

Coordination of material supply chains under multidimensional stochastic risks

Yang, C.^a, Jian, M.^{a,*}, Fang, X.^b

^aSchool of Transportation and Logistics, Southwest Jiaotong University, Chengdu, P.R. China

^bInternational College, Krirk University, Bangkok, Thailand

ABSTRACT

This paper investigates optimal decision-making and coordination in a material supply chain under multidimensional stochastic risks, including uncertain demand, yield, and processing activities. By analyzing a system consisting of a manufacturer and a supplier, we derive the unique optimal purchasing and stocking decisions that maximize the expected profit of the integrated supply chain. A wholesale price contract is proposed to coordinate decentralized participants, incorporating risk allocation through a linear combination of production cost risk and sales profit risk. The key findings indicate that elevated risk dimensions lead to an increase in optimal order and inventory quantities. However, they also result in a reduction in system profit and a narrowing of the coordination price range. Numerical analyses demonstrate that, when faced with heightened multidimensional risks, enterprises should increase safety stocks and ordering levels to maintain supply stability. At the same time, supply chain members should negotiate wholesale prices within a more restricted interval to achieve effective coordination. Contract flexibility and risk sharing become more significant in maintaining efficiency under high-uncertainty conditions. Sensitivity analysis demonstrates the robustness of the proposed mechanism, emphasizing its flexibility in profit sharing under stochastic conditions. This study contributes to supply chain risk management by providing a generalized contract framework that aligns decentralized decisions with centralized optimization, thereby ensuring stability and efficiency in high-risk industrial environments.

ARTICLE INFO

Keywords:

Material supply chain;
Coordination contract;
Wholesale price;
Demand uncertainty;
Yield uncertainty;
Processing uncertainty;
Supply chain risk

*Corresponding author:

jianming@swjtu.edu.cn
(Jian, M.)

Article history:

Received 8 May 2025
Revised 15 April 2026
Accepted 17 April 2026



Content from this work may be used under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

1. Introduction

This paper investigates the design of a generalized coordination mechanism for coordinating material supply chains across diverse uncertainty dimensions. These uncertainty dimensions arise from demand, yield, and processing activities [1]. Multiple uncertain risks affect the availability of materials during their transit from suppliers to construction projects. These risks can lead to performance degradation, cost escalation, scheduling delays, and ultimately, project failures [2, 3]. Consequently, inadequate supply chain management (SCM) can be regarded as a potential contributor to cost overruns and delays in the construction industry. Although the concept of supply chain management has its roots in the manufacturing industry, enterprises in the materials industry can also reap benefits from implementing such best-practice approaches in certain processes [4]. Nevertheless, SCM remains underdeveloped in the construction industry [5]. Furthermore, despite its significant potential, the application of supply chain risk management in the materials industry has yet to be investigated.

In the past few decades, both practitioners and scholars have emphasized that the complexity of engineering and construction exposes it to more significant risks than other industries. These risks can lead to reduced performance, increased costs, schedule delays, and ultimately, project failure [1]. There have been numerous natural and man-made disasters (e.g., earthquakes, economic crises, wars, terrorist attacks, and sanctions) that disrupt the operations of the material supply chain. Coleman [6] found extensive evidence showing that the frequency of disruptions caused by man-made disasters has increased exponentially since the 20th century. These disruptions have been observed to be increasing in both the probability of occurrence and their magnitude [7]. Supply chain disruptions are inevitable, making all supply chains risky [8]. Therefore, the effective management of risks in materials supply chains is of crucial importance for the successful delivery of projects.

More precisely, compared with other industries, large-scale engineering projects have faced a substantial number of risks due to the strategic characteristics of materials, the complexity of construction techniques, the dynamic construction environment, the participation of diverse stakeholders, and the lengthy construction cycle [9]. Ineffective supply chain management can be considered a potential cause of some of the cost overruns and delays in the engineering industry. Consequently, risk management is increasingly regarded in the engineering project management literature as a means to increase the probability of success of complex engineering projects [10]. Effective risk management systems aimed at preventing project performance deterioration, time delays, and unnecessary costs have prompted scholars to propose various risk management approaches [11]. Taroun conducted a review of 50 years of risk modeling and assessment in construction projects and argued that there is a disparity between practice and theory, that managers mainly rely on their experience, and that the application of the analytical tools proposed in the literature is highly limited.

In the face of uncertain risks across different dimensions, a fundamental issue that needs to be resolved is how the manufacturer (or supplier) formulates optimal purchasing (or stocking) decisions and how to mitigate these risks. To the best of our knowledge, no existing literature has explored the problem of optimal decision-making for materials with uncertainties in project demand, yield, and processing operations. Moreover, even fewer scholars have analyzed the coordinated contract design based on risk allocation among firms within the framework of a material integration system. The traditional "manufacturer + suppliers" model has the drawbacks of unstable transactions and contracts. In contrast, the manufacturer - supplier model based on the material integration system can ensure a stable contractual relationship, effectively reduce transaction costs, and contribute to the healthy and sustainable development of industrialization [12].

Therefore, based on the paradigm assumption that stochastic distributions describe multidimensional uncertain risks, this paper investigates the optimal procurement and inventory decisions of the manufacturer and the supplier, and proposes a coordinated contract encompassing multidimensional stochastic risks. The primary contribution of this article lies, on one hand, in extending the research on material operations optimization to scenarios where demand, yield, and processing activities are all stochastic, and conducting a distinctive analysis of the optimal decisions of the manufacturer and the supplier under multidimensional stochastic risks. Additionally, the sensitivity of the optimal decision to risk variations is explored. On the other hand, a coordinated wholesale-price contract covering risks is proposed, enabling the manufacturer and the supplier to flexibly share the optimal profit of the channel. Moreover, this contract can also coordinate the material supply chain with stochastic yield and demand or only stochastic demand, which is why it is defined as a generalized coordinated contract.

The subsequent sections review the relevant literature. Section 3 defines the modeling assumptions and notational implications. Section 4 analyzes optimal decisions and simulations. The final section presents the conclusions.

