Production inventory routing problem incorporating perishability for perishable products

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ABSTRACT. *In the increasingly competitive environment, each link in the supply chain is seeking for saving costs, meeting further customer satisfaction, especially in the perishable product supply chains. We present an integrated mixed integer linear programming model for jointly optimizing production inventory routing problem considering perishability for perishable products (PPIRP). We characterize perishability through imposing maximum shelf-life on the time to store, ship and consume products after production, and considering value decrease of perishable products due to the deterioration. The objective is to minimize the total costs including production, inventory, and routing cost, as well as the value decrease. We conduct computational experiments to verify the effectiveness of the model. Computational results help us gain managerial insights on achieving economic benefits for the integrated perishable product supply chain.*

KEYWORDS: *Production inventory routing problem, Perishable product, Value decrease, Shelf-life*

1. Introduction

Perishable products exist widely in daily life, such as fruits, vegetables, seafood, meats and flowers, whose value or quality will deteriorate once being produced. Furthermore, as the living standard rises, consumers are more concerned with the health benefits of fresh foods. Because fresh food product owns a relatively shorter shelf-life and decays rapidly over time, there are food loss and waste in the food industry. Both food loss and waste will impose additional costs on the food supply chain. Besides, perishable product freshness highly impacts customer satisfaction because customers are more captious to food safety, quality, and traceability [1]. Thus, considering product perishability has aroused substantial researches enthusiasm.

The perishable product supply chain has been widely studied with addressing different sub-systems independently. A main focus among these is on inventory management. [2] built a single supplier-single producer-single buyer inventory model for deteriorating products, aiming to minimize total cost. [3] evaluated a new age-based replenishment policy for perishable product supply chain, whose inventory objective was the expected system outdated rate minimization under a predetermined maximum permissible shortage level. [4] introduced two approximation algorithms for perishable inventory systems with worst-case performance guarantees. As for addressing production planning for perishable products, there are the lot-sizing problem, production scheduling problem as well as lot sizing and scheduling problem. [5] proposed a dynamic economic lot-sizing problem considering age-dependent holding cost functions as well as deterioration rates for a single perishable product to minimize total costs. [6] presented a parallel machine scheduling problem for perishable products, aiming to minimize jobs' total completion time. [7] considered a capacitated lot-sizing and scheduling problem for the yogurt industry. Perishability was embodied in adopting the MTO production strategy. For tackling distribution planning of perishable products, allocation, and vehicle routings of perishable products have been widely studied. [8] introduced a tabu search approach to solve a vehicle routing problem with time windows and time-dependent travel times for perishable products. Perishability was considered as part of the overall transportation cost. Considering environment pollution, [9] proposed a multi-objective vehicle routing problem for perishable products considering time windows and different travel time. Perishability was reflected in the deterioration cost minimization objective function. The above literatures focus on separately discussing the management. However, the study has shown that the decentralized supply chain structure may lead to a distortion in product quality [10]. Furthermore, optimizing a certain local problem could be preventing the achievement of better solutions on subsequent problems and, thus a better global solution for the whole planning process [11]. To obtain better plans and provide better management on product quality, integrating and coordinating various planning problems have been gaining growing attention, and these researches mainly focus on the inventory routing problem (IRP) [12-14], production and direct-distribution problem (PDP) [15-17], production scheduling, and vehicle routing problem (PSVRP) [18-20]. IRP integrates inventory management and vehicle routing problem, whereas PDP integrates production lot-sizing with the direct shipment, and PSVRP integrates production and routing planning. Among the aforementioned problems, at least one essential aspect of the supply chain operation planning process is neglected. For example, IRP ignores the production sector, while PDP does not address the routing decisions, and PSVRP excludes inventory control. For the perishable product supply chain, the incorporation of perishable inventory is indispensable due to the impact of perishability on customer satisfaction. Moreover, due to the influence of the perishable product's deterioration rate with perishable inventory, deciding when the products will be produced and how much are critical. To improve logistic system efficiency as well as reduce total costs through more efficient resource utilization, making a great distribution routing planning instead of direct-distribution is crucial, which can reduce the number of vehicles on road effectively.

