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A review of the joint replenishment problem from 2006 to 2022

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Abstract

In the increasingly competitive market, supply chain decision-makers are making efforts to improve operational efficiency and reduce costs by joint replenishment approach. Recognizing the value of joint replenishment strategy in the supply chain, we are motivated to write a review on the importance of joint replenishment strategy. Despite the vast literature on the joint replenishment problem (JRP), a comprehensive study survey for recent years is lacking. The goal of this study is to review and synthesize research on JRP from 2006 to 2022. Details of JRP are introduced first. Literature selection and an overview of the extant literature are then discussed. Recent research on JRP with relaxed assumptions is summarized, including stochastic demand, dynamic demand, and resource constraints. In addition, recent research on other JRPs and the joint replenishment and delivery (JRD) problem is summarized. The observations and insights of these studies can guide academics and practitioners to implement joint replenishment strategies in different aspects of supply chain management.

Keywords: Joint replenishment problem, Stochastic demand, Dynamic demand, Resource constraint, Joint replenishment and delivery problem

1 Introduction

In July 2022, the results of China's seventh batch of centralized medication procurement organized by the state showed that 60 medications were successfully purchased in the centralized procurement. The average price of the selected medications was reduced by 48%. It is estimated to save 18.5 billion RMB per year based on the agreed-upon procurement volume. Because of the high ordering cost, adopting a joint replenishment policy may result in significant cost reductions. Many companies have also adopted a joint replenishment policy in the operation management process (Qu et al. 2020). The joint replenishment problem (JRP) has been extensively investigated. Khouja and Goyal (2008) did a review of the JRP up to late 2005. Compared with the review of Khouja and Goyal (2008), this study has significant differences in two aspects. Firstly, the target of this study is to examine and summarize JRP research from 2006 to 2022. Secondly, recent studies on the joint replenishment and delivery (JRD) problem are summarized.

There are two types of JRP strategies: indirect grouping strategy (IGS) and direct grouping strategy (DGS). In IGS, the replenishment quantity of each item is an integer multiple of the regular period. Items of the same integer multipliers formed the groups. DGS divides items into predetermined sets, and items in every set are refilled simultaneously. According to the study of Van Eijs et al. (1992), IGS beats DGS for higher major ordering costs since multiple items may be restocked simultaneously while utilizing an IGS. Many scholars have designed different effective methods to solve the JRPs (Nilsson et al. 2007; Porras and Dekker 2008; Hong and Kim 2009; Tsai et al. 2009).

In this study, we examine the research of JRPs on five major expansions: JRPs assuming stochastic demand, JRPs assuming dynamic demand, JRPs under resource constraints, the other special JRPs, and the JRDs.

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Consequently, this study attempts to investigate the applications of JRP and its analysis in supply chain management. Approximately 90 journal papers are evaluated. This study examined JRP challenges, trends, and perspectives in supply chain management. JRPs are thoroughly investigated in order to provide industrial managers or decision-makers with a competitive advantage.

2 The classic JRP

The fundamental assumptions of JRP are related to the economic order quantity (EOQ). The assumptions involve deterministic and uniform demand, no shortages or quantity discounts, and a linear holding cost. The notations are specified in Table 1.

In IGS, the cycle time for item i is $T_i = k_iT$. and the order quantity for item i is $Q_i = T_id_i = k_iTd_i$.

Then the major and minor ordering cost is: $C_O = S/T + \sum_{i=1}^{n} (s_i/k_iT)$.

Major ordering cost is unaffected by the number of goods in the order. Minor ordering cost varies according to the number of distinct goods.

The inventory holding cost is given as: $C_H = \sum_{i=1}^{n} Q_ih_i/2 = \frac{T}{2}\sum_{i=1}^{n} k_id_ih_i$.

The total cost (TC) is: $TC = C_O + C_H = S/T + \sum_{i=1}^{n} (s_i/k_iT) + \frac{T}{2}\sum_{i=1}^{n} k_id_ih_i$.

In DGS, the group number m is established and the items are divided into m groups. T_j is the cycle time of the items in each group. This strategy focuses on identifying the optimum group decision and every group's appropriate cycle time. TC is generated $TC(T_1, T_2, \ldots, T_m) = \sum_{j=1}^{m}\left[(S + \sum_{i=1}^{n} s_i)/T_j + \frac{1}{2}T_j\sum_{i=1}^{n} d_ih_i\right]$.

Table 1 The notations of classic JRP

Indices
i: index of item,1 $\leq i \leq n$
Parameters
n: number of items
h_i: item i's inventory holding cost
d_i: item i's demand
s_i: item i's minor ordering cost
S: major ordering cost
Decision variables
T: basic replenishment cycle time
k_i: integer number that enables k_iT to be the replenishment cycle time for item i

3 Literature selection and overview of the extant literature

This study primarily evaluates papers on the topic of operations management. Web of Science, ScienceDirect, Springer, Wiley, and Taylor & Francis are chosen as the databases. Since 2006, articles relating to the joint replenishment problem have been collated. Given the nature of the research, only works that explicitly cover JRP are included. Finally, about 90 journal papers are chosen. Table 2 displays the findings of the journals in which at least two papers were included, except one paper from Production and Operations Management.

The citation is an essential metric for determining the influence of a single work. Table 3 shows some frequently cited works since 2006 in Web of Science (accessed October 18, 2022). The most frequently referenced publications were published in 2008. It is a review of JRP up to late 2005 summarized by Khouja and Goyal (2008).

4 Analysis of research content

Section 4.1 depicts the JRPs under stochastic demand, while Sect. 4.2 depicts the JRPs under dynamic demand. Section 4.3 describes the JRPs with resource limits, Sect. 4.4 displays the other special JRPs, and Sect. 4.5 displays the JRDs.