2. Literature review

The optimal procurement decision of the firm under uncertainty can be traced back to the groundbreaking research of Arrow *et al.* [13]. They initially derived an optimal inventory model where the future demand flow is a random variable with a known probability distribution. To

address the fundamental issue of how random yields impact the production or ordering decision in a periodic review system, Wang and Gerchak examined a periodic review production system characterized by random yield and demand uncertainty [14]. Numerous scholars have extended the research on firms' procurement or production under supply and demand stochasticity from multiple perspectives [15, 16]. Particularly, in the literature on project management, risk management is increasingly regarded as a means to enhance the probability of success in complex engineering projects [10]. Nevertheless, studies indicate that project managers inadequately utilize risk management practices [17]. More precisely, compared with other industries, the construction industry has been confronted with numerous risks owing to factors such as the strategic nature of its products, the complexities of construction techniques, the changing building environment, the involvement of diverse stakeholders, and long production cycles [11]. Therefore, the necessity of establishing an effective risk management system to prevent project performance degradation, time delays, and undesired costs has compelled project management scholars to propose a variety of risk management approaches.

The allocation of uncertain risks during the sales period poses a substantial impediment to inter-firm cooperation [18]. To mitigate these risks, Pasternack initially investigated a supply-chain coordination contract, namely the buyback contract, from the perspective of quantity buyback. That is, in the face of demand uncertainty, upstream firms commit to repurchasing the remaining inventory of downstream firms at the end of the sales period [19]. Over the subsequent three decades, scholars have formulated contracts to coordinate decentralized supply chains under stochastic demand from multiple viewpoints, such as revenue-sharing contracts, quantity flexibility contracts, and sales rebate contracts [20]. As an expansion of the uncertainty risk dimension, He and Zhang proposed several risk-sharing contracts that distribute the random yield risk among the involved parties [21]. Güler and Bilgiç proposed two contracts for coordinating the supply chain under forced compliance, where both customer demand and supplier yield are random [22]. Hu *et al.* examined a flexible purchasing policy considering random yield and demand uncertainty and proposed a revenue-sharing policy with an order penalty and rebate contract to fully coordinate the supply chain [23]. Güler and Keskin found that the randomness in yield does not alter the coordination capacity of the contracts but influences the values of the contract parameters [24]. Cai *et al.* introduced an option contract to enhance the performance of the inventory supply chain under yield uncertainty and stochastic demand [25]. Sonntag and Kiesmüller considered a single-stage production system with a favorable production time and random yield [26]. Stojic *et al.* presented the proposed model for monitoring and managing business risks in industrial systems [27].

Game theory and evolutionary game models have emerged as important tools for research on supply chain coordination and risk-sharing. Wang *et al.* [28] established a game-theory framework to optimize the cooperation and profit-sharing mechanisms between manufacturers and suppliers, offering a valuable reference for vertical cooperation and benefit distribution within supply chains. Zhao *et al.* [29] proposed an ANP–Hopfield neural network approach for supply chain stress testing, thereby enriching the quantitative methods for risk assessment and resilience verification under high degrees of uncertainty. Xi *et al.* [30] analyzed the influence of retailer fairness concerns on freshness-keeping efforts and pricing strategies in fresh agricultural product supply chains and explored effective coordination mechanisms, providing insights for contract design under behavioral factors. Xu *et al.* [31] employed evolutionary game models to conduct a comparative analysis of the impact of fairness concerns on resource-sharing decisions in manufacturing enterprises, uncovering the decision-making logic of cooperative behavior under risk asymmetry. Ji *et al.* [32] investigated the influence of government guidance on the production mode selection of automobile enterprises based on an evolutionary game, expanding the application scenarios of game theory in supply chain decisions with external policy interventions.

Regarding risk allocation contracts, He and Zhang proposed several risk-sharing contracts that allocate random yield risk among parties and evaluate supply chain performance [21]. They considered three scenarios in which the retailer shares random yield risk with the supplier. Zhou *et al.* constructed a model in which the retailer formulates a risk-sharing contract for the manufacturer under conditions of random yield and private productivity information to analyze the interaction between risk-sharing and asymmetric information [33]. Behzadi *et al.* comprehensively

reviewed the relatively scarce literature on quantitative risk management models for agricultural supply chains [34]. Besik *et al.* developed an integrated multi-tiered competitive agricultural supply chain network model in which farming and processing firms engage in competition to sell their differentiated products [35]. Our model takes into account multidimensional stochastic risks in the coordination contract parameters. In this model, multidimensional stochastic risks are incorporated into the coordination contract parameters, and the designed contract can be implemented as the cooperative system provides a stable environment.

3. The model

This paper considers a material integration system comprising a manufacturer (M) and a supplier (S), in which the manufacturer organizes the supplier to supply materials to fulfill the project needs. Fig. 1 shows a schematic of this collaboration system. In a desirable situation, the manufacturer can schedule the supplier to supply q units of material with a random project need X . However, the supplier may need to stock Q units due to various risks (e.g., uncontrollable processing failures, poor humidity management, etc.). Hence, we are interested in how to determine the optimal q and Q under a combination of uncertainties and how the manufacturer and the supplier can design the cooperative contract to achieve the optimal profit. The following generalized assumptions are introduced to address these questions.

Project material demand, material stock, and processing activities are assumed to be random. In practical applications, decision-makers often use probability distributions to characterize the uncertainties they face, as demonstrated in the classic newsvendor problem [16]. This approach is well established in the literature [1, 16, 20]. The assumptions are as follows.

1. Let X be a random project material needs variable on a closed interval $[\underline{X}, \bar{X}]$, $\underline{X}, \bar{X} \in \mathcal{R}^+$. The probability density function (p.d.f.) and cumulative distribution function (c.d.f.) of variable X are $f(x)$ and $F(x)$, respectively. $F(x)$ has monotonically increasing, second-order continuous differentiable, and reversible properties. Define $\bar{F}(x) = 1 - F(x)$, and the mean of demand is μ_x .
2. The actual materials yield is UQ units, where U is a random variable on the closed interval $[\underline{U}, \bar{U}]$, $0 \leq \underline{U} < \bar{U} \leq 1$. The p.d.f. and c.d.f. of U are $g(u)$ and $G(U)$, respectively. $G(U)$ has monotonically increasing, second-order continuous differentiable, and reversible properties.
3. Materials need to go through a series of processing activities before being applied to the project, such as stocking, picking, packing, transportation, etc. It is assumed that the processes are random and that the final quantity on the project is $O \min(UQ, q)$, where variable O is random on a closed interval $[\underline{O}, \bar{O}]$, $0 \leq \underline{O} < \bar{O} \leq 1$. The p.d.f. and c.d.f. of O are $m(o)$ and $M(o)$, respectively. $M(o)$ has monotonically increasing, second-order continuous differentiable, and reversible properties. The mean of variable O is μ_o .