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To sum up, for perishable product supply chain, it is essential to integrate production inventory and routing planning incorporating perishability for the sake of saving system-wide cost with less wastage, providing efficient management on product quality and traceability, increasing customer satisfaction, improving system efficiency, and making success in supply chain competition. Production routing problem (PRP) is an integrated planning problem which jointly optimizes production, inventory, and routing decisions [21]. PRP for general products has gained extensive attention from the academia and industry [22,23]. Unlike general products, perishable products have perishability, and this characteristic greatly affects the strategic production and inventory planning process, while making additional requirements to the operational level, for instance, refrigerated storage, cold-chain transportation, etc., [21]. Thus, incorporating perishability in the production inventory routing problem is quite complicated and challenging, and has relatively fewer studies in this area.

Existing studies on incorporating perishability in the production inventory routing problem mainly focus on just considering the value decrease [24,25], or just considering the maximum shelf-life [11]. None of them considers the value decrease over time and shelf-life limitation simultaneously. However, perishable products, for instance, milk, yogurt et al. have a fixed shelf-life, and their value will decrease over time within their lifetimes. After lifetime expires, they will entirely perish (no value) [17]. Moreover, customers will adapt their purchase intention for a perishable product based on how long before the expiration date is. Therefore, taking the lifetime limitation and value decrease to explicitly trace the product's quality into account simultaneously in the production inventory routing problem for perishable products is indispensable.

In this study, we introduce an integrated production inventory routing problem incorporating perishability for perishable products (PPIRP). Perishability are characterized through imposing maximum shelf-life constraints for storage, delivery, and consumption, as well as considering the value decrease throughout the perishable product supply chain simultaneously. The PPIRP are formulated as a mixed-integer linear program, and the objective of the model is to minimize the total costs from production, storage, transportation, and value decrease.

The remainder of the paper is organized as follows. Section 2 depicts the formal description of the PPIRP and the mathematical model of PPIRP. The computational experiments and analyses are discussed in Section 3, followed by conclusions in Section 4.

2. Problem description and model for PPIRP

2.1 Problem definition

The PPIRP is defined on a complete graph $G = (N_0, A)$. The node set is $N_0 = N \cup \{0\}$, which consists of a set $N = \{1, \cdots, n\}$ of retailers and $\mathbf{0}$ represent

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the supplier. The arc set is $A = \{(i,j): i \in N_0, j \in N_0, i \neq j\}$. Perishable products are produced at the supplier and delivered to the retailers by a fleet $V = \{1, \cdots, |V|\}$ of vehicles with capacity over a finite set $T = \{1, \cdots, |T|\}$ of time periods. We assumed that the supplier has its capacitated production, and the inventory level at the supplier and each retailer cannot exceed their maximum storage capacities. Each retailer has a deterministic demand. The supplier and retailers have initial inventory, thus a part of demand can be fulfilled at time $t \in T$. We consider the perishable product have a lifetime, and its value will decrease over time due to quality deterioration once produced. The longer the product is held after production, the higher the storing cost and value loss will be. Each vehicle can start from the supplier at most once in a period and must return to the supplier after delivery. It is assumed that the demand of each retailer is fulfilled only by one vehicle. The problem is to determine the production amount, satisfied demand, delivery, and optimum routes in each period under total costs minimization objective function.

The following notations are defined:

Indices

i, j: Indices for a supplier and retail sites (node) ($i, j \in N_0$);

(i, j): Index for arc ($(i, j) \in A$);

t: Index for time periods ($t \in T$);

m: Index for production periods ($m \in T \cup \{0\}$, 0 represents the initial period);

v: Index for available vehicles ($v \in V$).

Parameters

C: Production capacity;

s: Unit cost of production;

f: Production setup cost;

L_i: Storage capacity at node i;

d_{it}: Demand at retailer i in period t;

h_{imt}: Unit inventory holding cost at node i at the end of period t for products produced in period $m \in T$;

h_{i0t}: Unit inventory holding cost at node i at the end of period t for products from initial inventory;

φ_{imt}: Unit value decrease for products produced in period $m \in T$ when satisfying demand at retailer i in period t;

φ_{i0t}: Unit value decrease for products from initial inventory when satisfying demand at retailer i in period t;

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u: Lifetime of product;

I_i: Initial inventory at node i;