Table 2 Number of papers published in major journals

Journal	Number of papers
European Journal of Operational Research	15
International Journal of Production Economics	13
Computers & Industrial Engineering	7
Knowledge-Based Systems	6
Expert Systems with Applications	4
Applied Mathematical Modelling	3
Computers & Operations Research	7
Operations Research	4
Applied Soft Computing	2
International Journal of Production Research	2
International Journal of Systems Science	2
Transportation Research Part E: Logistics and Transportation Review	2
Operational Research	2
Production and Operations Management	1
Journal of the Operational Research Society	2

Table 3 Frequently cited papers

Title	Authors	Citations	Journal	Year
A review of the joint replenishment problem literature: 1989–2005	Khouja and Goyal	182	European Journal of Operational Research	2008
An improved fruit fly optimization algorithm and its application to joint replenishment problems	Wang et al.	127	Expert systems with Applications	2015
The joint replenishment problem with resource restriction	Moon and Cha	63	European Journal of Operational Research	2006
A multi-objective joint replenishment inventory model of deteriorated items in a fuzzy environment	Wee et al.	63	European Journal of Operational Research	2009
The joint replenishment and delivery scheduling of the one-warehouse, n-retailer system	Cha et al.	61	Transportation Research Part E: Logistics and Transportation Review	2008
An effective and efficient differential evolution algorithm for the integrated stochastic joint replenishment and delivery model	Wang et al.	56	Knowledge-Based Systems	2012
A novel differential evolution algorithm for joint replenishment problem under interdependence and its application	Wang et al.	50	International Journal of Production Economics	2012
A genetic algorithm for joint replenishment based on the exact inventory cost	Hong and Kim	47	Computers & Operations Research	2009
A contrastive study of the stochastic location-inventory problem with joint replenishment and independent replenishment	Qu et al.	47	Expert Systems with Applications	2015
The joint replenishment and freight consolidation of a warehouse in a supply chain	Moon et al.	46	International Journal of Production Economics	2011

5 The JRPs under stochastic demand

For JRP with stochastic demand (SJRP), the demand of item is stochastic but stationary in the mean. Özkaya et al. (2006) proposed a new parsimonious policy for SJRP. Viswanathan (2007) created techniques for identifying the best solutions among a set of lower bounds for SJRP based on the allocation of the joint setup cost. Kayiş et al. (2008) modeled the SJRP as a semi-Markov decision process for two items. Kiesmüller (2010) examined the SJRP where transportation costs are high and full truckloads or full container loads are considered. Mustafa Tanrikulu et al. (2010) investigated the SJRP using cost structures derived from transporting products in fixed-capacity trucks. Qu et al. (2015) developed a location-inventory model in conjunction with a joint replenishment approach under stochastic demand. Compared to the location-inventory model under the independent replenishment strategy, the use of JRP can greatly reduce the cost of the location-inventory model. Braglia et al. (2016) investigated the SJRP, which contains backorders-lost sales mixtures as well as adjustable lead time. They assumed that the lead time includes two components: one that applies to all things and one that is unique to each item. Braglia et al. (2017) investigated the periodic review SJRP with backorders and lost sales. Liang et al. (2016) studied the SJRP through the use of option contracts. Cui et al. (2020b) investigated the SJRP in the presence of a random number of imperfect items and devised the bare-bones differential evolutionary (BBDE) method to solve it. Table 4 shows the studies about the SJRP.

Table 4 Typical studies about the SJRP

Studies	Characteristics	Algorithms
Özkaya et al. (2006)	Parsimonious policy	Mathematic
Viswanathan (2007)	–	Heuristic
Kayis et al. (2008)	–	Enumeration algorithm
Kiesmüller (2010)	Capacity restrictions	–
Mustafa Tanrikulu et al. (2010)	Vehicle capacities	–
Qu et al. (2015)	Location-inventory	Differential evolution (DE)
Braglia et al. (2016)	Backorders-lost sales mixtures and controllable lead times	Heuristic
Liang et al. (2016)	Option contracts	Genetic algorithm (GA)
Braglia et al. (2017)	Backorders-lost sales mixtures	Heuristic
Cui et al. (2020b)	Imperfect items	BBDE

6 The JRP under dynamic demand

The products' demand is deterministic but not uniform over time for JRP with dynamic demand (DJRP). The goal of DJRP is to optimize the total cost during a H-period scheduling horizon. DJRP with capacity limits was studied by Federgruen et al. (2007). Robinson et al. (2007) developed several heuristics and evaluated the efficacy of heuristics through performing a series of test. According to Robinson et al. (2009), approaches for solving DJRP included the branch-and-cut method, the dynamic programming algorithm, and the branch-and-bound method. On the basis of Boctor et al. (2004), Narayanan and Robinson (2010) compared the performance of various heuristic algorithms. Lu and Qi (2011) used a novel JRP model to identify a dynamic lot sizing problem considering lost sales. Absi et al. (2013) investigated the DJRP model in the event of out-of-stock and created a Lagrangian method based on a smoothing algorithm and adaptive local search to solve it. Gutiérrez et al. (2013) proposed a structured heuristic approach to solve a DJRP model with storage capacity limitations. A vast number of numerical examples showed that the algorithm proposed by Gutiérrez et al. (2013) offered significant advantages in accuracy and stability over the previous heuristic algorithms. Baki et al. (2014) addressed the DJRP model in the context of product recycling and remanufacturing. They designed a heuristic algorithm that can split the model into sub-problem models of a single product and several cycles, and then solved it using dynamic programming. To solve the larger-scale DJRP model, Gicquel and Minoux (2015) devised a complicated cutting plane approach. Baller et al. (2019) extended the traditional DJRP by accounting transportation costs. Table 5 summarizes the research on the DJRP.

7 The JRP under resource constraints

Many manufacturing activities involve resource constraints. The JRP model with resource constraints is a joint replenishment research hotspot. The limits are financial constraints, capacity constraints, storage capacity constraints, and so on. Many researchers integrated these restrictions into JRPs. Hoque (2006) created a JRP model with inventory, transportation, and budget limitations, then used the model's mathematical properties to create a globally optimal post-issue algorithm model. Moon and Cha (2006) explored JRP with limited capital and created RAND and a genetic algorithm to solve it. Porras and Dekker (2006) explored JRP with a minimum order quantity limitation and established an effective global optimization strategy for solving the JRP with constraints. Ongkunaruk et al. (2016) solved a JRP model for defective items with a shipment constraint using DE and GA. Porras and Dekker (2006) developed a global optimization approach to solve the JRP model with the fewest orders. To solve the JRP model with budgetary limitations, Amaya et al. (2013) suggested a heuristic technique based on linear programming. Büyükkaramikli et al. (2014) investigated the influence of transportation fleet capacity. Rahmouni et al. (2015) analyzed the JRP's transportation capacity and route constraints. Wang et al. (2015) studied the use of the fly optimization algorithm (FOA) for the JRP model under storage capacity and capital limitations. Chen et al. (2016) provided a JRP for defective items that took into account shipment, budget, and transportation capacity constraints. To solve the special JRP, GA and an evolutionary algorithm (EA) are compared. Chen et al. (2019) provided a JRP for defective items that took into account budget, transportation capacity, and shipment requirements under partial demand substitution. Wang et al. (2020) investigated a new JRP with grouping