Although there are multiple uncertain risks in the material supply chain, for the sake of computational simplicity, this study posits that decision-makers, namely manufacturers and suppliers, are risk neutral and engage in collaboration through wholesale contracts. Risk neutrality is widely utilized in supply chain coordination literature to ensure analytical tractability when focusing on contract design and risk allocation [13, 20, 21]. In practical situations, construction material supply chains involve long-term integrated systems, where firms diversify risks at the corporate level, leading to approximately risk-neutral operational decisions at the project level [5, 15]. Since this paper emphasizes coordination and risk allocation through wholesale price contracts, risk neutrality helps to clarify the mechanism without introducing unnecessary complexity. Therefore,

4. The manufacturer purchases q units of materials for w per unit, where q is the decision variable, and w is the contract parameter.
5. The supplier plans to stock Q units of materials for the cost c_s per unit, in which Q is the decision variable.
6. The manufacturer receives $\min(UQ, q)$ units of materials and has $O \min(UQ, q)$ units applied to the project at unit price p after a series of processing activities with cost c_M per unit, where we assume p is an exogenous variable. Such an assumption is reasonable when a

particular supplier and manufacturer cannot influence the global market.

In summary, given the wholesale contract, the manufacturer purchases q units, and the supplier stocks Q units. However, the former receives $\min(UQ, q)$ units, and the final quantity of materials available for application is $O \min(UQ, q)$ due to uncertainties. Furthermore, the salvage value and stock-out penalty for the materials are assumed to be zero.

Assuming a zero salvage value and a zero stock-out penalty represents a standard simplification within supply chain coordination and newsvendor-based models. This simplification is employed to ensure analytical tractability without sacrificing generality [16, 19, 20]. This assumption facilitates the isolation of the impacts of multidimensional risks (including demand, yield, and processing uncertainty) and the coordination mechanism. It is extensively adopted in research concentrating on contract design and risk allocation [21, 24]. Extensions incorporating positive salvage or stock-out costs would merely adjust the optimal thresholds without altering the core coordination structure of the proposed wholesale price contract.

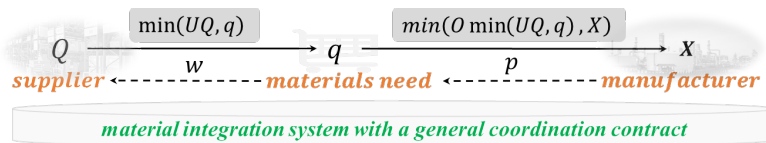


Fig. 1 Schematic diagram of the material integration system under uncertainties

4. Model analysis

The model analysis is conducted in two parts. Initially, the optimal decision, which serves as a benchmark for the material integration system, is determined. Subsequently, the wholesale price incorporating risk factors is formulated to encourage the decisions of the manufacturer and the supplier to align with the benchmark.

4.1. Optimal decisions

The expected profit function of the material integration system is shown as Eq. 1,

$$\Pi = pE[\min(O\min(UQ, q), X)] - c_M E[\min(UQ, q)] - c_S Q \tag{1}$$

The first item in Eq. 1 represents the expected revenue from the project, and the last two represent the cost of the manufacturer’s processing activities and the supplier’s stock, respectively. Let $L(Q, q)$ and $S(Q, q)$ be the manufacturer’s expected purchasing and expected sales quantity, respectively. Then we can calculate the optimal decisions of the system shown in proposition 1.

$$L(Q, q) = E[\min(UQ, q)] = Q \left[\int_{\underline{U}}^{q/Q} \bar{G}(u) du + \underline{U} \right],$$

$$S(Q, q) = E[\min(O\min(UQ, q), X)] = \left\{ \begin{aligned} & \underline{X} + Q \int_{\underline{U}}^{q/Q} \int_{\underline{O}}^{\bar{O}} ug(u) \bar{M}(o) \bar{F}(o) \bar{F}(ouQ) do du + \\ & \left[\int_{\underline{U}}^{q/Q} \int_{\underline{X}}^{uOQ} g(u) \bar{F}(x) dx du + \bar{G}(q/Q) \left[q \int_{\underline{O}}^{\bar{O}} \bar{M}(o) \bar{F}(o) do + \int_{\underline{X}}^{Oq} \bar{F}(x) dx \right] \right] \end{aligned} \right\}$$

Proposition 1. There is a unique set of optimal values (Q^*, q^*) that maximizes function Π and satisfies Eq. 2,

$$\left\{ \begin{aligned} & \int_{\underline{O}}^{\bar{O}} \{ \bar{M}(o) \bar{F}(oq^*) [1 - r(oq^*)] \} do + O \bar{F}(Oq^*) = \frac{c_M}{p} \\ & \int_{\underline{U}}^{q^*/Q^*} \int_{\underline{O}}^{\bar{O}} \{ ug(u) \bar{M}(o) \bar{F}(ouQ^*) [1 - r(ouQ^*)] \} do du + \int_{\underline{U}}^{q^*/Q^*} \{ ug(u) O \bar{F}(uOQ^*) \} du = \frac{c_M \int_{\underline{U}}^{q^*/Q^*} ug(u) du + c_S}{p} \end{aligned} \right. \tag{2}$$

where, $r(x) = xf(x)/\bar{F}(x)$.

Let Π^* be the optimal value of the material integration system, which can be calculated by taking (Q^*, q^*) into Eq. 1.

We can see from Eq. 2 that the manufacturer’s optimal purchasing does not include the randomness of material yield. The risk of both processing and demand affect the manufacturer’s optimal purchasing. However, the risk of yield, processing, and material demand affects the supplier’s optimal stock quantity.

To illustrate the practical implications of the model, an empirical case analysis is carried out using a large-scale transportation infrastructure project in western China. This project involves

the procurement of core construction materials, including high-strength steel bars, ready-mixed concrete, and asphalt mixtures. All these materials are subject to significant multidimensional stochastic risks, which are presented as follows. (1) Demand uncertainty: The actual consumption of materials fluctuates due to the dynamic nature of construction progress, adjustments in geological conditions, and design modifications. Based on the project's historical consumption data, it conforms to a normal distribution $X \sim N(60,10^2)$ (unit: tons/period). (2) Supply/yield uncertainty: The production yield of steel bars and concrete is affected by the quality of raw materials and the stability of the production line, with a random yield rate $U \sim N(0.8,0.1^2)$. (3) Processing/transportation uncertainty: Random losses occur during the transportation and on-site processing of materials as a result of road conditions, loading/unloading operations, and mixing errors. The processing efficiency is characterized by a normal distribution $O \sim N(0.8,0.2^2)$. These parameters are fully consistent with the project's actual operational data, providing real-world industrial validation for the proposed model.