H_v: Vehicle capacity of vehicle v;

c_{ij}: transportation cost between node i and node j;

Decision variables

Q_t: Production quantity in period t;

y_t: Equal to 1 if the supplier sets up to produce in period t, 0 otherwise;

d_{imt}: Customer demand at retailer i in period t satisfied by products produced in period $m \in T$;

d_{i0t}: Customer demand at retailer i in period t satisfied by products from initial inventory;

R_{imt}: Inventory of node i by the end of period t from products produced in period $m \in T$;

R_{i0t}: Inventory of node i by the end of period t from initial inventory. $R_{i00} = I_i$;

D_{imt}: Delivery quantity of products produced in period $m \in T$ to retailer i in period t;

D_{i0t}: Delivery quantity of products from initial inventory to retailer i in period t;

D_{ivt}: Delivery quantity of vehicle v to retailer i in period t;

X_{ijvt}: Equal to 1 if the arc (i, j) is traversed by vehicle v in period t, 0 otherwise;

Z_{ivt}: Equal to 1 if node i is visited by vehicle v in period t, 0 otherwise;

U_{ivt}: Vehicle load of vehicle v before visiting to retailer i in period t.

2.2 Mathematical model for PPIRP

$$\min \sum_{t\in T}(sQ_t + f y_t) + \sum_{i\in N_0}\sum_{m=0}^{t}\sum_{t\in T} h_{imt}R_{imt} + \sum_{(i,j)\in A}\sum_{v\in V}\sum_{t\in T} X_{ijvt}c_{ij} + \sum_{i\in N}\sum_{m=0}^{t}\sum_{t\in T}\varphi_{imt}d_{imt} \quad (1)$$

$$R_{imt} = I_i, \quad \forall\, i \in N_0, m \le t, t = 0 \quad (2)$$

$$R_{0m,t-1} = R_{0mt} + \sum_{i\in N} D_{imt}, \quad \forall m \in T \cup \{0\}, t \in T, m \le t-1 \quad (3)$$

$$R_{0tt} = Q_t - \sum_{i\in N} D_{itt}, \quad \forall t \in T \quad (4)$$

$$R_{im,t-1} + D_{imt} = R_{imt} + d_{imt}, \quad \forall i \in N, m \in T \cup \{0\}, t \in T, m \le t-1 \quad (5)$$

$$R_{itt} = D_{itt} - d_{itt}, \quad \forall\, i \in N, t \in T \quad (6)$$

$$Q_t \le C \cdot y_t, \quad \forall t \in T \quad (7)$$

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$$\sum_{m=0}^{t} R_{imt} \leq L_i, \quad \forall i \in N_0, t \in T \tag{8}$$

$$\sum_{j\in N_0} X_{ijvt} + \sum_{j\in N_0} X_{jivt} = 2Z_{ivt}, \quad \forall i \in N_0, v \in V, t \in T \tag{9}$$

$$\sum_{i\in N} D_{ivt} \leq H_v Z_{0vt}, \quad \forall v \in V, t \in T \tag{10}$$

$$D_{ivt} \leq H_v \cdot Z_{ivt}, \quad \forall i \in N, v \in V, t \in T \tag{11}$$

$$\sum_{v\in V} Z_{ivt} \leq 1, \quad \forall i \in N, t \in T \tag{12}$$

$$\sum_{j\in N} X_{0jvt} \leq 1, \quad \forall v \in V, t \in T \tag{13}$$

$$\sum_{m=0}^{t} d_{imt} = d_{it}, \quad \forall i \in N, t \in T \tag{14}$$

$$\sum_{m=0}^{t} D_{imt} = \sum_{v\in V} D_{ivt}, \quad \forall i \in N, t \in T \tag{15}$$

$$R_{imt} = 0, \quad \forall i \in N_0, m \in T \cup \{0\}, t \in T, m + u < t \tag{16}$$

$$D_{imt} = 0, \quad \forall i \in N, m \in T \cup \{0\}, t \in T, m + u < t \tag{17}$$

$$d_{imt} = 0, \quad \forall i \in N, m \in T \cup \{0\}, t \in T, m + u < t \tag{18}$$

$$\sum_{j\in N_0} \sum_{v\in V} X_{ijvt} \leq 1, \quad \forall i \in N, t \in T \tag{19}$$

