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A genetic algorithm approach for location-inventory-routing problem with perishable products

Abdelhalim Hiassat[a], Ali Diabat[b,*], Iyad Rahwan[c]

[a] University of Waterloo, Waterloo, Ontario N2L 3G1, Canada
[b] Masdar Institute of Science and Technology, Abu Dhabi, United Arab Emirates
[c] Massachusetts Institute of Technology, Cambridge MA 02139, USA

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ABSTRACT

In this paper, we address a location-inventory-routing model for perishable products. The model determines the number and location of required warehouses, the inventory level at each retailer, and the routes traveled by each vehicle. The proposed model adds location decisions to a recently published inventory routing problem in order to make it more practical, thus supporting the prevalent claim that integration of strategic, tactical and operational level decisions produces better results for supply chains. Given that the model developed here is NP-hard, with no algorithm capable of finding its solution in polynomial time, we develop a Genetic Algorithm approach to solve the problem efficiently. This approach achieves high quality near-optimal solutions in reasonable time. Furthermore, the unique structure of the problem requires developing a new chromosome representation, as well as local search heuristics. Finally, an analysis is carried out to verify the effectiveness of the algorithm.

1. Introduction

Researchers and practitioners often classify supply chain decisions into strategic, tactical, and operational, based on the time horizon of impact [1]. Strategic decisions have a longer time horizon of impact, which could even be years, as they deal with decisions that cannot change easily, such as the location of facilities. Tactical decisions have a time horizon of months and they include planning aspects pertaining to inventory management. Finally, operations decisions are made on a daily basis, with almost immediate impact and they include distribution decisions.

Historically, these decisions are treated separately. Each entity in the supply chain tries to minimize the cost incurred within the same facility without considering the implications of these measures on upstream or downstream entities of the supply chain. While this approach ensures that the cost for each level is minimized, the summation of all costs across the supply chain might not be at minimum. The situation where each level tries to maximize their benefit regardless of the others leads to a local optimum and sometimes sub-optimality of the systems and excessive costs [2–6], all cited in [7].

Recently, supply chain managers and researchers have realized the importance of the integration of supply chain decisions. Many researchers showed significant savings when considering a combination of the aforementioned decisions into a single model. See, for example, Nagy and Salhi [8], Wu et al. [9], Baita et al. [10], Moin and Salhi [11], Daskin et al. [12], Shen et al. [13], and Diabat et al. [7]. Many models presented in the literature combine two of the supply chain decisions into one single model. These models are location-inventory, location-routing, and inventory-routing models. However, few models integrate all three decisions and solve them simultaneously. In other words, location-inventory-routing models have not been studied extensively.

In general, one might argue about the applicability of integrating a strategic-level decision, such as location, with tactical- and operational-level decisions, such as inventory and routing. This argument is valid since these decisions belong to different levels of supply chain management and integrating them can increase the complexity of the resulting model. However, in the current work, we incorporate location decisions to the model developed by Le et al. [14], in the sense that we select which retailers will serve as distribution centers. More specifically, the model developed by Le et al. [14] deals with the storage and shipping of blood units between hospitals in a certain area. In this context, we aim to categorize these hospitals into two groups. The first group represents those medical centers which only receive blood units from other

* Corresponding author. Tel.: +971 2 810-9101; fax: +971 2 810-9901.
E-mail address: adiabat@masdar.ac.ae (A. Diabat).

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ones (according to their respective demand). The other group represents the medical centers which receive more blood cells than their demand, store them, and ship them to other hospitals if needed. The problem studied by Le et al. [14] is an NP-hard problem and therefore the problem developed in this paper is also NP-hard.

Members of this latter group are named Distribution Centers (DCs) in the supply chain management literature. The former is the group of retailers. Hence, our model deals with already existing facilities. Location decisions in this sense represent the decision of which hospital will hold inventory of blood units to be shipped to other hospitals. Moreover, the fixed location cost in this regard is the overhead and extra managerial costs associated with the extra space and handling, rather than the cost of building a new facility from the ground up. This argument would justify integrating location decisions with inventory and routing decisions into a single model. In addition to this, the importance of integrating inventory with routing, as underlined by Bertsimas and Simchi-Levi [15] among others, and location with inventory, as underlined by Shen et al. [13], has been readily highlighted in the literature, further validating the integration not only of two aspects at a time, but of all three aspects simultaneously.

Knowing the fact that a moderate size mixed-integer program (MIP) can have tens of thousands of variables, it is challenging and perhaps impossible to find a global optimal solution in reasonable time with readily available computing resources. Thus, instead of searching for a global optimum, an approximate optimal, or near optimal, solution is sufficient for the problem at hand. The Genetic Algorithm (GA) is a stochastic optimization technique that depends on a random-based searching mechanism. Genetic algorithms have been successfully adapted in many areas to solve a large number of optimization problems, including scheduling and transportation problems.