Scenario I in Table 1 presents the optimal purchasing (77.60) and optimal stock (88.00) decisions under the given parameter assignment and the optimal profit (20.53) of the system under these optimal decisions.

Table 1 Optimal values for given parameter assignments

Scenarios	q^*	Q^*	θ	θ	w_L/p	w_U/p	Π^*/p
I	77.60	88.00	1.27	0.72	0.13	0.42	20.53
II	65.24	80.00	1.15	0.81	0.12	0.51	27.37
III	62.53	62.53	1.00	0.91	0.10	0.61	32.14

Note: $X \sim N(60,10^2)$, $U \sim N(0.8,0.1^2)$, $O \sim N(0.8,0.2^2)$, $[\underline{U}, \bar{U}] = [O, \bar{O}] = [0.2, 1.0]$, $(\frac{c_M}{p}, \frac{c_S}{p}) = (0.30, 0.10)$

Corollary 1 is an extension of the firm's optimal decision. More specifically, if $S(Q, q)$ is modified as $\int_{\underline{X}}^q \bar{F}(x)dx + \underline{X} - Q \int_{\underline{U}}^{q/Q} \bar{F}(uQ)G(u)du$, then proposition 1 reduces to an optimization decision solution when the yield and demand of materials are random. If $L(Q, q)$ is modified to be q , and $S(Q, q)$ is corrected to be $\int_{\underline{X}}^q \bar{F}(x)dx + \underline{X}$, Eq. 2 reduces to an optimization decision problem that only assumes random demand.

Corollary 1. (1) When the randomness of the processing activity is not considered, the optimal values that maximize (q^*, Q^*) the system's profit can be calculated as Eq. 3,

$$\begin{cases} p\bar{F}(q^*) - c_M = 0 \\ p \left[\int_{\underline{O}}^{q^*/Q^*} \bar{F}(uQ^*)G(u)du - \int_{\underline{U}}^{q^*/Q^*} G(u)\bar{F}(uQ^*)[1 - r(uQ^*)]du \right] - c_M \int_{\underline{U}}^{q^*/Q^*} uG(u)du - c_S = 0 \end{cases} \quad (3)$$

and (2) when only market demand is considered as a random variable, the optimal decision is shown as Eq. 4,

$$q^* = Q^* = \bar{F}^{-1} \left(\frac{c_M + c_S}{p} \right). \quad (4)$$

In Model I, the yield, processing operations, and demand are assumed to be stochastic. In Model II, there is no risk associated with processing operations, and in Model III, only the demand is stochastic. As can be observed from Table 1, with the expansion of risk, the manufacturer's procurement volume (q^*) increases, which further necessitates the supplier to hold a larger inventory of materials (Q^*). Fig. 2 depicts the trend of the manufacturer's procurement quantity in relation to its cost structure. From this, it can be seen that as the manufacturer's cost gradually rises, their procurement quantity tends to decline. Simultaneously, Fig. 2 also indicates that the magnitude of the decrease in the manufacturer's procurement volume increases as the type of risk intensifies.

Likewise, Fig. 3 depicts the supplier's production quantity decision. It is evident that the supplier's optimal production quantity declines as both its own cost structure and that of the manufacturer increase. Additionally, Fig. 3 shows that for any given party's cost structure, the supplier's optimal production quantity decreases in relation to the given cost structure. Moreover, by comparing the three scenarios in Fig. 3, it is shown that the supplier's optimal production rises as the type of risk escalates.

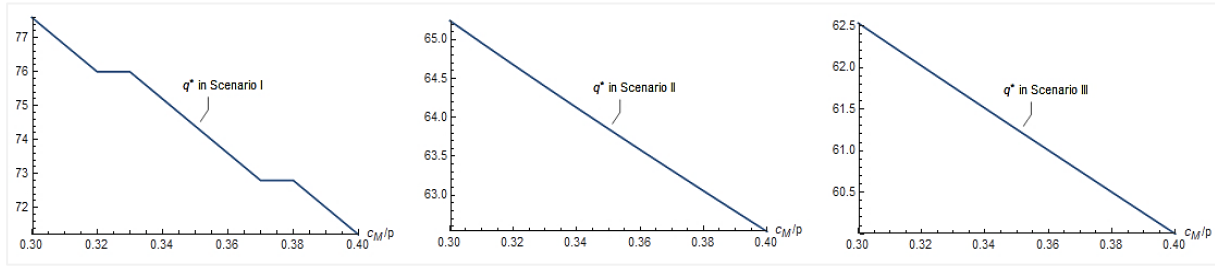


Fig. 2 The changes of q^* with the cost structure in different scenarios

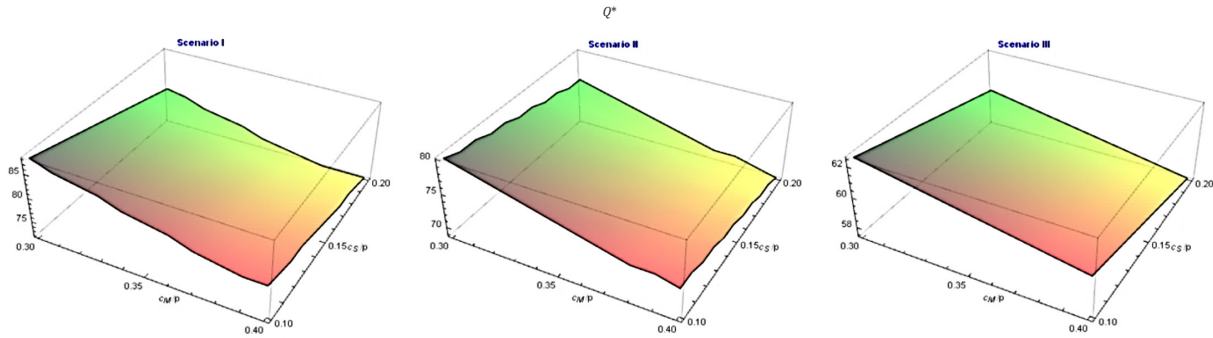


Fig. 3 Changes in Q^* with parties' cost structures under different scenarios

4.2. Contract design

The question is how these rational entities can distribute this optimal "resource" in the context of multiple stochastic risks. In order to achieve this, not only do the manufacturer and the supplier jointly share various stochastic risks, but their optimal decisions also align with those of the material integration system.