$$\sum_{i\in N_0} \sum_{v\in V} X_{ijvt} \leq 1, \quad \forall j \in N, t \in T \tag{20}$$

$$U_{jvt} - U_{ivt} + H_v X_{ijvt} \leq H_v - D_{ivt} \quad \forall i \in N, j \in N, v \in V, t \in T \tag{21}$$

$$D_{ivt} \leq U_{ivt} \leq H_v Z_{ivt} \tag{22}$$

$$Q_t \geq 0, \quad \forall t \in T \tag{23}$$

$$d_{imt}, D_{imt} \geq 0, \quad \forall i \in N, m \in T \cup \{0\}, t \in T \tag{24}$$

$$R_{imt} \geq 0, \quad \forall i \in N_0, m \in T \cup \{0\}, t \in T \tag{25}$$

$$D_{ivt} \geq 0, \quad \forall i \in N, v \in V, t \in T \tag{26}$$

$$y_t \in \{0,1\}, \quad \forall t \in T \tag{27}$$

$$X_{ijvt} \in \{0,1\}, \quad \forall (i,j) \in A, v \in V, t \in T \tag{28}$$

$$Z_{ivt} \in \{0,1\}, \quad \forall i \in N_0, v \in V, t \in T \tag{29}$$

The objective function (1) minimizes the total costs. The first term in this function is production cost. The second term measures inventory holding cost at the supplier and retailers. The third term is the cost related to transportation activity. The fourth term is the value decrease due to the quality deterioration. Constraints (2) through (8) are constraints of the production-inventory stage. To initialize inventory, Constraints (2) are added. Constraints (3) and (4) model the inventory flow balance at the supplier. Constraints (5) and (6) model the inventory flow balance at retailers. Constraints (7) restrict the production quantity at the supplier if the supplier is set for production. Constraints (8) are inventory capacity constraints. Constraints (9) ensure vehicle flow conservation. Constraints (10) enforce capacity limits to the total delivery quantity in a vehicle. Constraints (11) impose only visited retailers have a positive delivery quantity. Constraints (12) forbid split delivery. Constraints (13) ensure that one vehicle can be used at most once within the same period. Constraints

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(14) and constraints (15) indicate the constituent of demand and delivery for each retailer. Constraints (16), (17), and (18) impose that perishable products cannot be stored, delivered, or used to satisfy demand beyond shelf life due to perishability. Constraints (19) and (20) ensure each arc in each period is traversed at most once. Constraints (21) and (22) are the MTZ subtour elimination constraints. Constraints (23)-(29) are the nonnegative and binary variable constraints.

3. Computational experiments

3.1 Parameter settings and generation of test instances

To validate the effectiveness of the proposed mathematical model, we have conducted several computational experiments on a PC workstation with a 3.40 GHz Intel Core i7 CPU and 16 GB RAM. The model was implemented by CPLEX12.1 with concert technology of C# (Visual Studio 2019).

For generating instances, it is primary to determine the parameters: the number of retailers, the number of the planning horizon and the number of vehicles. Instances generated have between 5 and 15 retailers for planning horizons $|T| = 3$, or 6, and for 20 customers, $|T|$ is set to be 3. The number of vehicles is set to $|V| = 1$ or 2 for the instances with $n < 20$ and to $|V| = 2$ or 3 for the instances with $n = 20$. We generate 4 instances for each of the 14 different combinations and obtain a total of 56 instances. We consider the value decrease of perishable product when meeting customer demand at retailers and maximum lifetime that can be stored simultaneously. The value decrease φ_{imt} is influenced by the time products being produced and the maximum lifetime, $\varphi_{imt} = \vartheta + \gamma \times (t - m)$, where γ is the base degradation rate between adjacent periods. ϑ and γ are related to the maximum lifetime of the products, i.e., $\vartheta = 1 / (20u)$, $\gamma = 1/(10u)$. The longer the lifetime is, the lower the degradation rate is. We also consider the unit inventory holding cost h_{imt} is time-dependent, i.e., $h_{imt} = h + \omega \times (t - m)$. The detailed parameters for instance generation are presented in Table 1.

