the hash values are built by using a secure hash algorithm (SHA) 256 and specified target difficulty. According to the decision criteria discussed in Section 3, three sets of pairwise comparisons for carrier selection, shipping lane selection, and 3PL service provider selection are required for evaluating the importance of the decision criteria. Moreover, subject to the number of potential carriers, shipping lanes, and 3PL service providers, the corresponding pairwise comparisons are conducted to select the most appropriate carrier, shipping lane, and 3PL service provider in the specific ASCs. For the pairwise comparisons under the Bayesian BWM, vectors of best-to-others ( $V_{B2O}$ ) and others-to-worst ( $V_{O2W}$ ) are built by assigning the weightings following Saaty’s scale, as in Equations (1) and (2), respectively. The value  $n$  denotes the total number of criteria considered in the pairwise comparison, and  $v_{Bk}$  and  $v_{kW}$  represent the preference in the Saaty’s scale of (i) the best criterion to other criteria, and (ii) other criteria over the worst criterion. Also,  $v_{Bi}$  and  $v_{jW}$  are equal to 1 when  $i$  and  $j$  are referred to the best

and worst criteria, respectively, where  $i \neq j$ . Therefore, the use of industrial blockchain opens a permissioned platform to update the pairwise comparisons continuously, subject to the changes in the business environment.

$$V_{B2O} = (v_{B1}, v_{B2}, \dots, v_{Bn}) \tag{1}$$

$$V_{O2W} = (v_{1W}, v_{2W}, \dots, v_{nW})^T \tag{2}$$

To obtain the consensus in the global freight network for the industrial blockchain platform, the proof of authority (PoA) which is regarded as Istanbul Byzantine Fault Tolerance (IBFT) 2.0 is considered, rather than the traditional consensus mechanisms, for example, proof of work and proof of stake. Using the PoA, a group of designated and trustworthy nodes are assigned as validators to proceed the transactions and updates in the peer-to-peer network, which is energy-efficient and resource-effective for reaching the consensus. For building industrial applications in the consortium network, PoA is advantageous in term of block finality, liveness, and transaction throughput rate, given that authenticated validators are pre-determined [43]. In the global freight network, the owner and its delegates play the role of block validators, where a minimum of four validators are required in the PoA mechanism. System fault tolerance can be improved by having more validators in the blockchain platform. In view of the identity management, system nodes and validators are assigned with unique public identifiers (IDs). The formal identification of validators is needed to grant for additional privilege in the block forging process, while other system nodes can only provide the updates of the pairwise comparisons over the network. Consequently, the industrial blockchain can be formulated to collect the data of pairwise comparisons securely, and the trend of the perspectives on carriers, shipping lanes, and 3PL service providers can be investigated.

### 3.2.2. Pairwise Comparisons and Bayesian Best-Worst Method

For incorporating the probabilistic and group decision-making behaviors in BWM, Bayesian BWM is developed to evaluate the overall optimal weight of criteria using the concept of conditional probability [7]. Rezaei reported that BWM itself outperforms AHP, a well-known multi-criteria decision-making method [25,44], in terms of the complexity of pairwise comparison and result consistency, and thus, the BWM-based approach was chosen in this study to support the decision-making processes for choosing carriers, shipping lanes, and 3PL service providers for the global freight management. However, the traditional BWM is not effective for group-based decision-making processes, which includes diversified opinions from independent decision makers. This study is motivated to adopt Bayesian BWM to address the multi-criteria and group-based decision-making problems. There are  $m$  decision makers ( $m = 1, 2, \dots, M$ ) to evaluate the criteria  $C = \{c_1, c_2, \dots, c_n\}$  by making  $V_{B2O}^m$  and  $V_{O2W}^m$ . The optimal weight  $w^m$  for decision maker  $m$  is calculated, and the aggregated weight  $w^*$  for all decision makers are obtained by averaging all the optimal weights, i.e.,  $w^{1:M}$ . Therefore, the joint probability distribution to conduct statistical inference is presented in Equation (3), and the probability of each individual variable can be calculated by following the relationship of  $P(x) = \sum_y P(x, y)$ , where  $x$  and  $y$  are two arbitrary random variables. The probabilistic model of the Bayesian BWM is graphically illustrated as shown in Figure 5. The best-to-others and others-to-worst vectors are the observed variables collected from the pairwise comparisons, and the weights presented in circle nodes are the estimates of the probabilistic model.