Given the wholesale contract, the expected profit functions of the manufacturer (π_M) and the supplier (π_S) are shown in Eq. 5,

$$\begin{cases} \pi_M = pE[\min(O\min(UQ, q), X)] - (w + c_M)E[\min(UQ, q)] \\ \pi_S = wE[\min(UQ, q)] - c_S Q \end{cases} \quad (5)$$

In Eq. 5, the wholesale price serves as the sole link facilitating the profit transfer between the manufacturer and the supplier. Proposition 2 demonstrates the existence of an acceptable wholesale price, enabling both the manufacturer and the supplier to attain Pareto optimality.

Proposition 2. Consider the parameter w shown in Eq. 6,

$$w = \delta c_S \theta + (1 - \delta)(p\theta - c_M), \quad (6)$$

and $\delta \in (0,1), \theta = Q/L, \theta = S/L$. Under the wholesale price contract with the parameter w , the manufacturer's and the supplier's profit functions are shown in Eq. 7,

$$\begin{cases} \pi_M(Q, q) = \delta \Pi(Q, q) \\ \pi_S(Q, q) = (1 - \delta) \Pi(Q, q) \end{cases} \quad (7)$$

Moreover, the set (q^*, Q^*) represents the manufacturer's optimal procurement and the supplier's optimal inventory. The wholesale contract coordinates the material integration system.

The proposition suggests that δ represents the manufacturer's share of the profit within the material integration system. Consequently, a wholesale price contract with parameter w can coordinate the system and allocate profit arbitrarily. The specific profit split selected likely hinges on the firm's relative bargaining power. As the manufacturer's bargaining position is enhanced, an increase in δ is anticipated.

Parameters θ and θ describe different random risks in the material integration system. $\theta, \in [1, \infty)$ is a ratio of the supplier's optimal stock quantities to the manufacturer's expected purchasing and reflects the random yield risk of materials. The larger the value of θ is, the lower the expected purchasing will be, which means that the random yield risk of the materials is more significant. Conversely, the manufacturer's expected purchasing quantity tends towards the supplier's optimal stock when $\theta \rightarrow 1$, which means there is almost no random yield risk. $\theta, \in (0,1]$

represents the ratio of the manufacturer’s expected sales quantity to its expected purchasing. The value of θ reflects the combined risk of the random yield, processing activities, and demand. The larger the value of θ is, the closer the project sales are to the manufacturer’s expected purchasing; by contrast, the expected sales quantity is close to zero when $\theta \rightarrow 0$. In the case of the given risk, Table 1 mentioned above shows the values of θ and θ of the three models.

Notably, w serves as the link between the manufacturer and the supplier and is used to achieve the purpose of profit sharing and risk allocation. On the one hand, it is a linear combination of $c_S\theta$ and $(p\theta - c_M)$, representing the stock cost risk and sales-profit risk. It can be calculated that $w_L = c_S\theta$ when $\delta \rightarrow 1$, which indicates that the value per unit purchased from the supplier is meager. At this time, the manufacturer’s purchasing cost is low and captures the entire optimal profit of the material integration system. Conversely, we have $w_U = (p\theta - c_M)$ when $\delta \rightarrow 0$, the supplier obtains the highest selling price, and the manufacturer must pay a higher marginal purchasing cost. Parameter w is also a function of both parameters θ and θ . These two parameters characterize the risks derived from the material integration system’s random yield, processing activities, and demand. Hence, risk allocation is achieved between the manufacturer and the supplier based on the coordinated wholesale price contract.

The proposed wholesale price contract can be systematically implemented in practical material supply chains through a standardized operational approach. First, channel members calibrate stochastic parameters such as demand, yield, and processing efficiency based on historical industrial data. Second, the system-optimal procurement quantity (q^*) and stocking quantity (Q^*) are jointly calculated to align individual decisions with the integrated optimum. Third, the feasible coordination wholesale price range ($[w_L, w_U]$) is determined to ensure acceptable profits for both parties. Fourth, the profit-sharing coefficient (δ) is negotiated according to relative bargaining power and risk-bearing capacity. Finally, the contract can be applied within the long-term material integration system to achieve sustained risk sharing and efficient operation. This implementation path ensures the operability, transparency, and stability of the coordination mechanism in real industrial scenarios.

As can be observed from Table 1, the coordination thresholds for wholesale prices vary across the three models. Fig. 4 depicts the variability of the coordinated wholesale price in relation to the firms’ cost structure under the three scenarios. A comparison of the three models indicates that as the dimension of risks gradually expands, the range of coordination prices progressively contracts. In other words, as the level of risk increases, the range of wholesale prices available for negotiation between manufacturers and suppliers diminishes.

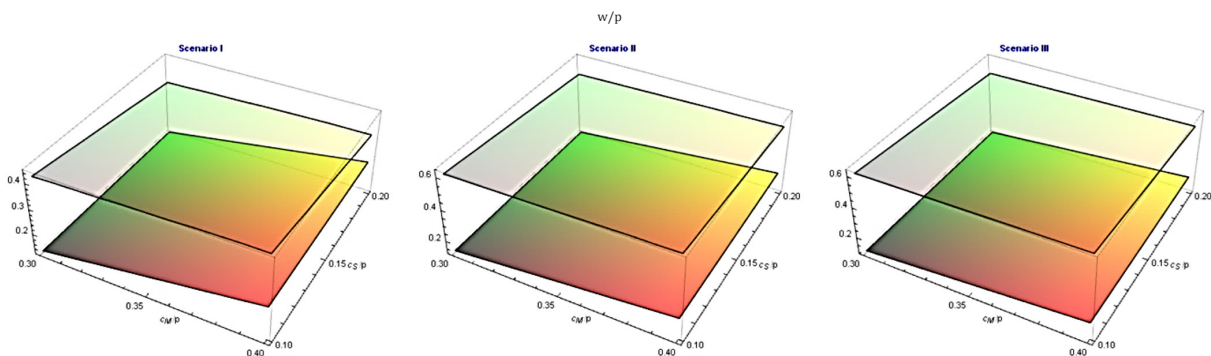


Fig. 4 Changing rules of coordinated wholesale prices with firms’ cost structures