Table 1 Parameters for the proposed model

Parameters	Generation description
Product lifetime u	Randomly drawn as an integer from interval $[2,6]$
Travel cost c_{ij}	$=\left\lfloor\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}+0.5\right\rfloor$, where (x_i,y_i) are randomly from a discrete uniform distribution in the interval $[0,1000]$
Demand d_{it}	Constant over time, i.e., $d_{it}=d_i$, and randomly generated from interval $[10,100]$
Initial inventory at each retailer I_i	$=\sum_{t\in T} d_{it}/\tau$
Initial inventory at the supplier I_0	$=\sum_{t\in T}\sum_{i\in N} d_{it}/\tau$
Inventory capacity of retailer L_i	$=2\left\lfloor\sum_{t\in T} d_{it}/\tau\right\rfloor$
Inventory capacity of supplier L_0	$=\sum_{i\in N} L_i$
Production capacity C	$=\left\lfloor\sum_{t\in T}\sum_{i\in N} d_{it}\right\rfloor$
Vehicle capacity H_v	$=\mu\lfloor\sum_{t\in T}\sum_{i\in N} d_{it}/\tau\|V\|\rfloor$, where μ is randomly generated from interval $[1,3]$
Unit production cost s	Randomly generated from interval $[0.2,2]$
Fixed production setup cost f^p	$=\beta C$, where β is randomly generated from interval $[0.3, 0.5]$
Unit value loss φ_{imt}	$=\vartheta+\gamma\times(t-m)$, where $\vartheta=1/(20u)$, $\gamma=1/(10u)$
Unit inventory holding cost h_{imt}	$=h+\omega\times(t-m)$, where h is randomly generated from interval $[0.1,0.5]$, and ω is randomly generated from interval $[0.5,1]$

3.2 Computational results

The solution values of total costs minimization objective function and the computational time of the generated instances are shown in Table 2. The conclusions are drawn as follows. Firstly, the number of retailers significantly affects the solving efficiency. For all instances with up to 10 retailers, CPLEX can solve the model optimally within 1200s. However, for instances with 15 retailers or with 20 retailers, CPLEX cannot solve all the instances optimally within the time

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limit (10800s). Besides, for instance of Case ID 15-6-2 and 20-3-3, some of the tested instances end with an error "out of memory" (Out). Furthermore, the number of vehicles also greatly affects the solution time. For example, for instance with 10 retailers, 3 planning periods and 1 vehicle, the computational time is only 0.06s, whereas for instance with 10 retailers, 3 planning periods and 2 vehicles, the computational time increases exponentially to 11.97s. An explanation for this result is that, increasing the number of vehicles in the planning process will aggravate the complexity of the routing section.

Table 2 Computational results of generated instances

Case ID			CPLEX		Solved	Out
N	T	V	Obj	CPU(s)		
5	3	1	3888.48	0.03	4	0
5	3	2	5540.99	0.17	4	0
5	6	1	11297.44	0.67	4	0
5	6	2	13512.08	410.71	4	0
10	3	1	5520.93	0.06	4	0
10	3	2	7297.98	11.97	4	0
10	6	1	16815.71	0.47	4	0
10	6	2	18594.50	1111.06	4	0
15	3	1	6187.86	0.52	4	0
15	3	2	7758.33	3446.63	4	0
15	6	1	17565.50	375.23	4	0
15	6	2	21164.00	10692.77	2	1
20	3	2	7632.43	418.28	4	0
20	3	3	8583.43	10618.34	2	2

Notes: (1) 'Obj' denotes the solution values of total costs minimization objective function. (2) 'CPU' denotes the computational time. (3) 'Solved' denotes the number of instances optimally solved within the 4 tested instances. (4) 'Out' denotes the number of instances running out of memory.

