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A hybrid fuzzy bi-objective delivery planning model for leagile e-tailing under uncertainty

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A hybrid fuzzy bi-objective delivery planning model for leagile e-tailing under uncertainty

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The rapid growth of e-business has paved the way for traditional retailers to distribute their items via the Internet. The success of online retailers (e-tailers) in the extremely competitive online marketplace depends on providing a beneficial and efficient scheme for customers’ orders fulfillment. In this paper, a joint model of pricing and online fulfillment assignment is presented for a distribution system in which a supplier sells items through an e-tail channel under the possibility of using substitute items with the satisfaction of customers’ demands and delivery times. The aim of the model is to be ‘lean’ by minimizing operational cost and ‘agile’ through providing quick simultaneous reactions to market changes. We present a hybrid fuzzy bi-objective nonlinear programming model which is composed of a qualitative objective related to customers’ satisfaction and a quantitative objective function, i.e. the maximization of revenue minus the total cost. After applying an appropriate strategy to defuzzify the model, the equivalent bi-objective crisp model is solved by an interactive fuzzy goal programming method to handle goals as well as their imprecise target levels simultaneously in order to find an efficient compromise solution. Moreover, an illustrative example is provided in order to prove the usefulness and efficiency of the proposed model and the solution approach.

Keywords: online retailer; leagile; pricing; delivery planning; optimization method; uncertainty

JEL Classification: C44; C61; M11; L81

1. Introduction

Due to globalization of market competition, necessity of information availability, changing relationships, rapid development of technologies, and growing complexity of business, an eminent need to manage business more efficiently and effectively is increasingly highlighted. Thus, many successful modern organizations decentralize their business activities throughout the world and shift to e-business, which creates longer and more complex supply chains and in turn changes the requirements. In fact, the advent of e-business has enabled customers to use the World Wide Web in order to gather all kinds of requirements from different spheres around the world. Therefore, lots of traditional companies have been motivated to increase sales and improve profitability by e-tail channels (Bretthauer, Mahar, & Venakataramanan, 2010).

Dynamic Internet commerce environments share information in a speedy and reliable way that yields benefits such as reducing information asymmetries, making real-time decisions, accelerating the decision-making process, increasing collaboration between participants, and facilitating the automation of conventional activities.

Since e-tailing has become increasingly imperative as a new sales channel through a direct relationship with customers on one hand, and on the other hand due to the impact on the success of e-tailing of rapid response to customers’ orders, it is crucial to take into account efficient customers’ orders fulfillment, which would lead to customer satisfaction and loyalty in today’s aggressive e-business environment.

In this paper, a joint pricing and online fulfillment assignment model of a distribution system is presented. The proposed system aims at the combination of lean (increasing efficiency) and agile (increasing effectiveness and/or responsiveness) objectives. Being lean and agile simultaneously calls for a ‘leagile’ system (Okongwu, Laurasab, Dupont, & Humez, 2012).

The rest of the paper is organized as follows. The relevant literature is presented in Section 2. A brief introduction to the proposed e-tailer is followed by the description and formulation of the corresponding fuzzy mathematical model in Sections 3 and 4. In Section 5, appropriate strategies are applied for converting the fuzzy model into the equivalent auxiliary crisp one. In Section 6, a hybrid fuzzy goal programming model is proposed, and the resulting equivalent crisp model is solved with a numerical example in Section 7. Finally, Section 8 is devoted to concluding remarks and some future research directions.

2. Literature review

Even though e-tailing has become a popular and convenient business mode all over the world, there is relatively limited investigation addressing e-tailing as the dominant business model to design an information sharing mechanism in order to save the system costs and consequently improve the performance of the supply network. In this paper, relevant work on the single channel concludes and some future research directions.