$$P(w^*, w^{1:M} | V_{B2O}^{1:M}, V_{O2W}^{1:M}) \tag{3}$$

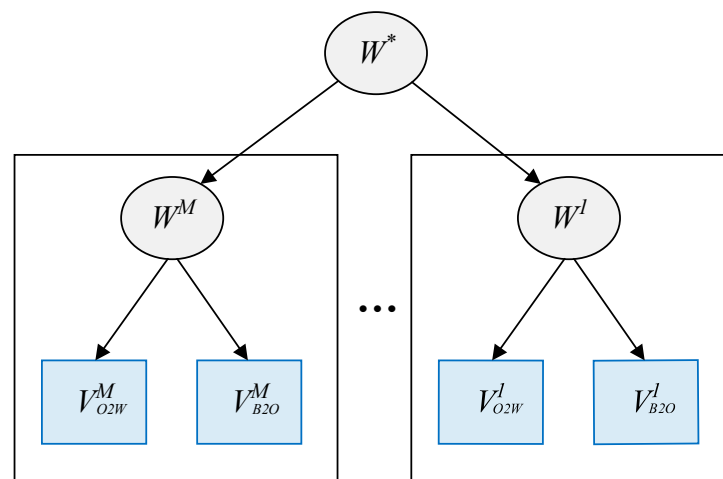


Figure 5. Graphical illustration of the probabilistic model of the Bayesian BWM.

Regarding the statistically conditional inference, the joint probability distribution can be further extended to Equation (4) according to the Bayes rule. Equation (4) implies that the estimation of parameters relies on other variables and that there is thus a hierarchy to chain the different parameters in the model. To compute the posterior distribution in the above model, Markov-chain Monte Carlo techniques are adopted, where the ‘just another Gibbs sampler’ is a well-known module for sampling and evaluating the posterior in Equation (4). Consequently, the optimal weights for all the decision makers, and aggregated weight can be computed by using the probabilistic model, and the confidence between a pair of criteria can be inspected, named as ‘credal ranking’.

$$P(w^*, w^{1:M} | V_{B2O}^{1:M}, V_{O2W}^{1:M}) = P(w^*) \prod_m P(V_{O2W}^m | w^m) P(V_{B2O}^m | w^m) P(w^m | w^*) \quad (4)$$

#### 4. Case Study in an Australian Context

To verify the contribution of the proposed framework in the field of global freight management, a case study was conducted to illustrate the proposed framework step by step, supported by an Australian firm working in agricultural supply chains. Due to the advocacy of the RCEP across multiple countries, free trade agreements definitely open more business opportunities and market potential, but the market competition becomes fierce and dynamic. With regard to agricultural supply chains, Australia is playing a critical role by exporting agricultural products all around the world: approximately 70% of agricultural output, particularly beef, mutton, canola, sugar, and wheat, is exported to Asian markets such as Korea, Singapore and Hong Kong [45]. The Asian demand for agriculture is expected to be doubled between 2007 and 2050 for high-value, high-quality agricultural and food products. In view of the above fierce business environment, Australian firms are motivated to establish effective global freight management to improve cost-effectiveness and business sustainability. In this case study, the entire implementation of the proposed framework is divided into three stages, namely, (i) deployment of the industrial blockchain, (ii) deployment of the Bayesian BWM, and (iii) results from the selection decision.

##### 4.1. Stage 1: Deployment of the Industrial Blockchain

According to the design of industrial blockchain presented in Section 4.1, Microsoft Azure blockchain workbench was selected for developing the system prototype based on the decentralized digital ledger technology, where the PoA is an active consensus mechanism. For the Microsoft Azure blockchain workbench, the standard packages, including APP service plan, application insights, event grid, Azure key vault, service bus, SQL database, Azure storage account, virtual machine with the capacity of 1, and Azure

blockchain service, are defined. The blockchain resource group for the proposed system is formulated, while Azure Active Directory (AD) is configured to register the application. Moreover, the Ethereum PoA blockchain network is selected in the workbench. By doing so, a jumpstart blockchain system can be built to customize the smart contracts and business logic for the global freight management. The applications roles of counterparty (carriers/3PL service providers/others), owner and observer are defined in the permissioned decision framework, which have the privilege to conduct the pairwise comparisons on carrier selection, shipping lane selection, and 3PL service provider selection. In the permissioned blockchain, each data block contains the index, timestamp, nonce, hash value, and previous hash value and data of pairwise comparisons, where the hash values are generated using the SHA256 algorithm. By applying the IBFT 2.0 consensus algorithm in Azure blockchain workbench, or called as proof of authority (PoA), the owner of the supply chain is regarded as the validators to verify the updates of pairwise comparisons so as to prevent malicious actions and data tampering.