In what follows, the integration of the location decisions into a recently published inventory-routing model for perishable products is introduced. Section 2 shows a brief literature of the research most related to our work. An explanation of how location decisions make previous models more practical and realistic is provided. Section 3 provides an overview of the model, and discusses its motivation and interpretation. The genetic algorithm used to solve this model is thoroughly explained in Section 4. The new chromosome representation and the new local search heuristic are also detailed. Numerical analysis to show the effectiveness of the model and the solution method is shown in Section 5, while the conclusions and the potential future work is discussed in Section 6.

2. Literature review

Researchers have recently realized the importance of integration of all the three components of the supply chain management into one model. Max Shen and Qi [16] modified the model by Daskin et al. [12] and proposed a stochastic model that considers the location, inventory and routing costs. They approximate the shipment from a warehouse to its customers using a vehicle routing model. They used Lagrangian relaxation to solve the subproblems. Lagrangian relaxation has also been implemented by Diabat et al. [17], who focus on developing an improved approach that is able to solve problems more efficiently, while Diabat and Richard [18] develop a nested Lagrangian relaxation approach for the integrated problem. Javid and Azad [19] present a model which simultaneously optimizes location, inventory and routing decisions without approximation. They show that the approximation by Max Shen and Qi [16] is only applicable under some restrictive assumptions. The model is formulated as a mixed integer convex program. They proposed a hybrid algorithm of Tabu Search and Simulated Annealing. Piece-wise linearization is applied to the joint location-inventory problem without capacity constraints [20] as well as with the consideration of capacity constraints [21].

Liu and Lee [22] consider a stochastic customer demand and include inventory costs in the location-routing problem. An initial solution is found by clustering the customers, based on an increasing order of their marginal inventory costs. Ambrosino and Grazia Scutellà [23] consider a four level location-routing problem. The authors also introduce inventory considerations. Both static and dynamic problem cases are treated. Furthermore, a heterogeneous fleet is allowed. Recently, Le et al. [14] combined inventory and routing components into one model. They proposed a column generation based heuristic to solve the model. They showed significant savings when using their model.

Supply chains with perishable products have been studied in various lines of research. Some researchers extended the economic order quantity (EOQ) policy for inventory models which include perishable products. For example, Giri and Chaudhuri [24] proposed an inventory model for a perishable product where the demand rate is a function of the on-hand inventory, and the holding cost is nonlinear. Moreover, Padmanabhan and Vrat [25] proposed a stock-dependent selling rate model where the backlogging function was assumed to be dependent on the amount of demand backlogged. Dye and Ouyang [26] extended their model by introducing a time proportional backlogging rate. In a different line of research, Hsu et al. [27] extended the vehicle routing problem with time-windows discussed in a number of papers (e.g. Koskosidis et al. [28] and Sexton and Choi [29]), by considering the randomness of the perishable food delivery process. However, both EOQ and VRP extensions lack the integration of inventory and transportation decisions. Hence, the problem of sub optimality is likely to arise.

The model described here is an extension of the model proposed by Le et al. [14]. While the authors account for transportation and inventory costs only, our model accounts for all three levels of integration. Adding the fixed location cost component makes the model more realistic and closer to real world application, without proportionally increasing its complexity. Moreover, the model is carefully formulated to maintain its linearity. A naive formulation would make the model non-linear and, consequently, much more complicated and harder to solve. In particular, Le et al. [14] use column generation to solve their model. This works well with small and medium sized instances. However, the addition of the location decisions, as well as the introduction of very large real life instances represent a challenge to existing exact solution methods. In fact, later work of Diabat and Al-Salem [30] addresses the joint inventory and routing problem with the help of a tabu search heuristic, while authors report that their heuristic outperforms the column generation approach for many problem instances. In light of this, we also develop a customized heuristic approach for the same model, which we expect will produce good quality results within reasonable time, thus making an important contribution.

Genetic algorithms are effective in achieving optimal or near-optimal solutions by solving optimization problems. As such, GAs have been widely implemented to solve a variety of single- and multi-objective problems in production and operations management that are combinatorial and NP hard [31]. However, few researchers have used GAs to tackle integrated models. Diabat et al. [32] study the capacitated facility location problem with risk pooling, while Ali Diabat and Deskoores [33] develop a hybrid GA to solve the integrated problem. Ali Diabat and Al-Salem [34] additionally consider environmental factors to their formulation. Hybrid heuristics have also been used, as in the case of Diabat [35] who study a vendor managed inventory system in a two-echelon supply chain, with a single vendor and multiple buyers.

Alp et al. [36] propose a genetic algorithm for a well-known facility location problem, the P-Median model. The P-Median model