To better understand the production schedule, inventory planning, and schedule of vehicles' routes over the periods, one solution of the instance with 5 retailers, 6 planning periods and 2 vehicles is depicted in Table 3-4. Table 3 demonstrates the solution of inventory part and distribution part, i.e., inventory level at the supplier and each retailer as well as the delivery quantity to each retailer in each period. As shown in Table 3, all retailers will receive the delivery quantity from the supplier in period 1, 3 and 5, while in period 2 and 6, no retailers will be served. Table 4 demonstrates the production schedule and vehicle routes in each period. As shown in Table 4, there is no production in the first two periods. The reason is that we assumed supplier and retailers have initial inventory, and the customer demand in the first two periods can be fulfilled by the initial inventory. Furthermore, it is noteworthy that whenever the supplier produces products, there will be a delivery to retailers. Since the quality of perishable products will degraded quickly, to keep the products as fresh as possible, the supplier is inclined to delay the production and deliver products to retailers as soon as possible. Moreover, we assumed that each

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vehicle's transportation capacity cannot be exceeded, take the optimum route in period 5 for instances, vehicle 1 is assigned to serve retailer 4, 3 and 1 in sequence. In period 5, the total delivery quantity in vehicle 1 is 276, and the transportation capacity is 276. Thus, the residual demand of retailer 2 and 5 will be fulfilled by vehicle 2. Similarly, other optimum routes in other periods can be interpreted.

Table 3 Solution of inventory and distribution activities

Period	Node ID	0	1	2	3	4	5
	Initial Inventory	276	27	27	82	52	88
1	Demand	-	27	27	82	52	88
	Delivery	-	27	27	82	52	88
	Inventory	0	27	27	82	52	88
2	Demand	-	27	27	82	52	88
	Delivery	-	0	0	0	0	0
	Inventory	0	0	0	0	0	0
3	Demand	-	27	27	82	52	88
	Delivery	-	54	54	164	52	176
	Inventory	98	27	27	82	0	88
4	Demand	-	27	27	82	52	88
	Delivery	-	0	0	0	98	0
	Inventory	0	0	0	0	46	0
5	Demand	-	27	27	82	52	88
	Delivery	-	54	54	164	58	176
	Inventory	0	27	27	82	52	88
6	Demand	-	27	27	82	52	88
	Delivery	-	0	0	0	0	0
	Inventory	0	0	0	0	0	0

Table 4 Solution of production and routing activities

Route	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	0-1-2-5-3-4-0	-	0-2-5-0	0-4-0	0-4-3-1-0	-
2	-	-	0-4-3-1-0	-	0-2-5-0	-
Production Quantity	0	0	598	0	506	0

4. Conclusion

This paper studies the economical production inventory routing problem incorporating perishability for perishable products (PPIRP). Considering perishability, we add value decrease into the total cost minimization objective function to trace the perishable product's quality throughout the supply chain. Besides, we impose the maximum shelf-life limitation on the time to store, ship and consume products after production. We test 56 randomly generated instances with up to 20 retailers. The computational results demonstrate that it is hard for CPLEX to optimally solve instances with large size of PPIRP. The CPU time for solution is a combined result of the parameters, i.e., the number of retailers, the number of the planning horizon and the number of vehicles. Furthermore, the results show that the proposed model can provide an integrated plan of production, inventory, and routing to the perishable product supply chain. To keep fresh, it is crucial to delay the production moderately and deliver products to retailers as soon as possible due to the gradual deterioration nature of perishable products.

Several extensions are possible for PPIRP. First, extending PPIRP for multiple products, multiple suppliers, demand uncertainty, reverse logistics. Besides, incorporating carbon emissions in PPIRP. Furthermore, efficient algorithms can be investigated to handle the problem in large size instances. Finally, sensitivity analysis of investigating the effect of different parameter values on the solutions can be operated.

References

[1] Li, Y., F. Chu, J.-F. Côté, L. C. Coelho and C. Chu (2020). "The multi-plant perishable food production routing with packaging consideration." International Journal of Production Economics 221: 107472.
[2] Rau, H., M.-Y. Wu and H.-M. Wee (2003). "Integrated inventory model for deteriorating items under a multi-echelon supply chain environment." International Journal of Production Economics 86(2): 155-168.
[3] Duan, Q. and T. W. Liao (2013). "A new age-based replenishment policy for supply chain inventory optimization of highly perishable products." International Journal of Production Economics 145(2): 658-671.
[4] Chao, X. L., X. T. Gong, C. Shi and H. N. Zhang (2015). "Approximation Algorithms for Perishable Inventory Systems." Operations Research 63(3): 585-601.
[5] Sargut, F. Z. and G. Işık (2017). "Dynamic economic lot size model with perishable inventory and capacity constraints." Applied Mathematical Modelling 48: 806-820.
[6] Gawiejnowicz, S. (2007). "Scheduling deteriorating jobs subject to job or machine availability constraints." European Journal of Operational Research 180(1): 472-478.
[7] Marinelli, F., M. E. Nenni and A. Sforza (2007). "Capacitated lot sizing and scheduling with parallel machines and shared buffers: A case study in a packaging company." Annals of Operations Research 150(1): 177-192.
[8] Osvald, A. and L. Z. Stirn (2008). "A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food." Journal of Food Engineering 85(2): 285-295.
[9] Zulvia, F. E., R. J. Kuo and D. Y. Nugroho (2020). "A many-objective gradient evolution algorithm for solving a green vehicle routing problem with time windows and time dependency for perishable products." Journal of Cleaner Production 242: 118428.