Additionally, the expected peer-to-peer network size is  $3F + 1$ , where  $F$  denotes the estimated number of Byzantine nodes. The block validation process requires a number of validators defined in the network to sign the block digitally, and the blocks are approved when more than two-thirds of validators agree with the transactions. In other words, the minimum network size of the above permissioned blockchain is four for considering one Byzantine node that is malicious to the permissioned network. Once the nodes are authenticated in the P2P network, they are authorized to update the data of pairwise comparison, while the supply chain owner can deploy the Bayesian BWM to analyze the final pairwise comparisons. The workflow detail of the pairwise comparison process in the decision framework is illustrated in Figure 6. In the Microsoft Azure blockchain workbench, a smart contract code in the solidity format to organize the instance field variables, the constructor, and the function of the updates about pairwise comparison is made to be invoked at the system initialization. In addition, configuration metadata in the JavaScript Object Notation (JSON) format to list out the application roles and states is prepared. Therefore, a system prototype of the proposed framework can be built effectively in the Azure blockchain services. In order to prevent the conflict of interest, the carriers and 3PL service providers cannot involve the pairwise comparisons on carrier selection and 3PL service provider selection, respectively. In view of the above permissioned network, a group decision-making process is built to analyze the opinions from multiple stakeholders in the permission freight network, and therefore fair and commonly-agreed decisions on global freight management can be made.

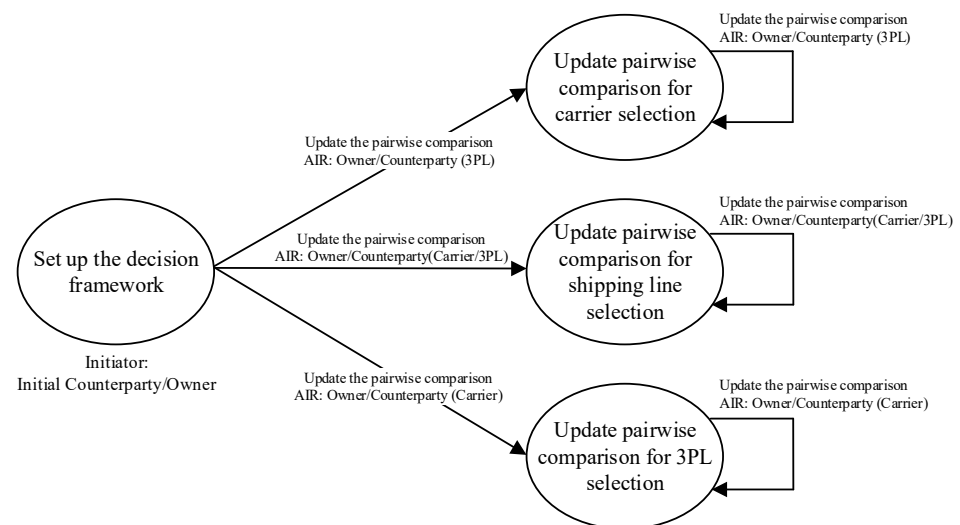


Figure 6. Workflow details of the pairwise comparison process in the permissioned blockchain.

4.2. Stage 2: Deployment of the Bayesian BWM

In this case study, an agricultural supply chain managed by the case company was selected as the focus for demonstrating the deployment of the proposed Bayesian BWM method. The authors’ knowledge of the internal operations of the case study was utilized, and five potential carriers and five 3PL service providers as recommended by the case company were included; five potential shipping lanes from Australia to various ports in China were considered. The reasons behind the above selection of carriers and 3PL service providers are based on the company’s business network and customers’ preferences. In other words, the most frequently used carriers and 3PL service providers based on historical shipments were invited to participate in the decision-making process. Regarding their demographic characteristics, three Australian sea-freight and two air-freight carriers were invited to conduct and update the pairwise comparisons of shipping lane and 3PL selection. Similarly, five international 3PL companies were invited that have extensive agent networks in China, including Shanghai, Shenzhen, Guangzhou, Ningbo, and Hong Kong, were invited because representatives would be knowledgeable about handling Australia-China agricultural shipments. In short, the selection of the decision makers from carriers and 3PL companies are subject to their global freight capabilities and commercial intercourse in the past such that the decision framework can be built by means of the consortium blockchain technology for the case company.

According to the hierarchical structure presented in Figure 3, nine pairwise comparison tables (one table for evaluating the weights between eight criteria and eight tables for evaluating the weights of the alternatives based on each criterion) were formulated for each selection problem. Therefore, 27 data tables about the pairwise comparisons were considered in this study. Each data table consisted of the best-to-others and other-to-worst comparisons. In this study, the Bayesian BWM was run on MATLAB® R2019a environment using the Bayesian BWM solver developed by Mohammadi and Rezaei in 2019 (URL: <https://github.com/Majeed7/BayesianBWM> (accessed on 17 August 2022)).

To illustrate the use of Bayesian BWM, the pairwise comparisons of the decision criteria of the carrier selection problem are elaborated in detail. Since the five carriers cannot be involved in the carrier selection problem, contributions from only seven decision making actors, namely D1 to D7 (two from the case company, and five from the 3PL service providers), were considered for the pairwise comparisons. The corresponding data of pairwise comparisons were extracted from the permissioned blockchain platform, as shown in Tables 1 and 2. Moreover, eight criteria in the carrier selection problem, namely costs (C11), geographic proximity (C12), port infrastructure (C13), hinterland and intermodal connectivity (C14), number of available routes (C15), quality control and assurance (C16), ICT capability (C17), and security and safety (C18) are covered.