In general, the majority of previous studies in the area of online order fulfillment have considered decisions taken in order to reduce costs, and few researchers have highlighted non-cost factors such as lead time. Becerril-Arreola, Leng,
and Parlar (2013) focused on the joint pricing, inventory/purchasing and contingent free shipping (CFS) threshold decisions in the online retailing industry. They proposed a two-stage decision process in which an online retailer first determines a profit margin and free-shipping threshold, and then an inventory level to satisfy consumers’ online orders. Liu (2013) investigated effective customer factors in the online retailer environment and their effects on consumer purchasing behavior, and found that all types of costs, i.e. monetary, time, and psychological, do play a role in how consumers select online retailers. Lo, Chou, and Teng (2013) investigated the advertised reference price (APR) source as a factor to influence consumers’ perception of transaction value in online shopping environments. Yan, Rabinovich, Dooley, and Evers (2010) focused on managing both quantity variation and lead time variation in online order fulfillment. Min, Ko, and Ko (2008) developed a mixed-integer programming model and a genetic algorithm in order to manage reverse logistics problems dealing with products returned from e-tail sales. Hsu and Li (2006) presented a nonlinear mathematical programming model for a delivery service strategy of Internet shopping in terms of service cycle frequency and duration by considering the relationship between time and consumer demand. A considerable and comprehensive review in a multi-channel, e-fulfillment environment was presented by Agatz, Fleischmann, and Van Nunen (2008) comprehensively reviewed the studies presented in the e-fulfillment area.

Moreover, in the context of leagility in the supply chain; Babazadeh and Razmi (2012) developed a supply chain planning model incorporating efficient factors of agile and responsive logistics such as direct shipments, alliance (information and process integration) between supply chain echelons, and delivery time minimization in strategic level planning. Okongwu et al. (2012) applied a multi-criteria performance measurement system to support decision-making for being leagile in the case of disruptions in the customer order fulfillment process in order to optimize order fulfillment planning and increase customer satisfaction. Mason-Jones, Naylor, and Towill (2010) focused on optimal supply chain performance by employing a leagile strategy. Christiansen, Kotzab, and Mikkelson (2007) investigated logistics information sharing and coordination frameworks in leagile supply chains. Goldsby, Griffis, and Roath (2006) studied lean, agile, and leagile strategies in supply chains. They concluded that lean systems would improve customer service performance, and that leagile systems would reduce inventory levels.

In this study, by assuming allowable substitution and transshipment of items in conditions of shortage so as to move items between distributors with excess inventory to those lacking sufficient inventory, the problem of joint pricing and online fulfillment of customer demands aimed at leagility under a fuzzy environment is presented. We present a hybrid (including quantitative and qualitative objectives) fuzzy bi-objective nonlinear programming (H-FBONLP) Internet-based distribution system composed of a qualitative objective related to customer satisfaction and a quantitative objective function, i.e. maximization of revenue minus the total cost of the system (that is, shipment cost, delivery cost considering shipment time and inventory holding cost, shortage cost, delay cost, substitution cost, and advertising cost). The important factors imposed by customers are order fulfillment, substitution, delay and shortage (undelivered) quantity, acceptable levels of quality, on-time delivery, and service level; on the other hand, the e-tailer considers some significant factors such as order quantity, sale price, and advertising expenditure.

Overall, our work differs from the above-mentioned experimental articles in e-tailing environments with respect to the following main contributions.

- Traditionally, the main objective of the previous studies has been either to maximize total profit or minimize total cost. However, in practice, customer satisfaction is a significant goal for increasing customer trust and loyalty. Thus, both economic and social objectives are considered as two managerial goals.
- Generally, attention is paid merely to transportation costs, and few researchers consider lead time. In this work, delivery time minimization is considered in order to deliver products within the due date stated by customers.
- The effective and most desired attributes of customers are taken into account for achieving system leagility, i.e. acceptable levels of quality, on-time delivery, service level, and cost, by defining performance measurement.
- Effective strategies leading to leagility of the system are applied including substitution, interconnected and transshipment of inventory between distributors to meet fluctuating and dynamic demand for coping with shortage and consequently lowering costs associated with inventory holding and back-ordering.
- The adoption of incentive schemes such as discounting and advertising in order to increase customer attraction and satisfaction level, and obtain the maximum profit.
- In existing studies in the e-tailer literature, demand is deterministic and assumed as the average consumption of the previous periods, while we assume customer demand to be uncertain, with a continuous function of price and advertising.