Table 5 Typical studies about the DJRP

Studies	Characteristics	Algorithms
Federgruen et al. (2007)	Capacity constraints	Heuristic
Robinson et al. (2007)	–	Heuristic
Robinson et al. (2009)	–	Branch-and-cut, dynamic programming algorithm, and branch-and-bound method
Narayanan and Robinson (2010)	–	Heuristic
Lu and Qi (2011)	Lost sales	Heuristic
Absi et al. (2013)	Out-of-stock	Lagrangian algorithm
Gutiérrez et al. (2013)	Storage capacity constraints	Heuristic
Baki et al. (2014)	Product recycling and remanufacturing	Heuristic
Gicquel and Minoux (2015)	–	Cutting plane method
Baller et al. (2019)	Approximated transportation costs	Branch-and-Cut-and-Price

constraints and designed an effective backtracking search optimization algorithm (BSA). Muriel et al. (2022) investigated JRP with minimum order quantity constraints. Zeng et al. (2022) investigated cooperative replenishment among numerous merchants under various carbon constraints, such as a carbon cap-and-price, a carbon cap-and-offset, a tight carbon cap, and a carbon tax. They investigated the cost allocation problem using cooperative game theory. Table 6 shows the studies about the DJRP.

8 The other special JRPs

Some authors addressed specific instances of the traditional JRP. The research is organized into the following categories:

(1) The JRPs consider discounts. Moon et al. (2008) investigated the JRP while taking into account quantity discounts. Taleizadeh et al. (2015) devised a policy of joint replenishment with a temporary discount. Cui et al. (2016) developed a JRP that took into account the incremental quantity discount and all-unit quantity discount simultaneously.

(2) The JRPs take into account the specific properties of the products. For degrading products, Wee et al. (2009) created a fuzzy multi-objective joint replenishment inventory model. Zhang et al. (2012) presented a method for hedging inventory risk by taking into account probable item linkages in a novel JRP model with complete backordering and linked demand. Paul et al. (2014) investigated the JRP in the presence of defective products and price discounts. Salameh et al. (2014) used EOQ model to solve JRP with a substitution for two items. Maddah et al. (2016) investigated JRP with a substitution for various items. Ai et al. (2017) studied JRP for non-instantaneous deteriorating products with a constant demand rate that allows for full backlog.

(3) The JRPs are under trade credit. Tsao et al. (2010), Tsao and Teng (2013), and Wang et al., (2020) both investigated joint replenishment issues within the allowable payment delay. Lin and Yao (2020) investigated the joint replenishment problem in which every product may have a replenishment cycle and permissible delay period that is different from others.

(4) The JRPs are under different demand distributions. Wang and Cheng (2008) explored how misestimates of uncertain demand and unit holding costs may affect replenishment policy. Larsen (2009) investigated JRP with a compound correlated Poisson demand. Yang and Kim (2020) investigated an adaptive JRP for nonstationary demand products. Creemers and Boute (2022) utilized an embedded Markov chain for evaluating any stable JRP under compound Poisson demand.

(5) The JRPs employ some inventory control systems. Hsu (2009) studied joint replenishment decisions for a central factory using a Just in Time management system. Korpeoglu et al. (2013) used a non-cooperative game with asymmetric knowledge to investigate JRP in an EOQ-like context. They demonstrated the existence of a Bayesian Nash equilibrium in the game. Zhou et al. (2013) constructed a multi-product and multi-echelon inventory control model using the JRP. The results demonstrated that GA algorithm had a advantage in terms of reducing cost. Verma et al. (2014) presented a novel

Table 6 Typical studies about the JRP under resource constraints

Studies	Characteristics	Algorithms
Hoque (2006)	Storage, transport capacities and budget constraints	Heuristic
Moon and Cha (2006)	Capital constraint	Rand; GA
Porras and Dekker (2006)	Minimum order quantity constraint	Heuristic
Amaya et al. (2013)	Financial constraints	Heuristic
Büyükkaramikli et al. (2014)	Transportation fleet capacity	–
Rahmouni et al. (2015)	Transportation capacity and routing constraints	Mixed integer linear programming
Wang et al. (2015)	Storage capacity and capital constraints	FOA
Chen et al. (2016)	Defective items; shipment constraint, budget constraint, transportation capacity constraint	GA; EA
Ongkunaruk et al. (2016)	Defective items; Shipment constraint	DE; GA
Chen et al. (2019)	Budget, transportation capacity, and shipment requirement constraints	DE; GA
Wang et al. (2020)	Trade credit and grouping constraint	DE; GA; BSA
Muriel et al. (2022)	Minimum order quantity constraints	Heuristic
Zeng et al. (2022)	Carbon constraints	Cooperative game theory

replenishment method that would allow for distinct replenishment periods for each merchant. Rosales et al. (2019) offered various joint replenishment policies for coordinating periodic and continuous replenishment across items.

(6) Other studies. Bayndr et al. (2006) investigated JRP with variable production costs and devised a Lipschitz optimization method. Anily and Haviv (2007) investigated an infinite-horizon deterministic JRP with first order interaction and solved the cost allocation problem of an optimal power-of-two policy among numerous merchants. Olsen (2008) developed an enhanced JRP model for the scenario of ordering cost dependency. Dror et al. (2012) focused on the challenge of determining how to share joint replenishment costs across individual items. Wang et al. (2012b) contrasted the JRP model of direct grouping with the JRP model of indirect grouping. They concluded that the solution impact of differential evolution algorithm is better than evolutionary calculation through a large number of numerical examples. Silva and Gao (2013) created the location-inventory problem for the first time by using the joint replenishment approach. The random adaptive search approach was used to choose sites first, and the results were then used to solve the relevant JRP issue. Wang et al. (2013a) explored JRP in a fuzzy setting and developed a new fuzzy simulation approach to solve it. Wang et al. (2013b) added a new decision variable (the maximum number of distribution centers), updated the model designed by Silva and Gao (2013), and created a novel differential evolution technique to solve the model. Guler et al. (2017) sought a mechanism for determining the combined replenishment frequency and allocating joint ordering fee to enterprises on the basis of their reported stand-alone replenishment rates. The JRP with infinite-horizon multiple retailer and first-order interaction was studied by He et al. (2017). They discovered a reward dominant Nash equilibrium and quantified the efficiency loss of the noncooperative outcome. Wang et al. (2019) investigated retailers' joint replenishment and supply chain participants' carbon trading behavior. Vanvuchelen et al. (2020) solved the joint replenishment problem with complete truckload shipments using proximal policy optimization. Yao et al. (2020) investigated a multi-customer JRP with districting consideration to identify a best districting setup for all zones. Shi and Wang (2022) developed a cost allocation method to allocate the whole cost of a cooperative coalition. They demonstrated how JRP may assist small cross-border e-commerce businesses in reducing costs, shortening replenishment cycles, and accelerating product turnover. Ventura et al. (2022) addressed a more sophisticated cost structure with joint replenishment costs for raw resources.