**Table 1.** Best-to-others comparison between eight criteria in the carrier selection problem.

	C11	C12	C13	C14	C15	C16	C17	C18
D1	1	9	8	4	7	9	6	8
D2	6	3	6	9	8	1	3	3
D3	2	3	5	2	6	2	1	7
D4	7	2	2	3	4	1	3	8
D5	9	8	1	7	3	8	5	9
D6	6	3	1	3	8	3	9	4
D7	9	2	1	2	9	8	9	5

Remark: D1–D7 denote the decision makers in the selection problem, while C11–C18 denote the eight criteria in the carrier selection problem.

**Table 2.** Others-to-worst comparison between eight criteria in the carrier selection problem.

	C11	C12	C13	C14	C15	C16	C17	C18
D1	9	3	6	2	1	3	5	3
D2	6	5	1	9	8	4	2	6
D3	4	9	3	1	3	2	7	6
D4	6	3	7	6	1	5	5	6
D5	6	4	8	1	9	9	4	7
D6	1	8	8	3	3	3	8	4
D7	2	8	8	5	4	7	8	1

Remark: D1–D7 denote the decision makers in the selection problem, while C11–C18 denote the eight criteria in the carrier selection problem.

Subsequently, two  $7 \times 8$  matrices for pairwise comparisons on the decision criteria of the carrier selection problem were built. After the deployment of the Bayesian BWM, the average weights of the eight criteria were: 0.1137, 0.1443, 0.1549, 0.1212, 0.0980, 0.1279, 0.1321, 0.1078, and the statistical confidence between the criteria is expressed in Table 3. The statistical confidence values between criteria show the strengths and importance when comparing two criteria, where the high confidence value refers to the superiority of the antecedent criterion. For example, the confidence value of 0.8669 from C12 to C11 represents the geographical proximity is more important than costs, with the confidence of 0.8669 among all involved decision makers. Traditionally, the average weights of criteria are compared to evaluate the superiority which is a zero-one decision, which does not consider the probabilistic behavior of the decision makers.

**Table 3.** Confidence value between eight decision criteria in the carrier selection problem.

	C11	C12	C13	C14	C15	C16	C17	C18
C11	0	0.1331	0.0764	0.3879	0.7453	0.2928	0.2467	0.5952
C12	0.8669	0	0.3681	0.7894	0.9601	0.7172	0.6619	0.9120
C13	0.9236	0.6319	0	0.8715	0.9797	0.8160	0.7748	0.9529
C14	0.6121	0.2106	0.1285	0	0.8308	0.4019	0.3467	0.7028
C15	0.2546	0.0399	0.0203	0.1692	0	0.1170	0.0900	0.3366
C16	0.7071	0.2828	0.1840	0.5981	0.8830	0	0.4395	0.7803
C17	0.7533	0.3381	0.2251	0.6533	0.9100	0.5605	0	0.8227
C18	0.4048	0.0880	0.0472	0.2972	0.6634	0.2197	0.1772	0

With the use of Bayesian BWM, the superiority can be further investigated to see the result consistency and statistical confidence to obtain the results. Consequently, the credal ranking can be visualized to graphically illustrate the confidence values between the eight decision criteria, as shown in Figure 7. It is found that the port infrastructure, geographic proximity, and ICT capability were the three most important factors in selecting a carrier in the Australian context.

By repeating the above procedures to analyze the pairwise comparisons of five potential carriers, the average weights of the carriers with respect to decision criteria were obtained and named priority vectors. The adjusted weights and priority vectors were aggregated by summing the product of adjusting weights and priority factors, as shown in Table 4. Therefore, carrier 2 with the aggregated weight of 0.3048 was deemed to be the most appropriate carrier in the freight network from the perspective of the case company.

In order to make the decisions on shipping lane selection and 3PL service provider selection, the most appropriate shipping lane and 3PL service provider can also be obtained with the largest aggregated weight to handle the freight on designated agricultural supply chains. With the aid of the proposed framework, the decision makers can conveniently update a partial pairwise comparison based on their expertise and professional views, instead of completing the whole pairwise comparison again. Moreover, the trend of

pairwise comparisons which refer to the perspective of the supply chain stakeholders can be constructed by leveraging the benefits of blockchain technology.

