

Coordinated Production Inventory Routing Planning for Perishable Food

Yantong LI*. Feng CHU*. Kejia CHEN***

*Laboratory IBISC, University of Evry-Val d'Essonne, Batiment IBGBI, Bd de France, 91034 Evry, France (Tel:33 0763102936; e-mail: yantongli@ibisc.univ-evry.fr; feng.chu@ibisc.univ-evry.fr).

**Management Engineering Research Center, Xihua University, 610039 Chengdu, China.

***School of Management, Fuzhou University, Fuzhou, China (e-mail: kjchen@fzu.edu.cn)

Abstract: The production inventory routing problem is an integrated supply chain planning problem where the decisions concerning production, inventory and routing are simultaneously determined. We present an extended production inventory routing model dealing with the perishable food where the quality is explicitly formulated. We adapt a two phase iterative approach to solve the propose model. The model is first decomposed into two sub-problems and solved sequentially, then an iterative procedure is applied to remedy the flaw of the decomposition method. The computational results on randomly generated instances with up to 50 retailers show that we can obtain good quality solutions within acceptable time.

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INTRODUCTION

In recent years, food supply chain (FSC) has been gaining increasing attention. The stakeholders are competing under globalized market. The consumers become more critical on the food quality, safety, traceability and transparency. Meanwhile, the researchers and practitioners are dedicated in reducing the total chain cost as well as providing customers with good service. In order to meet the need of today's high competitive markets, decision makers are focusing on integrating different activities within the FSC so as to benefit from the coordination of different activities. Examples of partially integrated planning are the production distribution problem with direct shipment (PD) (Federgruen and Tzur, 1999; Jin and Muriel 2009) and the vendor managed inventory (VMI) (Campbell and Savelsbergh 2004), arising the production distribution problem (PDP) and the inventory routing problem (IRP). These two patterns have been widely studied and large amount of cost savings have been obtained. Going one step further, one may expect to benefit more with a fully integrated policy, then comes the production inventory routing problem (PRP).

PRP is an integrated operational planning problem that jointly optimizes production, inventory and routing decisions simultaneously. 3% to 20% cost savings are realized with applying the PRP to the traditional supply chain (Chandra & Fisher, 1994). By apply the PRP, the decision maker is able to implement integrated plans, which may significantly improve the recourse utilization, e.g. reduce the number of vehicles. Applying PRP can also relieve the traffic congestion and reduce pollution. However, coordinating different parts within the supply chain is complicated and challenging.

Comparing with the normal FSC, fresh food or perishable food supply chain (PFSC) is more challenging: a short shelf life, special requirements on inventory and transportation, high

requirements on packaging and greater potential on selling unsafe food. The most challenging part of the PFSC is to offer the customers fresher and safer food with shorter shelf life. Therefore, the stakeholders should coordinate with each other to make the FSC leaner and more integrated. Although it is advantageous to integrating the traditionally decoupled decisions, most of the previous studies on FSC deal with different sub-systems independently (Nahmias, 1982; Goyal & Giri, 2001; Bakker et al., 2012). Literature dealing with perishable food in an integrated manner is relatively scarce.

There are some examples of partially integrated models where two or more activities within the FSC are integrated. The single source capacitated production distribution problem was studied by Ahuja et al. (2007). Amorim et al. (2013) presented a multi-objective production distribution problem that simultaneously minimized the total cost and maximized mean remaining shelf-life of the products at the distribution center. The effect of shelf-life changing type (fix and loose) was shown by an illustrative example, which also illustrated the effect of the integrated and decoupled approach. Le et al. (2013) developed a column generation-based solution method for the IRP with perishable goods that had a limited shelf life. Soysal et al. (2015) presented an IRP and several variants where the truckload, service level and perishability were considered. The proposed models were applied to a real life case and the results showed that the proposed integrated model could provide better support to decision makers. Mirzaei and Seifi (2015) presented an IRP model for perishable food with considering lost sale. A hybrid meta-heuristic based on Simulated Annealing and Tabu Search was developed.

Note that all the above studies except Amorim et al. (2013) treat the perishability by imposing a constraint which limits the maximum periods that the perishable food can be stored.

However, it is promising to explicitly trace the food quality when modeling the FSC, and this can be beneficial in many aspects: 1) help accomplish good quality control throughout the FSC; 2) reduce food spoilage and waste; 3) provide the decision makers with transparency; 4) obtain high consumer satisfactory by offering quality labeling. (Tekin et al., 2001; Duan and Liao 2013; Rong et al., 2011; Coelho and Laporte, 2014). In addition, with the quick development of the information and communication technology, it is realistic and economical to obtain the items' instantaneous condition through information tracking and tracing systems, e.g. the radio frequency identification (RFID). Especially, in a centralized and integrated circumstance, explicitly tracing the food quality helps the decision maker to intervene the supply chain control more precisely and efficiently.