9 The joint replenishment and delivery problem

JRD is a subset of JRP. The JRD model offers a wide range of practical applications. The JRD model's three-layer supply chain structure is widely used in enterprise management in the manufacturing and retail industries. These companies frequently acquire items in large quantities from suppliers via centralized procurement, then keep them in a central warehouse for distribution before distributing them to terminal merchants or customers. The JRD considers replenishment and delivery at the same time. As shown in Fig. 1, the basic JRD structure was introduced by Cha et al. (2008).

In JRD, the following assumptions are used. For all items, the demand rates and accompanying costs are known and constant. There will be no scarcity. Instant replenishment occurs. Table 7 displays the notations of JRD.

The total ordering costs (C_O) involves the major and minor ordering cost as follows: $C_O = \frac{S}{T} + \sum_{i=1}^{n} \frac{s_i^w}{k_i T}$.

The total inventory cost of the central warehouse (C_H) is: $C_H = \sum_{i=1}^{n} \frac{(f_i - 1)k_i T d_i h_i^w}{2f_i}$.

The cost of distribution to the retailer (C_D) is: $C_D = \sum_{i=1}^{n} \frac{f_i s_i^r}{k_i T}$.

The cost of distribution for items through the central warehouse is the distribution cost per unit and distribution times.

The total inventory cost of the retail (C_R) is: $C_R = \sum_{i=1}^{n} \frac{k_i T d_i h_i^r}{2f_i}$.

The total cost (TC) is:

$$\begin{aligned} TC(T,K,F) &= C_O + C_H + C_D + C_R \\ &= \frac{S}{T} + \sum_{i=1}^{n} \frac{s_i^w}{k_i T} + \sum_{i=1}^{n} \frac{(f_i - 1)k_i T d_i h_i^w}{2f_i} \\ &\quad + \sum_{i=1}^{n} \frac{f_i s_i^r}{k_i T} + \sum_{i=1}^{n} \frac{k_i T d_i h_i^r}{2f_i}, \end{aligned}$$

where K and F are a set of integer multipliers.

In recent years, some scholars have focused on the issue of JRD. Moon et al. (2011) developed some heuristics on the basis of optimal characteristics to solve JRD. Wang et al. (2012a) designed a DE technique to tackle JRD with stochastic demand. Qu et al. (2013) examined the

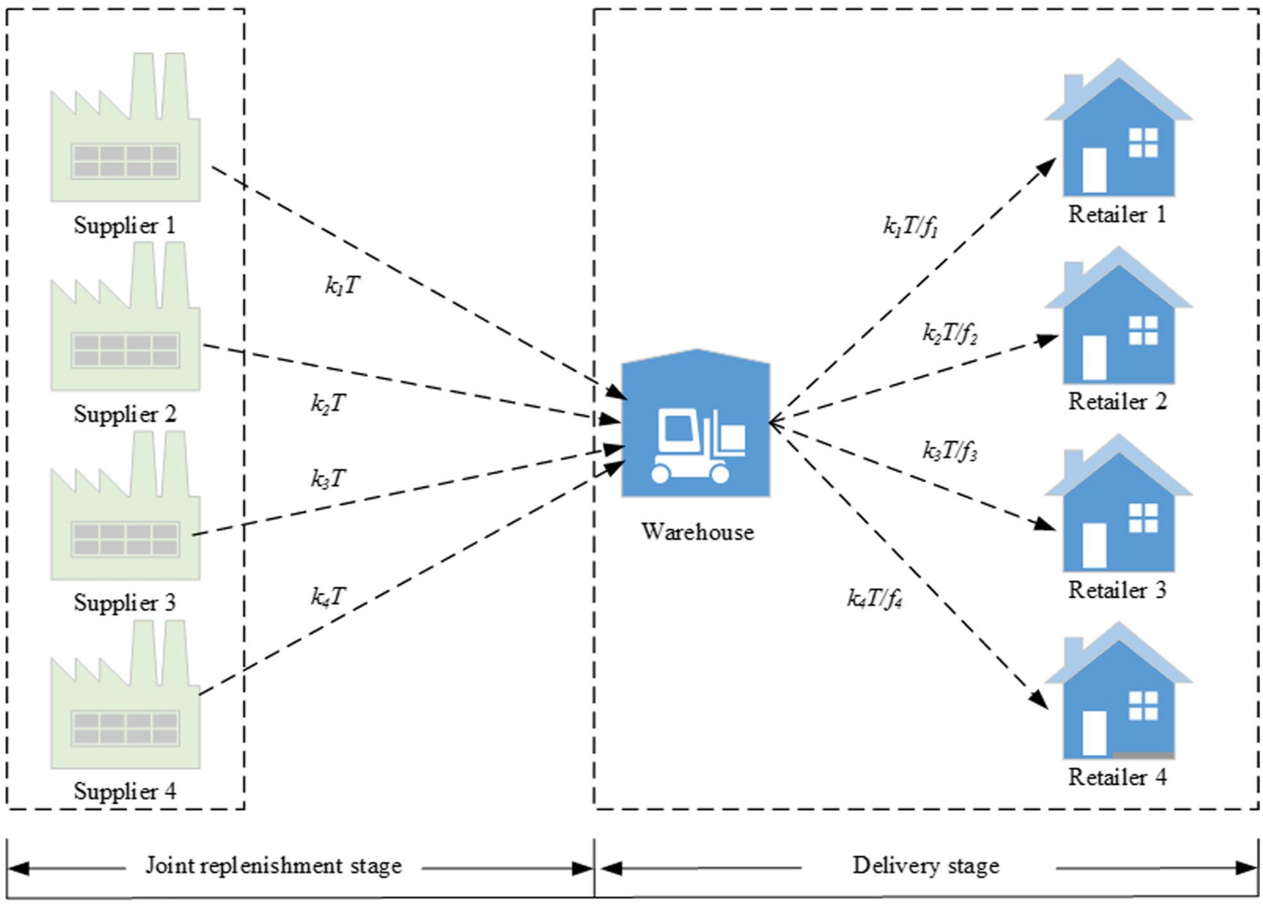

Fig. 1 The basic JRD structure

Table 7 Notations used in the basic JRD model

Description of parameters	
n	Number of items
d_i	Item i's demand
S	Major ordering cost
s_i^w	Minor ordering cost for item i purchased through central warehouse
h_i^w	Inventory holding cost for item i in the central warehouse
s_i^r	Distribution cost for item i
h_i^r	Inventory holding cost per unit for item i in the retail
Description of indices	
i	Index of item,$1 \leq i \leq n$
Description of decision variables	
T	Basic replenishment cycle time
k_i	Integer number that decides the replenishment schedule of item i
f_i	Integer number that decides the outbound schedule of item i