3. Proposed e-tailing structure

With the prevailing popularity of the Internet, thousands of customers prefer to purchase items and services directly through online processes without visiting stores. Examples of these new business Internet sites are Amazon, E-bay, Froogle, and MFG.

In this section, a brief introduction to e-tailing structure is provided. Moreover, the roles and interactive behaviors of customers and distributors involved in the decision-making process are elaborated.

Each customer registers the requested information and specifications of the order via the Internet, such as order quantity, satisfaction of substitution for each item, acceptable defective rate and service level. Then, a window
of decision opportunity opens in which the e-tailer can make the best decisions about order fulfillment. In other words, the e-tailer investigates the inventory availability and shipment time of each distribution center to fulfill the orders with only one distributor. After receiving orders, customers express ideas related to quantitative and qualitative attributes as expressed in Table 1 similar to that of Mohebbi and Shafaei (2012). Then, the customers profile is created. The effective and most desired attributes of customers are determined by performance measurement described in Table 1.

It is noteworthy that, in general, transshipment strategies are divided into two groups: ‘complete pooling’ and ‘partial pooling’. In complete pooling, the transshipment locations share all of their available items, while in a partial pooling strategy the transshipment locations hold a part of their available items. In this study, a complete pooling type transshipment strategy is applied, i.e. the quantity of items shipped between distributors is equal to the minimum of the excess inventory at one distributor (the nearby one) and the shortage at the other (Tagaras, 1989).

4. Problem definition

In this study, we consider an online fulfillment assignment problem for a distribution system. An e-tailer channel consisting of a single supplier, multiple distributors, and customers is established.

In order to provide the e-tailer with powerful opportunities to enhance competitiveness, market share, and profitability, and to improve customers satisfaction and responsiveness to the dynamic market, the aim of the model is to be ‘lean’ by minimizing operational cost and ‘agile’ through providing a speedy response to market changes.

Leagility can be achieved by combining the following three dimensions (Okongwu et al., 2012).

- **Efficiency** is the fulfillment of orders correctly, which can be measured as the total cost of fulfilling customer orders.

<table>
<thead>
<tr>
<th>Category</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>Life cycle</td>
</tr>
<tr>
<td></td>
<td>Dimensions</td>
</tr>
<tr>
<td></td>
<td>Mechanical characteristics</td>
</tr>
<tr>
<td></td>
<td>Metallurgical characteristics</td>
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<tr>
<td></td>
<td>Aesthetics</td>
</tr>
<tr>
<td>Service</td>
<td>Guarantee</td>
</tr>
<tr>
<td></td>
<td>After sales service</td>
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<tr>
<td></td>
<td>Information confidence</td>
</tr>
<tr>
<td></td>
<td>Commercial confidence</td>
</tr>
<tr>
<td></td>
<td>Commitment to long-term relationship</td>
</tr>
<tr>
<td>Cost</td>
<td>Sale price</td>
</tr>
<tr>
<td></td>
<td>Discount policy</td>
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<tr>
<td></td>
<td>Advertising cost</td>
</tr>
<tr>
<td></td>
<td>Shipment and packaging cost</td>
</tr>
<tr>
<td>Lead time</td>
<td>Order processing time</td>
</tr>
<tr>
<td></td>
<td>Delivery lead time</td>
</tr>
</tbody>
</table>

- **Effectiveness** is the fulfillment of orders exactly and completely, which can be measured as the percentage of orders fulfilled within the acceptable due date by the customer, with or without substitute products.

- **Responsiveness** is the fulfillment of orders quickly, which can be measured as the normalized average delivery time of the total delivered quantity.