Proposition 2 demonstrates that a wholesale-price contract incorporating risk factors can achieve coordination between the manufacturer and the supplier within the material integration system. In this case, their decisions align with the system’s optimal decisions. Consequently, when the wholesale-price contract is configured according to Eq. 6, the manufacturer’s optimal purchase quantity q^* and the supplier’s optimal stock Q^* can be derived from Proposition 1. Subsequently, the material integration system’s optimal profit Π^* can be computed in accordance with Eq. 1. Table 1 documents q^* , Q^* , and Π^* for three models under the assumption that the stochastic risk is $X \sim N(60, 10^2)$, $U \sim N(0.8, 0.1^2)$, and $O \sim N(0.8, 0.2^2)$, respectively. Fig. 5 depicts the influence of fluctuations (i.e., variance changes) in each risk on the optimal profitability of an

integrated supply chain. One key finding is that as the dimension of risk (or the variance of risk) increases, the optimal profit declines.

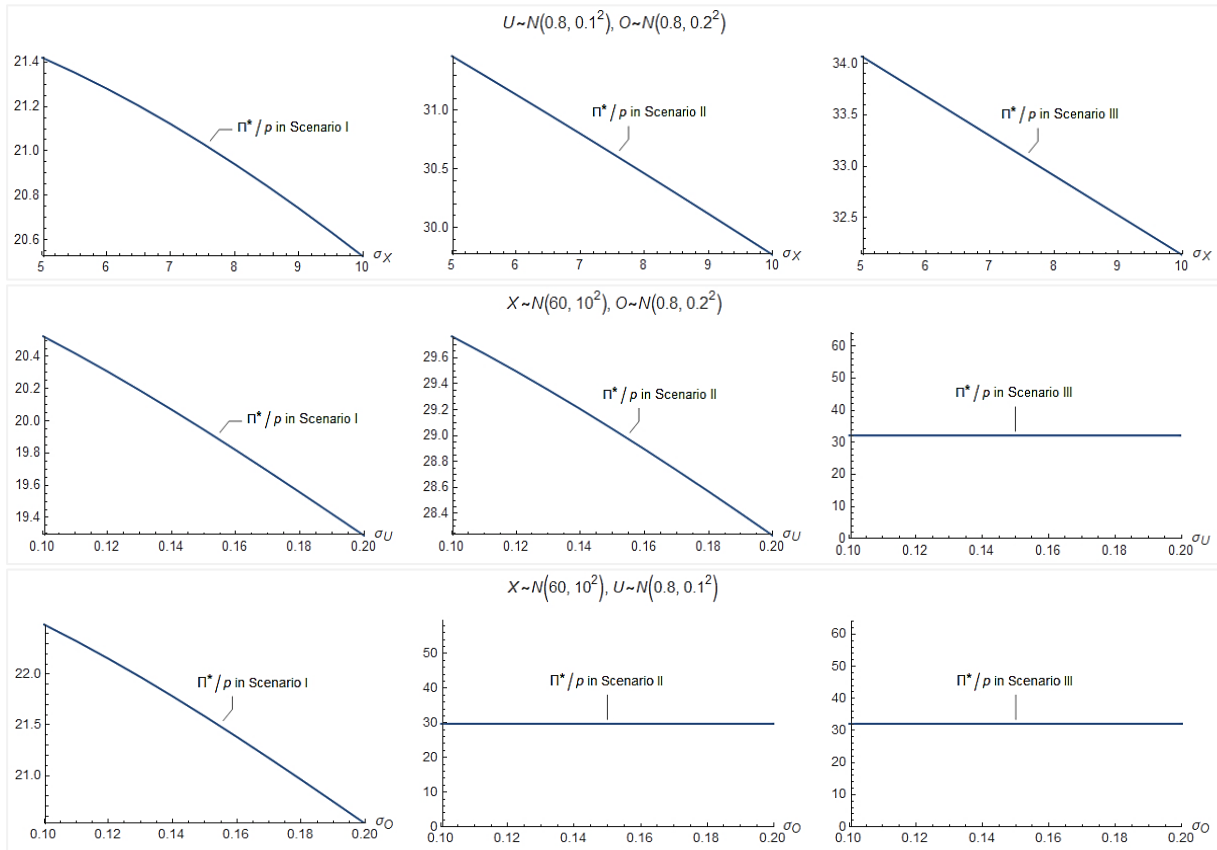


Fig. 5 Variation in the integrated supply chain's optimal profit with risk fluctuations

5. Conclusion

This paper investigates the optimal decision-making and risk allocation mechanism for the manufacturer and the supplier within the framework of the material integration system under conditions of random materials demand, yield, and processing activities. The main conclusions are as follows.

First, there is a set of optimal decision-making strategies that maximize the expected profit of the material integration system. Specifically, when faced with stochastic risks of various dimensions within the material integration system, the manufacturer's optimal procurement quantity and the supplier's optimal inventory level are unique. These can be calculated according to Proposition 1 and Corollary 1. The numerical and sensitivity analysis indicates that as the risk dimension increases, the optimal decisions of both the manufacturer and the supplier gradually increase, whereas the optimal expected profit gradually declines. Meanwhile, it is found that the manufacturer's optimal procurement quantity rises with the increase in risk (i.e., variance). Additionally, as the risk increases, the supplier's optimal inventory level ascends, while the optimal profit of the integrated system declines.

Second, the designed wholesale-price contract incorporating multidimensional random risks can coordinate the actions of the participants. Both the manufacturer and the supplier can flexibly allocate the optimal expected profit of the material integration system. In this simple wholesale-price contract, the negotiated transaction price is a linear combination of the inventory-cost risk and sales-profit risk. This implies that the coordinated wholesale price will be determined when the material supply chain is risk-free. However, as the risk dimension broadens, the lower bound of the coordinated trading price gradually increases due to the increase in θ . Meanwhile, its upper bound gradually decreases due to the decrease in θ . Consequently, the price range for coordinating the material supply chain narrows as the risk dimension increases. The sensitivity analysis validates this conclusion, as depicted in Fig. 4. The contract with multidimensional risk factors can

be executed once the firms participate in the material integration system.

In summary, the major contribution of this paper lies in its analysis of an operations research model to address the optimal decision-making problem for the manufacturer and the supplier under the conditions of random demand, yield, and processing operations. A comprehensively coordinated wholesale price contract integrating multidimensional risks is formulated to flexibly allocate the optimal profit of the integrated system. The imbalance between supply and demand influences the price fluctuations of materials. Hence, it would be more practical to consider optimal decision-making and coordination contracts with endogenous price variables.