JRD model for heterogeneous products. Cui et al. (2014) studied a RFID-based investment evaluation model for the JRD model in the presence of stochastic demand. Cui et al. (2015) believed that the "one-to-one" distribution method may be improved. They proved that the distribution tasks of merchants can be packaged together for integrated transportation to gain economies of scale. Ongkunaruk et al. (2016) looked into the problem of malfunctioning items. Several items are easily damaged and lose quality while in transit. Zeng et al. (2016) studied the JRD with trade credit and a hybrid DE with simulated annealing (SA) to tackle the problem. Ai et al. (2017) addressed the optimization problem of non-immediate deterioration products, taking into account that products may decay and affect inventory under specific situations. Conflicts in goods resulted in additional expenditures due to the wide range of goods. Liu et al. (2017) examined a JRD with several warehouses. Wang et al. (2018) created a fast-bounding strategy based on a variable neighborhood search (VNS) for JRD. Liu et al. (2018) examined a more realistic extended JRD that included a quantity discount and resource constraints. Carvajal et al. (2020) offered a more flexible distribution technique based on the findings of Liu et al. (2018). To solve these challenges, Cui et al. (2020a), Cui et al. (2020b), and Cui et al. (2020c) researched JRDs with stochastic demand. To balance the costs of setup, inventory storage, and outbound delivery, Qu et al. (2020) examined JRD with a joint outward delivery policy. Wang et al. (2020) and Liu et al. (2021) examined JRDs under dynamic demand. Liu et al. (2022) sought to investigate the optimization of centralized medication procurement based on a JRD under production and distribution capacity limitations. Wang and Wang (2022) introduced a Lipschitz optimization technique and a RAND method to handle a JRD with stochastic demand. Wang et al. (2022) studied the stochastic JRD considering the location problem. The preceding literature is summarized in Table 8.

10 Discussion and concluding remarks

For the assumptions about the demand of JRP, many researchers have adjusted the JRP model's assumption of constant demand into a dynamic demand or a specific probability distribution. In reality, real-world requirements are different to predict. There are many studies on the JRP problem of dynamic demands, but the research on the JRD problem of dynamic demands is relatively few.

For the constraints of JRP, researchers primarily add one or two capital constraints, inventory constraints, and traffic constraints to the basic JRP model from the standpoint of resource limitations. For these special JRPs, researchers mostly use artificial intelligence optimization

Table 8 Typical studies about the JRD

Studies	Characteristics	Algorithms
Cha et al. (2008)	Deterministic demand	Heuristic; GA
Moon et al. (2011)	Consolidated freight	Heuristic
Wang et al. (2012a)	Stochastic demand	DE; GA
Qu et al. (2013)	Heterogeneous products	DE
Cui et al. (2014)	Stochastic demand, RFID-based investment	DE
Cui et al. (2015)	Integrated transportation	EA
Ongkunaruk et al. (2016)	Defective items	GA
Zeng et al. (2016)	Trade credit	DE-SA
Ai et al. (2017)	Non-immediate deterioration products	Heuristic
Liu et al. (2017)	Multi-warehouse	Heuristic; Tabu Search (TS)
Wang et al. (2018)	Deterministic demand	Heuristic; VNS
Liu et al. (2018)	Quantity discount and resource constraints	Heuristic; TS
Carvajal et al. (2020)	Resource constraints, free distribution strategy	Matheuristic
Cui et al. (2020a); Cui et al. (2020b); Cui et al. (2020c)	Stochastic demand	Heuristic; DE
Qu et al. (2020)	Coordinated outbound delivery	DE
Wang et al. (2020)	Dynamic demand	Heuristic
Liu et al. (2021)	Dynamic demand and capacity constraint	Heuristic
Liu et al. (2022)	Production and distribution capacity constraint	Heuristic
Wang and Wang (2022)	Stochastic demand	Heuristic
Wang et al. (2022)	Stochastic demand, Location cost	Improved DE

algorithms and heuristic algorithms based on the structural aspects of the problem to handle such nonlinear combination optimization problems.

Other expansions include volume discounts, trade credit, and so on. Overall, the JRP extension model is getting more and closer to the real environment, while simultaneously becoming more complex. It is often difficult to build an accurate solution approach when the problem becomes more complex. Instead, more adaptable artificial intelligence-based optimization techniques and heuristic algorithms based on the problem's structural features are applied.

Also, it is critical to connect the joint procurement strategy with other management decisions such as supplier selection, order quantity allocation, as well as location-inventory-distribution Optimization. For example, the study about cooperative procurement strategy-based location-inventory problem is very limited. Few studies about joint procurement and distribution scheduling are based on the standard JRP, with the majority of them assuming deterministic and stochastic demand. In future, research on the joint procurement and other management decisions of dynamic demands can be further studied.

The ability of methodologies to find the best solutions for JRPs has varied. Furthermore, the complexity of these techniques, both conceptual and computational, varies greatly. The extended JRP is also more complex to solve. For example, in a complicated and uncertain environment, model decision variables increase exponentially for integrated optimization of the location-inventory-distribution problem under the joint procurement strategy. To facilitate real-time decision-making, new intelligent optimization methods with high accuracy, fast convergence, and steady performance are needed to further designed.

Although the joint replenishment strategy and its use in supply chain management have a long history, many essential issues remain unresolved. We stress several practical assumptions in JRP in this work. However, the collecting and application of data in the supply chain has provided new opportunities, which may lead to new research avenues. Relevant data from consumers' search and purchase activity is more likely to boost the value of the appliance. How to employ consumer behavior data in an electronic platform to forecast demand and connect it with a joint replenishment policy is also a unresolved problem.

Abbreviations

BBDE: Bare-bones differential evolutionary; BSA: Backtracking search optimization algorithm; DE: Differential evolution; DGS: Direct grouping strategies; DJRP: JRP with dynamic demand; EA: Evolutionary algorithm; EOQ: Economic order quantity; FOA: Fly optimization algorithm; IGS: Indirect grouping strategies; JRP: Joint replenishment problem; JRD: Joint replenishment and delivery; SA: Simulated annealing; SJRP: JRP with stochastic demand; TS: Tabu search.