Following our previous work (Li et al., 2016), where an integrated PRP model with explicitly tracing the food quality was proposed, we aim at developing efficient algorithms to solve this hard combinatorial optimization problem in realistic size in this paper. The proposed model has the similar structure with the classical PRP, however, it is more complicated because of the inclusion of selling decisions and the newly introduced index for tracing the food quality. The computational results using CPLEX show that it is not practical to solve this problem with a local solver. Even for a small instance with 15 customers, 4 periods, two vehicles and minimum quality level 2, only 2 out of 5 randomly generated instances are optimally solved with a time limit 7200 s. So a good solution method which can solve the problem optimally or near optimally is strongly needed.

As for the classical PRP, different solution methods have been developed to obtain good solutions within acceptable time, e.g. branch and cut (Archetti et al., 2011; Adulyasak et al., 2014), uncoupled and coupled constructive heuristic (Boudia et al., 2008), branch and price (Boudia and Prins, 2009a; Bard and Nananukul, 2010), MIP based heuristic (Absi et al., 2014), metaheuristic (Boudia et al., 2007; Boudia and Prins (2009); Bard and Nananukul, 2009b; Adulyasak et al., 2012; Armentano et al., 2011). For more details of the solution methods and the computational results on benchmark instances, please refer to the reviews on PRP of Díaz-Madroñero et al. (2015) and Adulyasak et al. (2015).

From the aforementioned literature, we notice that the MIP based two phase iterative approach proposed by Absi et al. (2014) generally outperforms all exist algorithms on the two sets of classical benchmark instances. The iterative method decomposes the original model into two phases. The distinguishing feature of this two heuristic is the introduction of an approximate routing cost which is updated iteratively. This approximate routing cost (service cost) is included in the objective function of the first phase lot sizing model and is updated according to the solution of the second phase model where the routing decisions are made.

In this paper, we adapt the two phase iterative heuristic to solve the proposed model. Section 2 gives the notations and formulations. Section 3 deliberates the proposed method.

Section 4 presents the computational experiments and analyses. The conclusion and future research are provided in section 5.

NOTATION AND FORMULATION

2.1 Problem description and notation

In this section, starting from the model proposed by Li et al. (2016), we extended the model by including the inventory capacity at the depot. This makes the model more realistic. Given a single depot that is responsible for resupplying a set of retailers with a single item of perishable food. The time varying demand of retailers should be met without backlogging and lost sale. The production capacity is limited and a fixed setup cost is incurred once there is some production. Both the depot and the retailer can hold a limited amount of inventory, with an inventory cost proportional to inventory quantity. A fleet of vehicles are used to accomplish the transportation task, and a vehicle that leaves the depot must return to the depot at the end of the route. Split delivery is not allowed, i.e. one retailer can be visited at most once within the same time period.

Let $E = (N, A)$ denote a directed graph, where N represents the set of the depot and retailers indexed by $i \in \{0, 1, 2, \dots, n\}$ and $A = \{(i, j) : i, j \in N, i \neq j\}$ is the edge set. Vertex 0 represents the depot and the remaining vertices $R = N \setminus \{0\}$ correspond to the set of all retailers. The following notations are defined:

Parameters:

t	time index $t \in T = \{1, 2, \dots, Nbp\}$
q	food quality level index $q \in Q = \{0, 1, \dots, Nbpq\}$
k	vehicle index $k \in K = \{1, 2, \dots, Nbv\}$
C	production capacity
V	vehicle capacity
U_i	inventory capacity of vertex $i \in N$
a_t	unit production cost in time period $t \in T$
h_i^q	unit inventory cost of food with quality $q \in Q$ at vertex $i \in N$
f_t	production set up cost in time period $t \in T$
c_{ij}	transportation cost on arc $(i, j) \in A$
d_i^t	total demand of retailer $i \in R$ in time period $t \in T$
Inv_i^q	initial inventory at node $i \in N$ with quality $q \in Q$
s_i^q	food price with quality $q \in Q$ at retailer $i \in R$

Variables:

w_t	1 if the production facility is set up in time period $t \in T$; 0 otherwise
p_t	production quantity in time period $t \in T$
I_i^{qt}	inventory level at node $i \in N$ with quality $q \in Q$ at the end of time period $t \in T \cup \{0\}$
v_i^{kt}	1 if vehicle $k \in K$ visit retailer $i \in R$ in time period $t \in T$; 0 otherwise
x_{ij}^{kt}	1 if vehicle $k \in K$ traverses arc $(i, j) \in A$ in time period $t \in T$, 0 otherwise
y_i^{qkt}	delivery quantity to retailer $i \in R$ with quality

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