Moreover, this paper assumes that the costs of the manufacturer and the supplier are common knowledge. However, under multiple uncertainties, validating these costs presents challenges, which directly influence the determination of wholesale-price parameters. Additionally, it is assumed that the salvage value and stock-out costs of the materials are zero. Nevertheless, these assumptions significantly impact the structure of the decision-making problem. Based on this paper, these aspects shape the directions for future research.

Acknowledgments

This work was carried out with the financial support of the Youth Program of Chongqing Social Science Planning (No. 2024NDQN043), the Program of Chongqing Municipality Natural Science Foundation (2023NSCQ-MSX3688); the Western Project of National Social Science Foundation (No. 23XGL037); the CSC (grant number 201908505102).

References

- [1] Xing, G.M., Zhong, Y.G., Zhou, Y.-W., Cao, B. (2025). Distributionally robust production and pricing for risk-averse contract-farming supply chains with uncertain demand and yield, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 198, Article No. 104074, doi: [10.1016/j.tre.2025.104074](https://doi.org/10.1016/j.tre.2025.104074).
- [2] Zou, Y., Kiviniemi, A., Jones, S.W. (2017). Retrieving similar cases for construction project risk management using Natural Language Processing techniques, *Automation in Construction*, Vol. 80, 66-76, doi: [10.1016/j.autcon.2017.04.003](https://doi.org/10.1016/j.autcon.2017.04.003).
- [3] Wiśniewski, T. (2025). Using large language models (LLMs) to support simulation-based optimization in supply chain management, *Advances in Production Engineering & Management*, Vol. 20, No. 4, 491-506, doi: [10.14743/apem2025.4.554](https://doi.org/10.14743/apem2025.4.554).
- [4] Ellram, L.M., Tate, W.L., Billington, C. (2004). Understanding and managing the services supply chain, *Journal of Supply Chain Management*, Vol. 40, No. 3, 17-32, doi: [10.1111/j.1745-493X.2004.tb00176.x](https://doi.org/10.1111/j.1745-493X.2004.tb00176.x).
- [5] Liao, L.H., Yang, C., Quan, L.R. (2023). Construction supply chain management: A systematic literature review and future development, *Journal of Cleaner Production*, Vol. 382, Article No. 135230, doi: [10.1016/j.jclepro.2022.135230](https://doi.org/10.1016/j.jclepro.2022.135230).
- [6] Coleman, L. (2006). Frequency of man-made disasters in the 20th century, *Journal of Contingencies and Crisis Management*, Vol. 14, No. 1, 3-11, doi: [10.1111/j.1468-5973.2006.00476.x](https://doi.org/10.1111/j.1468-5973.2006.00476.x).
- [7] Blackhurst, J., Craighead, C.W., Elkins, D., Handfield, R.B. (2005). An empirically derived agenda of critical research issues for managing supply-chain disruptions, *International Journal of Production Research*, Vol. 43, No. 19, 4067-4081, doi: [10.1080/00207540500151549](https://doi.org/10.1080/00207540500151549).
- [8] Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., Handfield, R.B. (2007). The severity of supply chain disruptions: Design characteristics and mitigation capabilities, *Decision Sciences*, Vol. 38, No. 1, 131-156, doi: [10.1111/j.1540-5915.2007.00151.x](https://doi.org/10.1111/j.1540-5915.2007.00151.x).
- [9] Zeng, J., An, M., Smith, N.J. (2007). Application of a fuzzy based decision making methodology to construction project risk assessment, *International Journal of Project Management*, Vol. 25, No. 6, 589-600, doi: [10.1016/j.ijproman.2007.02.006](https://doi.org/10.1016/j.ijproman.2007.02.006).
- [10] Olechowski, A., Oehmen, J., Seering, W., Ben-Daya, M. (2016). The professionalization of risk management: What role can the ISO 31000 risk management principles play?, *International Journal of Project Management*, Vol. 34, No. 8, 1568-1578, doi: [10.1016/j.ijproman.2016.08.002](https://doi.org/10.1016/j.ijproman.2016.08.002).
- [11] Taroun, A. (2014). Towards a better modelling and assessment of construction risk: Insights from a literature review, *International Journal of Project Management*, Vol. 32, No. 1, 101-115, doi: [10.1016/j.ijproman.2013.03.004](https://doi.org/10.1016/j.ijproman.2013.03.004).
- [12] Xia, N., Zou, P.X.W., Griffin, M.A., Wang, X., Zhong, R. (2018). Towards integrating construction risk management and stakeholder management: A systematic literature review and future research agendas, *International Journal of Project Management*, Vol. 36, No. 5, 701-715, doi: [10.1016/j.ijproman.2018.03.006](https://doi.org/10.1016/j.ijproman.2018.03.006).
- [13] Arrow, K.J., Harris, T., Marschak, J. (1951). Optimal inventory policy, *Econometrica*, Vol. 19, No. 3, 250-272, doi: [10.2307/1906813](https://doi.org/10.2307/1906813).
- [14] Wang, Y., Gerchak, Y. (1996). Periodic review production models with variable capacity, random yield, and uncertain demand, *Management Science*, Vol. 42, No. 1, 130-137, doi: [10.1287/mnsc.42.1.130](https://doi.org/10.1287/mnsc.42.1.130).