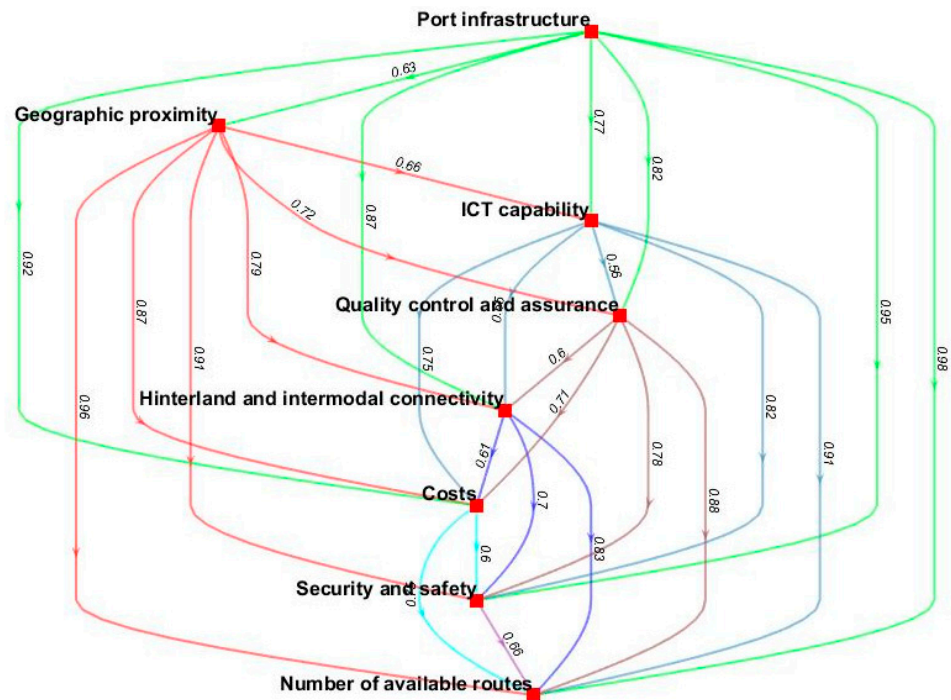


Figure 7. Graphical illustration of the credal ranking of the eight criteria in the carrier selection problem.

Table 4. Aggregated result summary of the carrier selection problem.

Criteria (Adjusted Weight)	Carrier 1	Carrier 2	Carrier 3	Carrier 4	Carrier 5
C11 (0.1137)	0.0327	0.4333	0.0161	0.3090	0.2318
C12 (0.1443)	0.0864	0.3984	0.1481	0.3500	0.3855
C13 (0.1549)	0.0425	0.3079	0.3146	0.2366	0.0983
C14 (0.1212)	0.2392	0.1887	0.1807	0.3225	0.1830
C15 (0.0980)	0.0334	0.1242	0.2259	0.4925	0.3046
C16 (0.1279)	0.0849	0.4526	0.4273	0.1957	0.3970
C17 (0.1321)	0.356	0.3877	0.4328	0.1933	0.0171
C18 (0.1078)	0.3261	0.057	0.0325	0.2351	0.4269
Aggregated weight:	0.1481	0.3048	0.2313	0.2856	0.2483

### 4.3. Stage 3: Results on Selection Decision

Apart from the carrier selection problem, the results of shipping lane selection and 3PL service provider selection are obtained by means of Bayesian BWM. For the shipping lane selection, 12 decision maker actors were considered, while the average weights of the eight decision criteria for costs (C21), cold storage capacity (C22), prioritized berth/loading bay (C23), average transit time (C24), the average number of ports of call (C25), available capacity (C26), the complexity of customs requirements (C27), and gateway support (C28) are 0.1008, 0.1094, 0.1260, 0.1481, 0.1534, 0.1317, 0.1239, and 0.1067. According to its credal ranking as shown in Figure 8, it is found that the average number of ports of call, average transit time, and available capacity are the top three criteria to select the shipping lanes for transporting the cargoes of agricultural products. Due to the time- and temperature-sensitive nature of the agricultural products, the supply chain stakeholders tend to shorten the shipment journey and reduce the ports of call in the freight forwarding process. The result aggregation of adjusted weights and priority vectors are summarized in Table 5, and it is found that the shipping lane 5 is deemed to be the most effective one when considering eight decision criteria in the shipping lane selection problem.