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Author contributions

LP: Conceptualization, Methodology, Investigation, Writing Original draft preparation. LW: Conceptualization, Writing Reviewing, and Editing. SW: Conceptualization, Investigation, Validation, Visualization, Writing Reviewing and Editing. All authors read and approved the final manuscript.

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Availability of data and materials

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Declarations

Competing interests

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References

Absi, N., B. Detienne, and S. Dauzère-Pérès. 2013. Heuristics for the multi-item capacitated lot-sizing problem with lost sales. *Computers & Operations Research* 40 (1): 264–272.

Ai, X.Y., J.L. Zhang, and L. Wang. 2017. Optimal joint replenishment policy for multiple non-instantaneous deteriorating items. *International Journal of Production Research* 55 (16): 4625–4642.

Amaya, C.A., J. Carvajal, and F. Castano. 2013. A heuristic framework based on linear programming to solve the constrained joint replenishment problem (C-JRP). *International Journal of Production Economics* 144 (1): 243–247.

Anily, S., and M. Haviv. 2007. The cost allocation problem for the first order interaction joint replenishment model. *Operations Research* 55 (2): 292–302.

Baki, M.F., B.A. Chaouch, and W. Abdul-Kader. 2014. A heuristic solution procedure for the dynamic lot sizing problem with remanufacturing and product recovery. *Computers & Operations Research* 43: 225–236.

Baller, A.C., S. Dabia, W. Dullaert, and D. Vigo. 2019. The dynamic-demand joint replenishment problem with approximated transportation costs. *European Journal of Operational Research* 276 (3): 1013–1033.

Bayındır, Z.P., Şİ Birbil, and J.B.G. Frenk. 2006. The joint replenishment problem with variable production costs. *European Journal of Operational Research* 175 (1): 622–640.

Boctor, F.F., G. Laporte, and J. Renaud. 2004. Models and algorithms for the dynamic-demand joint replenishment problem. *International Journal of Production Research* 42 (13): 2667–2678.

Braglia, M., D. Castellano, and M. Gallo. 2016. An extension of the stochastic Joint-Replenishment Problem under the class of cyclic policies. *Operations Research Letters* 44 (2): 278–284.

Braglia, M., D. Castellano, and D. Song. 2017. Distribution-free approach for stochastic Joint-Replenishment Problem with backorders-lost sales mixtures, and controllable major ordering cost and lead times. *Computers & Operations Research* 79: 161–173.

Büyükkaramikli, N.C., Ü. Gürler, and O. Alp. 2014. Coordinated logistics: Joint replenishment with capacitated transportation for a supply chain. *Production and Operations Management* 23 (1): 110–126.

Carvajal, J., F. Castaño, W. Sarache, and Y. Costa. 2020. Heuristic approaches for a two-echelon constrained joint replenishment and delivery problem. *International Journal of Production Economics* 220: 107420.

Cha, B.C., I.K. Moon, and J.H. Park. 2008. The joint replenishment and delivery scheduling of the one-warehouse, n-retailer system. *Transportation Research Part E: Logistics and Transportation Review* 44 (5): 720–730.

Chen, Y., M.I.M. Wahab, and P. Ongkunaruk. 2016. A joint replenishment problem considering multiple trucks with shipment and resource constraints. *Computers & Operations Research* 74: 53–63.

Chen, Y., L. Yang, Y. Jiang, M. Wahab, and J. Yang. 2019. Joint replenishment decision considering shortages, partial demand substitution, and defective items. *Computers & Industrial Engineering* 127: 420–435.

Creemers, S., and R. Boute. 2022. The joint replenishment problem: Optimal policy and exact evaluation method. *European Journal of Operational Research* 302: 1175–1188.

Cui, L., L. Wang, and J. Deng. 2014. RFID technology investment evaluation model for the stochastic joint replenishment and delivery problem. *Expert Systems with Applications* 41 (4): 1792–1805.

Cui, L., L. Wang, J. Deng, and J. Zhang. 2015. Intelligent algorithms for a new joint replenishment and synthetical delivery problem in a warehouse centralized supply chain. *Knowledge-Based Systems* 90: 185–198.

Cui, L., J. Deng, L. Wang, M. Xu, and Y. Zhang. 2016. A novel locust swarm algorithm for the joint replenishment problem considering multiple discounts simultaneously. *Knowledge-Based Systems* 111: 51–62.

Cui, L., J. Deng, R. Liu, D. Xu, Y. Zhang, and M. Xu. 2020a. A stochastic multi-item replenishment and delivery problem with lead-time reduction initiatives and the solving methodologies. *Applied Mathematics and Computation* 374: 125055.

Cui, L., J. Deng, Y. Zhang, Z. Zhang, and M. Xu. 2020b. The bare-bones differential evolutionary for stochastic joint replenishment with random number of imperfect items. *Knowledge-Based Systems* 193: 105416.

Cui, L., J. Deng, Y. Zhang, G. Tang, and M. Xu. 2020c. Hybrid differential artificial bee colony algorithm for multi-item replenishment-distribution problem with stochastic lead-time and demands. *Journal of Cleaner Production* 254: 119873.

Dror, M., B.C. Hartman, and W. Chang. 2012. The cost allocation issue in joint replenishment. *International Journal of Production Economics* 135 (1): 242–254.

Federgruen, A., J. Meissner, and M. Tzur. 2007. Progressive interval heuristics for multi-item capacitated lot-sizing problems. *Operations Research* 55 (3): 490–502.

Gicquel, C., and M. Minoux. 2015. Multi-product valid inequalities for the discrete lot-sizing and scheduling problem. *Computers & Operations Research* 54: 12–20.

Gutiérrez, J., M. Colebrook, B. Abdul-Jalbar, and J. Sicilia. 2013. Effective replenishment policies for the multi-item dynamic lot-sizing problem with storage capacities. *Computers & Operations Research* 40 (12): 2844–2851.

Guler, K., E. Korpeoglu, and A. Sen. 2017. Design and analysis of mechanisms for decentralized joint replenishment. *European Journal of Operational Research* 259 (3): 992–1002.

He, S., J. Sethuraman, X. Wang, and J. Zhang. 2017. A noncooperative approach to cost allocation in joint replenishment. *Operations Research* 65 (6): 1562–1573.

Hong, S.P., and Y.H. Kim. 2009. A genetic algorithm for joint replenishment based on the exact inventory cost. *Computers & Operations Research* 36 (1): 167–175.