- [15] Shishehgharkhaneh, M.B., Moehler, R.C., Fang, Y.H., Aboutorab, H., Hijazi, A.A. (2024). Construction supply chain risk management, *Automation in Construction*, Vol. 162, Article No. 105396, doi: [10.1016/j.autcon.2024.105396](https://doi.org/10.1016/j.autcon.2024.105396).
- [16] Fang, X., Wang, R., Yuan, F.J., Gong, Y., Cai, J.R., Wang, Y.L. (2020). Modelling and simulation of fresh-product supply chain considering random circulation losses, *International Journal of Simulation Modelling*, Vol. 19, No. 1, 169-177, doi: [10.2507/IJSIMM19-1-C05](https://doi.org/10.2507/IJSIMM19-1-C05).
- [17] Papke-Shields, K.E., Beise, C., Quan, J. (2010). Do project managers practice what they preach, and does it matter to project success?, *International Journal of Project Management*, Vol. 28, No. 7, 650-662, doi: [10.1016/j.ijpro-man.2009.11.002](https://doi.org/10.1016/j.ijpro-man.2009.11.002).
- [18] Fang, X., Huang, Y., He, J., Lai, Y., Chen, S., Liang, G. (2024). An operations optimisation model for fresh food produce supply chain considering time-varying freshness and consumer utility, *Economic Computation and Economic Cybernetics Studies and Research*, Vol. 58, No. 3, 38-52, doi: [10.24818/18423264/58.3.24.03](https://doi.org/10.24818/18423264/58.3.24.03).
- [19] Pasternack, B.A. (1985). Optimal pricing and return policies for perishable commodities, *Marketing Science*, Vol. 4, No. 2, 166-176, doi: [10.1287/mksc.4.2.166](https://doi.org/10.1287/mksc.4.2.166).
- [20] Cachon, G.P., Larivière, M.A. (2005). Supply chain coordination with revenue-sharing contracts: Strengths and limitations, *Management Science*, Vol. 51, 30-44, doi: [10.1287/mnsc.1040.0215](https://doi.org/10.1287/mnsc.1040.0215).
- [21] He, Y., Zhang, J. (2008). Random yield risk sharing in a two-level supply chain, *International Journal of Production Economics*, Vol. 112, No. 2, 769-781, doi: [10.1016/j.ijpe.2007.06.003](https://doi.org/10.1016/j.ijpe.2007.06.003).
- [22] Güler, M.G., Bilgiç, T. (2009). On coordinating an assembly system under random yield and random demand, *European Journal of Operational Research*, Vol. 196, No. 1, 342-350, doi: [10.1016/j.ejor.2008.03.002](https://doi.org/10.1016/j.ejor.2008.03.002).
- [23] Hu, F., Lim, C.-C., Lu, Z. (2013). Coordination of supply chains with a flexible purchasing policy under yield and demand uncertainty, *International Journal of Production Economics*, Vol. 146, No. 2, 686-693, doi: [10.1016/j.ijpe.2013.08.024](https://doi.org/10.1016/j.ijpe.2013.08.024).
- [24] Güler, M.G., Keskin, M.E. (2013). On coordination under random yield and random demand, *Expert Systems with Applications*, Vol. 40, No. 9, 3688-3695, doi: [10.1016/j.eswa.2012.12.073](https://doi.org/10.1016/j.eswa.2012.12.073).
- [25] Cai, J., Zhong, M., Shang, J., Huang, W. (2017). Coordinating VMI supply chain under yield uncertainty: Option contract, subsidy contract, and replenishment tactic, *International Journal of Production Economics*, Vol. 185, 196-210, doi: [10.1016/j.ijpe.2016.12.032](https://doi.org/10.1016/j.ijpe.2016.12.032).
- [26] Sonntag, D., Kiesmüller, G.P. (2018). Disposal versus rework – Inventory control in a production system with random yield, *European Journal of Operational Research*, Vol. 267, No. 1, 138-149, doi: [10.1016/j.ejor.2017.11.019](https://doi.org/10.1016/j.ejor.2017.11.019).
- [27] Stojic, N., Delic, M., Bojanic, T., Jokanovic, B., Tasic, N. (2024). Integrated model of risk management in business processes in industrial systems, *International Journal of Simulation Modelling*, Vol. 23, No. 3, 412-423, doi: [10.2507/IJSIMM23-3-689](https://doi.org/10.2507/IJSIMM23-3-689).
- [28] Wang, Y.L., Chen, J.H., Song, M.L., Tang, F. (2025). Optimizing cooperation strategies for new energy vehicle manufacturers and technology suppliers: A game theory approach, *Advances in Production Engineering & Management*, Vol. 20, No. 3, 340-350, doi: [10.14743/apem2025.3.544](https://doi.org/10.14743/apem2025.3.544).
- [29] Zhao, Y., Rao, H., Pei, J., Su, X. (2025). An ANP-hopfield neural network based approach for supply chain stress testing, *Tehnički Vjesnik – Technical Gazette*, Vol. 32, No. 2, 415-424, doi: [10.17559/TV-20240501001513](https://doi.org/10.17559/TV-20240501001513).
- [30] Xi, J., Lai, L., Li, Y., Yang, D. (2025). The coordination mechanism of fresh agricultural products supply chain: A game-theoretic approach considering retailer's fairness concern and price competition, *Economic Computation and Economic Cybernetics Studies and Research*, Vol. 59, No. 1, 120-137, doi: [10.24818/18423264/59.1.25.08](https://doi.org/10.24818/18423264/59.1.25.08).
- [31] Xu, W., Xu, S., Liu, D.Y., Awaga, A.L., Rabia, A.C., Zhang, Y.Y. (2024). Impact of fairness concerns on resource-sharing decisions: A comparative analysis using evolutionary game models in manufacturing enterprises, *Advances in Production Engineering & Management*, Vol. 19, No. 2, 223-238, doi: [10.14743/apem2024.2.503](https://doi.org/10.14743/apem2024.2.503).
- [32] Ji, X., Xu, W., Aslam, R., Yin, Y. (2024). The influence of government on automobile enterprise's production methods: An evolutionary game based study, *Economic Computation and Economic Cybernetics Studies and Research*, Vol. 58, No. 4, 223-240, doi: [10.24818/18423264/58.4.24.14](https://doi.org/10.24818/18423264/58.4.24.14).
- [33] Zhou, C., Tang, W., Lan, Y. (2018). Supply chain contract design of procurement and risk-sharing under random yield and asymmetric productivity information, *Computers & Industrial Engineering*, Vol. 126, 691-704, doi: [10.1016/j.cie.2018.10.022](https://doi.org/10.1016/j.cie.2018.10.022).
- [34] Behzadi, G., O'Sullivan, M.J., Olsen, T.L., Zhang, A. (2018). Agribusiness supply chain risk management: A review of quantitative decision models, *Omega*, Vol. 79, 21-42, doi: [10.1016/j.omega.2017.07.005](https://doi.org/10.1016/j.omega.2017.07.005).
- [35] Besik, B., Nagurney, A., Dutta, P. (2023). An integrated multi-tiered supply chain network model of competing agricultural firms and processing firms: The case of fresh produce and quality, *European Journal of Operational Research*, Vol. 307, No. 1, 364-381, doi: [10.1016/j.ejor.2022.07.053](https://doi.org/10.1016/j.ejor.2022.07.053).