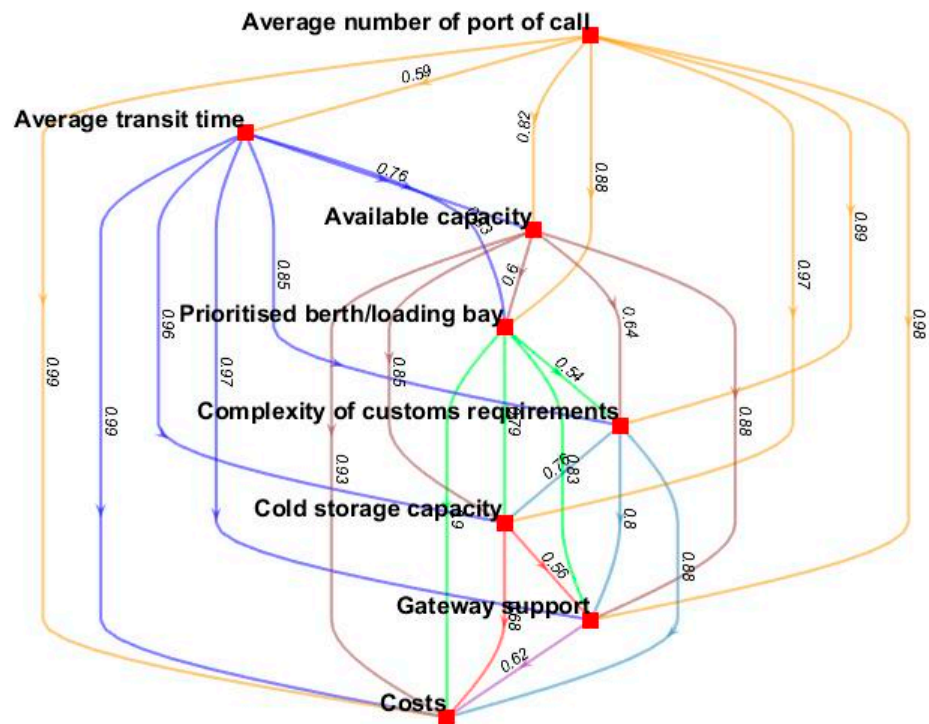


Figure 8. Graphical illustration of the credal ranking of the eight criteria in the shipping lane selection problem.

Table 5. Aggregated result summary of the carrier selection problem.

Criteria (Adjusted Weight)	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
C21 (0.1008)	0.0587	0.1569	0.3291	0.1865	0.0338
C22 (0.1094)	0.4597	0.3067	0.3375	0.1259	0.3675
C23 (0.1260)	0.2684	0.3135	0.266	0.3912	0.4837
C24 (0.1481)	0.4023	0.0656	0.0887	0.0735	0.4882
C25 (0.1534)	0.1136	0.4323	0.4847	0.0254	0.4755
C26 (0.1317)	0.1933	0.0371	0.1412	0.2458	0.1383
C27 (0.1239)	0.441	0.2531	0.3886	0.0042	0.3476
C28 (0.1067)	0.1099	0.0777	0.4546	0.169	0.193
Aggregated weight:	0.2589	0.2095	0.3064	0.1476	0.3317

For the 3PL service provider selection problem, seven decision makers excluding 3PL service providers were committed to updating the data table of pairwise comparisons, while the average weights of the eight decision criteria for costs (C31), service coverage (C32), global network capability (C33), flexibility (C34), service quality (C35), communication effectiveness (C36), ICT capability (C37), and service reliability (C38) are 0.1067, 0.1062, 0.1119, 0.1335, 0.1442, 0.1530, 0.1215, and 0.1230. Apart from the adjusted weights, the credal ranking is graphically illustrated in Figure 9, in which communication effectiveness, service quality and flexibility are top-three criteria for the selection decision. As the 3PL service providers play a role to communicate with different supply chain entities and coordinate the shipments in care of the shippers. Moreover, the services provided by the 3PL should be high-quality and flexible to maximize the supply chain value. By applying the adjusted weights of the eight decision criteria, the aggregation process to the priority vectors computed by analyzing pairwise comparisons by using Bayesian BWM are conducted. The results of the aggregation process are then summarized in Table 6 such that the 5th 3PL is selected for the case company.