Hoque, M.A. 2006. An optimal solution technique for the joint replenishment problem with storage and transport capacities and budget constraints. *European Journal of Operational Research* 175 (2): 1033–1042.

Hsu, S.L. 2009. Optimal joint replenishment decisions for a central factory with multiple satellite factories. *Expert Systems with Applications* 36 (2): 2494–2502.

Kayiş, E., T. Bilgiç, and D. Karabulut. 2008. A note on the can-order policy for the two-item stochastic joint-replenishment problem. *IIE Transactions* 40 (1): 84–92.

Khouja, M., and S. Goyal. 2008. A review of the joint replenishment problem literature: 1989–2005. *European Journal of Operational Research* 186 (1): 1–16.

Kiesmüller, G.P. 2010. Multi-item inventory control with full truckloads: A comparison of aggregate and individual order triggering. *European Journal of Operational Research* 200 (1): 54–62.

Korpeoglu, E., A. Sen, and K. Guler. 2013. Non-cooperative joint replenishment under asymmetric information. *European Journal of Operational Research* 227 (3): 434–443.

Larsen, C. 2009. The Q (s, S) control policy for the joint replenishment problem extended to the case of correlation among item-demands. *International Journal of Production Economics* 118 (1): 292–297.

Liang, Y., P.L. Qiao, Z.Y. Luo, and L.L. Song. 2016. Constrained stochastic joint replenishment problem with option contracts in spare parts remanufacturing supply chain. *International Journal of Simulation Modelling* 15 (3): 553–565.

Lin, J.Y., and M.J. Yao. 2020. The joint replenishment problem with trade credits. *Journal of Global Optimization* 76 (2): 347–382.

Liu, R., S. Liu, Y.R. Zeng, and L. Wang. 2017. Optimization model for the new coordinated replenishment and delivery problem with multi-warehouse. *The International Journal of Logistics Management* 28 (2): 290–310.

Liu, R., Y.R. Zeng, H. Qu, and L. Wang. 2018. Optimizing the new coordinated replenishment and delivery model considering quantity discount and resource constraints. *Computers & Industrial Engineering* 116: 82–96.

Liu, R., S. Wang, Y. Pi, and Q. Qin. 2021. An effective heuristic with evolutionary algorithm for the coordinated capacitated dynamic lot-size and delivery problem. *Computers & Industrial Engineering* 153: 107051.

Liu, R., Z. Zhou, Q. Qin, and B. Fan. 2022. Centralized drug procurement operation scheduling with a capacitated joint replenishment and delivery strategy: Evidence from China. *Computers & Industrial Engineering* 172: 108584.

Lu, L., and X. Qi. 2011. Dynamic lot sizing for multiple products with a new joint replenishment model. *European Journal of Operational Research* 212 (1): 74–80.

Maddah, B., M. Kharbeche, S. Pokharel, and A. Ghoniem. 2016. Joint replenishment model for multiple products with substitution. *Applied Mathematical Modelling* 40: 7678–7688.

Moon, I.K., and B.C. Cha. 2006. The joint replenishment problem with resource restriction. *European Journal of Operational Research* 173 (1): 190–198.

Moon, I.K., S.K. Goyal, and B.C. Cha. 2008. The joint replenishment problem involving multiple suppliers offering quantity discounts. *International Journal of Systems Science* 39 (6): 629–637.

Moon, I.K., B.C. Cha, and C.U. Lee. 2011. The joint replenishment and freight consolidation of a warehouse in a supply chain. *International Journal of Production Economics* 133 (1): 344–350.

Muriel, A., T. Chugh, and M. Prokle. 2022. Efficient algorithms for the joint replenishment problem with minimum order quantities. *European Journal of Operational Research* 300 (1): 137–150.

Mustafa Tanrikulu, M., A. Şen, and O. Alp. 2010. A joint replenishment policy with individual control and constant size orders. *International Journal of Production Research* 48 (14): 4253–4271.

Narayanan, A., and P. Robinson. 2010. Evaluation of joint replenishment lot-sizing procedures in rolling horizon planning systems. *International Journal of Production Economics* 127 (1): 85–94.

Nilsson, A., A. Segerstedt, and E. Van Der Sluis. 2007. A new iterative heuristic to solve the joint replenishment problem using a spreadsheet technique. *International Journal of Production Economics* 108 (1–2): 399–405.

Olsen, A.L. 2008. Inventory replenishment with interdependent ordering costs: An evolutionary algorithm solution. *International Journal of Production Economics* 113 (1): 359–369.

Ongkunaruk, P., M.I.M. Wahab, and Y. Chen. 2016. A genetic algorithm for a joint replenishment problem with resource and shipment constraints and defective items. *International Journal of Production Economics* 175: 142–152.

Özkaya, B.Y., Ü. Gürler, and E. Berk. 2006. The stochastic joint replenishment problem: A new policy, analysis, and insights. *Naval Research Logistics (NRL)* 53 (6): 525–546.

