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Multi-objective inventory routing problem: A stochastic model to consider profit, service level and green criteria

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A B S T R A C T

The Inventory Routing Problem has been mainly studied in recent decades under an economic performance perspective. In this paper, we develop a multi-objective mathematical framework for the IRP to link: (i) the economic performance, (ii) the achieved server level in terms of shortage and delivery delays and (iii) the environmental footprint. The framework developed addresses the uncertainty by considering fuzzy distributions for certain problem inputs, such as the demand and the transportation costs. We show the negative impact on the economic performance when service level targets are exogenously chosen without coordination with the logistics components (inventory and distribution).

1. Introduction

In its traditional mathematical modeling and optimization approaches, the Inventory Routing Problem (IRP) identifies the best inventory and distribution joint strategy, i.e., the inventory control of products, the determination type and number of vehicles, the type of products, their quantity to be delivered to each customer and the best routing in each period.

The main objective in the traditional IRP is the minimization of the total inventory and transportation cost as well as the traveling time or distance (Li et al., 2014; Madadi et al., 2010). However, this classical approach does not consider certain important criteria such as the inventory and distribution service levels and the environmental footprint of the IRP solution. Currently, managers must make their decisions by considering these different criteria in addition to the economic criterion; these may, in certain cases, conflict with each other.

It is obvious that the classical IRP should be extended in its modeling and in its optimization to consider the service levels and the green considerations in addition to the economic performance. The modeling and optimization extension may be more challenging when it is performed for perishable items where both the product non-freshness and the need to recycle perished products should also be modeled and considered.

With regards to the service level extension for IRP, it is worthwhile to note that the increasing competitiveness between firms in a global marketplace generates increasingly more pressure. The firms need to improve their efficiency as much as possible to ensure customer satisfaction. A high service level is indeed one of the key factors to strengthening customer satisfaction and loyalty. However, despite the positive impact on sales in the long-term, providing a higher service level to the customer may increase the associated inventory and distribution costs. From a business perspective, the service level presents a tradeoff between the opportunity costs and the operation costs (Schalit and Vermorel, 2014). Despite its importance

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for practitioners, very few investigations have integrated the service level into the IRP framework. With regard to the green footprint extension for IRP, it is obvious that ‘greenness’ has become a very much needed condition in the transportation industry. The IRP is naturally among the most interesting framework to deploy innovative and new decisions striving to decrease the CO_2 footprint of a supply chain.

The objective of this paper is to extend the classical IRP framework to integrate both the service level and the green considerations. We develop a multi-objective version of the IRP problem where we add to the classical economic objective two new objective functions that model and measure the inventory and transportation service level as well as the green footprint of the IRP solution. Our proposal is applicable for perishable items where we additionally model the products’ non-freshness as well as the reverse supply chain management of the perished products. To remain close to real IRP business cases, we allow certain problem parameters such as demand, variable transportation costs and vehicle speed to be uncertain. We model these parameters using fuzzy distribution; our framework is solved by using an adequate and well-motivated mathematical resolution approach. More importantly, a numerical study permits us to derive managerial insights about the following issues:

- We explore the linkage between the three objective measures; the framework permits us to numerically calculate the impact on costs and the green footprint of x% increase in the service level.
- Consequently, the framework permits us to derive the cost penalty if the service levels are exogenously decided without coordination with the logistics components of the IRP (inventory + transportation).
- We explore the non-freshness implication of the IRP three objective functions.

Regarding the practical applicability of our framework, we notice that the developed problem fits particularly with the IRP of fresh products in the last mile urban distribution where green considerations are important components of the decision making process. The problem developed in the paper is step forward making the IRP framework closer to a real distribution business case. Indeed:

- We introduce the service level measure as a second objective functions: service levels are very used in practice, particularly in the inventory control arena where they can be preferred for their ease of use from a technical point of view. The Cycle Service Level and the Fill Rate (both of them are modeled in the second objective function) are well known and very used measures for practitioners (SCHNEIDER, 1981). We also model the distribution time windows which may be an important constraint in practice particularly for urban vehicle touts and we model the non-respect of a visit time windows with a third service level measure.
- We introduce the environmental footprint as a third objective function and we measure it by the GHG emission during vehicles’ routes, product loading and unloading tasks. Nowadays, there are international standards permitting the calculation of the GHG output of an IRP solution (please cf. the World Resources Institute and the World Business Council on Sustainable Development reports (WRI;WBCSD, 2001)). Adding the green footprint of the IRP solution is not motivated by a wish to make the framework more sophisticated but we do believe that it is linked to a real need for practitioners. In some countries (Germany and France for instance) and in some urban cities (Berlin in Germany and Saint-Etienne in France for instance), the access to the city center is conditional to the green footprint of the vehicle performing the delivery. More and more legislation rules are set to at least track and limit the GHG emission particularly in urban zones.
- We introduce the non-freshness cost by either an extra holding cost (a cost to inspect items before transferring them to the next selling period) or/and by a need to discount non-fresh products if they are transferred from previous selling periods. Both practices are common in the management of fresh food products.
- We model some of the problem parameters as uncertain for the purpose to make the problem closer to real cases. We model these uncertain parameters by a possibility triangular distribution based on the pessimistic, optimistic and most likely values. We don’t claim that the triangular distribution is the best choice but we notice that the resolution approach presented in the paper will still apply for any discrete distribution of these parameters.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature and motivates as well as positions the contribution of our extended IRP proposal. Section 3 details the problem description and its mathematical modeling. The resolution approach of our extended IRP is presented in Section 4. A numerical analysis is performed in Section 5 in which the associated managerial insights are also provided. Finally, Section 6 presents the paper’s conclusions and suggests further research directions.

2. Literature review

This section presents the literature review and shows the existing gap in research on IRPs to highlight and position the contribution of our proposal. A significant amount of research has previously been done on IRPs: the reader is referred to Coelho et al. (2013) for an excellent and comprehensive overview of the subject. We limit our literature review to investigations addressing one or many of the following issues: product perishability, service level, and environmental considerations.