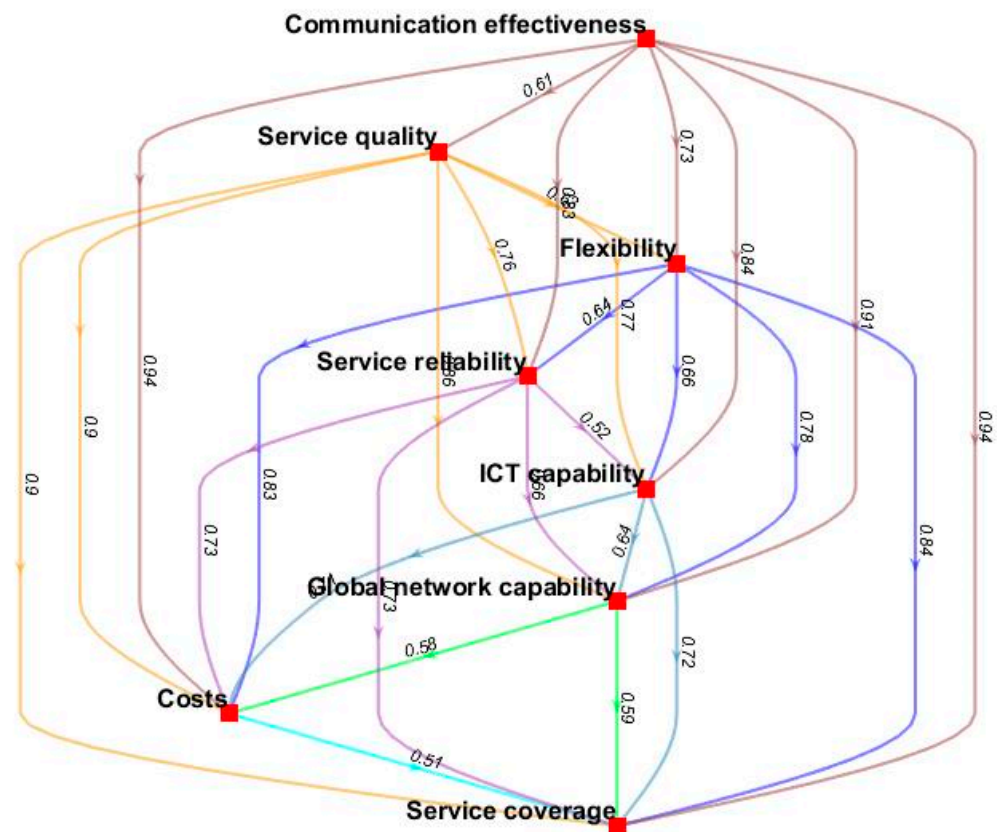


Figure 9. Graphical illustration of the credal ranking of the eight criteria in the 3PL selection problem.

Table 6. Aggregated result summary of the 3PL selection problem.

Criteria (Adjusted Weight)	3PL 1	3PL 2	3PL 3	3PL 4	3PL 5
C31 (0.1067)	0.2729	0.0903	0.0234	0.3309	0.2637
C32 (0.1062)	0.1595	0.2288	0.2202	0.1415	0.3491
C33 (0.1119)	0.2626	0.1827	0.175	0.1648	0.4342
C34 (0.1335)	0.0003	0.2371	0.2385	0.1802	0.4042
C35 (0.1442)	0.2930	0.4266	0.1275	0.4913	0.171
C36 (0.1530)	0.2012	0.1123	0.3707	0.1234	0.2167
C37 (0.1215)	0.3569	0.3662	0.289	0.0991	0.4836
C38 (0.1230)	0.2019	0.0129	0.4914	0.0264	0.1607
Aggregated weight:	0.2167	0.2108	0.2480	0.1979	0.3041

Overall, with the aid of the proposed decision framework, the multi-criteria selection problems on carriers, shipping lanes and 3PL service providers are addressed in a systematic manner. Instead of conducting the one-off pairwise comparison, the proposed framework enables a continuous update to the data table to obtain the resulting pairwise comparisons for further analysis. From the above case study based on a real case firm, it is found that port infrastructure, average number of ports of call, and communication effectiveness are the most important criteria in selecting carriers, shipping lanes, and 3PL service providers, respectively. These preferences are valuable inputs as the adjusted weights to make the final decisions on the selection problems. The findings imply that ASCs are concerned about the service providers’ capabilities and service quality, rather than simply considering the service costs, and service providers should focus more on their infrastructure, capabilities, and quality based on their role and values in the supply chains.

### 5. Discussion

In this section, the comparison between the proposed solution and existing work is conducted, while the implications of this study in the context of the business process management are discussed.

#### 5.1. Comparison with the Existing Work

After the deployment of the proposed system in the case company, the comparison between the proposed solution and state-of-the-art approaches is conducted as follows. MCDM approaches have been promisingly recognized to address complex selection decision problems which involve quantitative and qualitative considerations. In brief, Table 7 presents the summary of the comparison between this work and other existing studies [46,47]. Özceylan et al. integrated the geographic information system into the MCDM approaches to evaluate the locations for building freight villages which are defined as logistics centers for handling the cargoes with different transport modes [46]. Rezaei et al. revealed the power of BWM for configuring the air freight transportation [47], and thus the best configuration in term of the corresponding air freight key performance indicators can be determined. Furthermore, Aljohani et al. applied the MCDM to address the location problem for setting up a freight consolidation facility based on the geographic information system [48]. The above existing studies show that the MCDM approaches are good fits for solving complex selection problems based on the defined decision criteria and hierarchical structure.

**Table 7.** Comparison summary between the proposed work and existing studies.

	[46]	[47]	[48]	Proposed Work
Objectives	Selection decision on the appropriate location of the freight village	Selection decision on the appropriate freight planning from outstation to an airport hub	Selection decision on the appropriate location of a freight consolidation facility	Selection decision on carriers, shipping lanes and 3PL service providers
Decision criteria	Literature review and expert	Literature review	N/A	Literature review
Decision makers	A decision-making team	A decision-making team	Multiple experts	Multiple experts
Pairwise comparison data management	A survey format on SuperDecisions	A survey format	A survey format	Blockchain
Method of criteria prioritization	ANP	BWM	Fuzzy AHP	Bayesian BWM

Remark: ANP—Analytic Network Process; AHP—Analytic Hierarchical Process; BWM—Best Worst Method.