Paul, S., M. Wahab, and P. Ongkunaruk. 2014. Joint replenishment with imperfect items and price discount. *Computers & Industrial Engineering* 74 (1): 179–185.
Porras, E., and R. Dekker. 2006. An efficient optimal solution method for the joint replenishment problem with minimum order quantities. *European Journal of Operational Research* 174 (3): 1595–1615.
Porras, E., and R. Dekker. 2008. A solution method for the joint replenishment problem with correction factor. *International Journal of Production Economics* 113 (2): 834–851.
Qu, H., L. Wang, and Y.R. Zeng. 2013. Modeling and optimization for the joint replenishment and delivery problem with heterogeneous items. *Knowledge-Based Systems* 54: 207–215.
Qu, H., L. Wang, and R. Liu. 2015. A contrastive study of the stochastic location-inventory problem with joint replenishment and independent replenishment. *Expert Systems with Applications* 42 (4): 2061–2072.
Qu, H., X.Y. Ai, and L. Wang. 2020. Optimizing an integrated inventory-routing system for multi-item joint replenishment and coordinated outbound delivery using differential evolution algorithm. *Applied Soft Computing* 86: 105863.
Rahmouni, M., J.C. Hennet, and F. Fnaiech. 2015. Multi-product joint delivery planning in a retailers' network under resource constraints. *International Journal of Systems Science: Operations & Logistics* 2 (3): 125–134.
Robinson, E.P., A. Narayanan, and L.L. Gao. 2007. Effective heuristics for the dynamic demand joint replenishment problem. *Journal of the Operational Research Society* 58 (6): 808–815.
Robinson, P., A. Narayanan, and F. Sahin. 2009. Coordinated deterministic dynamic demand lot-sizing problem: A review of models and algorithms. *Omega* 37 (1): 3–15.
Rosales, C.R., M.J. Magazine, and U.S. Rao. 2019. Dual sourcing and joint replenishment of hospital supplies. *IEEE Transactions on Engineering Management* 67 (3): 918–931.
Salameh, M.K., A.A. Yassine, B. Maddah, and L. Ghaddar. 2014. Joint replenishment model with substitution. *Applied Mathematical Modelling* 38 (14): 3662–3671.
Shi, X., and H. Wang. 2022. Design of the cost allocation rule for joint replenishment to an overseas warehouse with a piecewise linear holding cost rate. *Operational Research*. https://doi.org/10.1007/s12351-022-00705-1.
Silva, F., and L. Gao. 2013. A joint replenishment inventory-location model. *Networks and Spatial Economics* 13 (1): 107–122.
Taleizadeh, A.A., H. Samimi, and B. Mohammadi. 2015. Joint replenishment policy with backordering and special sale. *International Journal of Systems Science* 46 (7): 1172–1198.
Tsai, C.Y., C.Y. Tsai, and P.W. Huang. 2009. An association clustering algorithm for can-order policies in the joint replenishment problem. *International Journal of Production Economics* 117 (1): 30–41.
Tsao, Y.C., and W.G. Teng. 2013. Heuristics for the joint multi-item replenishment problem under trade credits. *IMA Journal of Management Mathematics* 24 (1): 63–77.
Tsao, Y.C., M.Y. Wang, and P.L. Lee. 2010. Effects of joint replenishment policy on company cost under permissible delay in payments. *Mathematical and Computational Applications* 15 (2): 248–258.
Van Eijs, M.J.G., R.M.J. Heuts, and J.P.C. Kleijnen. 1992. Analysis and comparison of two strategies for multi-item inventory systems with joint replenishment costs. *European Journal of Operational Research* 59 (3): 405–412.
Vanvuchelen, N., J. Gijsbrechts, and R. Boute. 2020. Use of proximal policy optimization for the joint replenishment problem. *Computers in Industry* 119: 103239.
Ventura, J.A., B. Golany, A. Mendoza, and C. Li. 2022. A multi-product dynamic supply chain inventory model with supplier selection, joint replenishment, and transportation cost. *Annals of Operations Research* 316: 729–762.
Verma, N.K., A. Chakraborty, and A.K. Chatterjee. 2014. Joint replenishment of multi retailer with variable replenishment cycle under VMI. *European Journal of Operational Research* 233 (3): 787–789.
Viswanathan, S. 2007. An algorithm for determining the best lower bound for the stochastic joint replenishment problem. *Operations Research* 55 (5): 992–996.
Wang, Y.C., and W.T. Cheng. 2008. A sensitivity analysis of solving joint replenishment problems using the RAND method under inaccurate holding cost estimates and demand forecasts. *Computers & Industrial Engineering* 55 (1): 243–252.
Wang, S., and L. Wang. 2022. Efficient methods for stochastic joint replenishment and delivery problem. *International Transactions in Operational Research* 29 (4): 2288–2315.
Wang, L., C.X. Dun, W.J. Bi, and Y.R. Zeng. 2012a. An effective and efficient differential evolution algorithm for the integrated stochastic joint replenishment and delivery model. *Knowledge-Based Systems* 36: 104–114.
Wang, L., J. He, D.S. Wu, and Y.R. Zeng. 2012b. A novel differential evolution algorithm for joint replenishment problem under interdependence and its application. *International Journal of Production Economics* 135 (1): 190–198.
Wang, L., Q.L. Fu, C.G. Lee, and Y.R. Zeng. 2013a. Model and algorithm of fuzzy joint replenishment problem under credibility measure on fuzzy goal. *Knowledge-Based Systems* 39: 57–66.
Wang, L., H. Qu, T. Chen, and F.P. Yan. 2013b. An effective hybrid self-adapting differential evolution algorithm for the joint replenishment and location-inventory problem in a three-level supply chain. *The Scientific World Journal*. https://doi.org/10.1155/2013/270249.
Wang, L., Y. Shi, and S. Liu. 2015. An improved fruit fly optimization algorithm and its application to joint replenishment problems. *Expert Systems with Applications* 42 (9): 4310–4323.
Wang, L., R. Liu, and S. Liu. 2018. Variable neighborhood search incorporating a new bounding procedure for joint replenishment and delivery problem. *Journal of the Operational Research Society* 69 (2): 201–219.
Wang, M., L. Zhao, and M. Herty. 2019. Joint replenishment and carbon trading in fresh food supply chains. *European Journal of Operational Research* 277 (2): 561–573.
Wang, L., L. Peng, S. Wang, and S. Liu. 2020. Advanced backtracking search optimization algorithm for a new joint replenishment problem under trade credit with grouping constraint. *Applied Soft Computing* 86: 105953.
Wang, S., L. Wang, and Y. Pi. 2022. A hybrid differential evolution algorithm for a stochastic location-inventory-delivery problem with joint replenishment. *Data Science and Management* 5 (3): 124–136.
Wee, H.M., C.C. Lo, and P.H. Hsu. 2009. A multi-objective joint replenishment inventory model of deteriorated items in a fuzzy environment. *European Journal of Operational Research* 197 (2): 620–631.
Yang, Y.H., and J.S. Kim. 2020. An adaptive joint replenishment policy for items with non-stationary demands. *Operational Research* 20 (3): 1665–1684.
Yao, M.J., J.Y. Lin, Y.L. Lin, and S.C. Fang. 2020. An integrated algorithm for solving multi-customer joint replenishment problem with districting consideration. *Transportation Research Part e: Logistics and Transportation Review* 138: 101896.
Zeng, Y.R., L. Peng, J. Zhang, and L. Wang. 2016. An effective hybrid differential evolution algorithm incorporating simulated annealing for joint replenishment and delivery problem with trade credit. *International Journal of Computational Intelligence Systems* 9 (6): 1001–1015.
Zeng, Y., X. Cai, and H. Feng. 2022. Cost and emission allocation for joint replenishment systems subject to carbon constraints. *Computers & Industrial Engineering* 168: 108074.
Zhang, R., I. Kaku, and Y. Xiao. 2012. Model and heuristic algorithm of the joint replenishment problem with complete backordering and correlated demand. *International Journal of Production Economics* 139 (1): 33–41.
Zhou, W.Q., L. Chen, and H.M. Ge. 2013. A multi-product multi-echelon inventory control model with joint replenishment strategy. *Applied Mathematical Modelling* 37 (4): 2039–2050.

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