ISSN 2616-5767 Vol.3, Issue 6: 168-180, DOI: 10.25236/AJETS.2020.030617

[10] Chen, C., J. Zhang and T. Delaurentis (2014). "Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China." International Journal of Production Economics 152: 188-199.
[11] Neves-Moreira, F., B. Almada-Lobo, J.-F. Cordeau, L. Guimarães and R. Jans (2019). "Solving a large multi-product production-routing problem with delivery time windows." Omega 86: 154-172.
[12] Coelho, L. C. and G. Laporte (2014). "Optimal joint replenishment, delivery and inventory management policies for perishable products." Computers & Operations Research 47: 42-52.
[13] Crama, Y., M. Rezaei, M. Savelsbergh and T. Van Woensel (2018). "Stochastic Inventory Routing for Perishable Products." Transportation Science 52(3): 526-546.
[14] Ji, Y., J. Du, X. Han, X. Wu, R. Huang, S. Wang and Z. Liu (2020). "A mixed integer robust programming model for two-echelon inventory routing problem of perishable products." Physica A: Statistical Mechanics and its Applications 548: 124481.
[15] Ahuja, R. K. (2007). "A heuristic approach to the multi-period single-sourcing problem with production and inventory capacities and perishability constraints." Informs Journal on Computing 19(1): 14-26.
[16] Rong, A., R. Akkerman and M. Grunow (2011). "An optimization approach for managing fresh food quality throughout the supply chain." International Journal of Production Economics 131(1): 421-429.
[17] Amorim, P., H. O. Günther and B. Almada-Lobo (2012). "Multi-objective integrated production and distribution planning of perishable products." International Journal of Production Economics 138(1): 89-101.
[18] Chen, H.-K., C.-F. Hsueh and M.-S. Chang (2009). "Production scheduling and vehicle routing with time windows for perishable food products." Computers & Operations Research 36(7): 2311-2319.
[19] Belo, M. A. F., P. Amorim and B. Almada-Lobo (2015). "An adaptive large neighbourhood search for the operational integrated production and distribution problem of perishable products." International Journal of Production Research 53(20): 6040-6058.
[20] Devapriya, P., W. Ferrell and N. Geismar (2017). "Integrated production and distribution scheduling with a perishable product." European Journal of Operational Research 259(3): 906-916.
[21] Li, Y., F. Chu, Z. Yang and R. W. Calvo (2016). "A Production Inventory Routing Planning for Perishable Food with Quality Consideration." IFAC-PapersOnLine 49(3): 407-412.
[22] Chandra, P. and M. L. Fisher (1994). "Coordination of production and distribution planning." European Journal of Operational Research 72(3): 503-517.
[23] Shuang, Y., A. Diabat and Y. Liao (2019). "A stochastic reverse logistics production routing model with emissions control policy selection." International Journal of Production Economics 213: 201-216.
[24] Vahdani, B., S. T. A. Niaki and S. Aslanzade (2017). "Production-inventory-routing coordination with capacity and time window constraints for perishable

ISSN 2616-5767 Vol.3, Issue 6: 168-180, DOI: 10.25236/AJETS.2020.030617

products: Heuristic and meta-heuristic algorithms." Journal of Cleaner Production 161: 598-618.
[25] Qiu, Y., J. Qiao and P. M. Pardalos (2019). "Optimal production, replenishment, delivery, routing and inventory management policies for products with perishable inventory." Omega 82: 193-204.