Since most deployments of MCDM approaches involve the input of pairwise comparisons from decision makers, this study presents the consortium-blockchain-based platform for the data collection, resulting in better fairness and security in the decision-making process. On the other hand, the consortium/federated blockchain is exploited in the MCDM process to facilitate the data collection for pairwise comparisons in a secure and immutable manner. The consensus of the pairwise comparisons can be reached across various supply chain stakeholders in the network. Particular to the group decision-making process which involve multiple decision makers, the pairwise comparison data are collected and managed in a centralized manner, which may expose to the risks of being altered and corrupted. Moreover, the consensus of the pairwise comparisons over the network can be effectively reached by the blockchain technology, which facilitates the decision analytics for the global freight management. Through this study, the features of consortium blockchain were leveraged and integrated into the MCDM approaches, namely Bayesian BWM, such that pairwise comparison could be made in a commonly agreed-on manner to obtain the best selection decision in a peer-to-peer network. In addition, the global freight management decision for ASC companies is a valuable, but less-discussed, selection problem for obtaining the best configuration of the carrier, shipping lane, and 3PL company. This study is vital to enrich the research of the global freight management for making the suitable decision by ASC companies.

## 5.2. Managerial Implications

In the field of business process management (BPM), recent research studies focus on exploring various methods to analyze, optimize and automate business processes by means of intelligent tools [49,50]. Through this study, the business process on global freight management is investigated, in which core supply chain members, including shippers, consignees, carriers, and 3PL service providers are considered. In order to improve the effectiveness of global freight management, the decision framework incorporating blockchain and Bayesian BWM is built. Thus, the pairwise comparisons can be conducted effectively in the permissioned freight network for further analysis process by means of Bayesian BWM. In other words, the decisions in the freight management processes can be made intelligently by considering multiple criteria with respect to carriers, shipping lanes, and 3PL service providers. Consequently, the global freight management process can be established in a commonly agreed-on and fair approach, while the practicality of the multi-criteria decision-making process is further enhanced. By doing so, the decision makers involved in the multi-criteria decision-making problems are not required to complete the whole pairwise comparisons every time when they need to make the corresponding decisions. Instead, they can simply update a part of pairwise comparisons subject to their experiences and knowledge, while the rest of the pairwise comparisons follow the data stored in the blockchain previously. More importantly, a trend of the pairwise comparisons can be investigated through the proposed approach, such that the supply chain owners are effective to measure the competitiveness and performance of carriers, shipping lanes and 3PL service providers perceived by supply chain members. It is vital to refine the global freight process and strategies in the ASCs.

In summary, this study contributes to the context of BPM research in two facets. First, a blockchain-based process management tool is exploited to consolidate the data of pairwise comparisons in a secure and trusted manner, which aids the decision to be made in the global freight management process. Apart from cryptocurrency, traceability and access control, the industrial blockchain application explored in this study raises a new synergy with multi-criteria decision-making methods to enhance their practicality and reach a consensus in the freight network. Subsequently, the appropriate decisions can be made in the global freight management process with regard to carrier selection, shipping lane selection, and 3PL service provider selection. Secondly, the hierarchy of the decision criteria for global freight management is specialized for the agricultural supply chains, and thus additional criteria related to cold chain logistics are included. The proposed hierarchy enriches the research of BPM on cold chain management, particularly for the perspectives of carriers, shipping lanes, and 3PL service providers. Furthermore, a peer evaluation mechanism to inspect the performance of various supply chain stakeholders is established in this study.

## 6. Conclusions

To conclude, this study proposes the industrial blockchain-based global freight decision framework (IB-GFDF), which integrates consortium blockchain and Bayesian BWM to make the selection decision on carriers, shipping lanes, and 3PL service providers. Decision makers located in different demographic regions can securely participate the decision-making process, while the pairwise comparisons between various selection criteria are made in an immutable and commonly-agreed manner through the blockchain mechanism. Through the case study on an Australian ASC company, it is found that the port infrastructure, average number of port of calls, and communication effectiveness are the most essential criteria for the selection of carriers, shipping lanes, and 3PL service providers, respectively. The proposed system can be further extended to other ASC companies worldwide to assist their decision-making process of the global freight management. About the limitations of this study, only one case study was investigated considering 12 decision makers in the freight network. Additionally, only the core components in the global freight management, namely carriers, shipping lanes, and 3PL service providers,

were investigated. Subsequently, the proposed framework can be further extended to cover a large scope of the business processes in ASCs and include more decision makers in the network. Based on the successful deployment of the proposed framework, future work on multi-criteria decision-making problems concentrating on other business processes in ASCs, such as inland transportation, sustainability evaluation, and freight village management, can be explored.

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