Notably, flexibility has a positive impact on effectiveness, responsiveness, and efficiency, and is measured as the number of substitutes for each item. These performance dimensions can be defined as decision variables including the overall cost of fulfilling an order (Efficiency), shortage (Effectiveness), final back-order quantity (Responsiveness), and substitution quantity (Flexibility). In this respect, two strategies leading to leagility of the system are applied, including the possibility of using substitute items to the satisfaction of customers and inventory transshipment between distributors in conditions of shortage, delivered within the given delivery time, to meet fluctuating and dynamic demand for coping with shortage and consequently lowering the costs associated with inventory holding and back-ordering.

We consider the service level, quality, reliability, and speed of delivering orders as the key components of customer satisfaction. Consequently, our objective is to obtain the best decisions in an integrated and coordinated way for a qualitative objective related to customer satisfaction and a quantitative objective function, i.e. maximization of revenue minus total cost of the system.

Moreover, in practice, due to incompleteness and/or inaccessibility of required data and information over the planning horizon such as costs and the objective function’s aspiration level, negligence of inherent uncertainty, and assigning a set of crisp values for such imprecise parameters is not appropriate and may not lead to fully satisfactory and efficient results (GhasemyYaghin, Torabi, & FatemiGhomi, 2012). In this respect, fuzzy set theory is a very proper means of dealing with imprecise data (Zadeh, 1965). Therefore, we estimate such parameters subjectively based on both insufficient data and decision makers’ (DMs’) experiences.

4.1 Problem assumptions

The main assumptions used in the formulation of the problem are as follows.

- All customers order exclusively through online direct sales channels and the retailer represents a group of distribution centers.
- All distribution centers have similar parameters, such as inventory holding costs.
- Customers receive all ordered items from only one distributor in each period.
- The e-tailer determines only one requested due date (DD) for each order, and also late delivery is allowed after DD according to a deadline (DL) to provide the order with a delay cost that depends on the lapse of time between DD and DL, as well as on
the quantity delivered late. Beyond DL, customers wait to receive their back-orders in a future period.

- Inventory holding costs are linear and non-decreasing at distribution centers.
- There is no limitation on the warehouse inventory of each distributer at the beginning or end of the planning horizon.
- Owing to purchasing via the Internet, ordering costs are negligible, but unit shipment cost of an item and delivery cost are considered with shipment time.
- There is a deterministic dynamic demand which is a function of price and advertising over a given finite planning horizon.
- Some of the parameters, such as costs, predicted demand, defective rate, and service level, and objective functions are assumed to be fuzzy numbers. There are various types of membership functions proposed in the literature which express a vagueness factor of a DM, for which linear membership functions are used in the literature and in practice more than other nonlinear types of membership function (Watada, 1997). Here, we use linear membership functions as trapezoidal possibility distributions that are determined by both available objective and subjective data.

4.2 Model construction

In this section, joint pricing and customers’ orders delivery planning of the e-tailer is formulated as a hybrid fuzzy bi-objective nonlinear programming (H-FBONLP) problem in multi-periods and multi-items environments with different goal priorities.

The indices, parameters, and variables are described below.

Indices

\( t \): Index of time period \((1, \ldots, T)\)

\( p \): Index of item type \((1, \ldots, P)\)

\( S \): Index of substitute item \((1, \ldots, S)\)

\( d, d' \): Index of distributer center \((1,2, \ldots, D)\)

\( C \): Index of customer \((1,2, \ldots, C)\)

Parameters

\( S_p \): Set of substitute items for item \( p \)

\( D_{pc} \): Predicted demand rate of \( c \)th customer for \( p \)th item in each period

\( DR_p \): Average defective rate of item \( p \) delivered by each distribution center

\( DR_{pc} \): Acceptable defective rate for incoming shipments of item \( p \) for \( c \)th customer

\( SL \): Average service level

\( SL_c \): Acceptable service level for \( c \)th customer

\( A_{max} \): Maximum marketing and advertising cost in period \( t \)

\( P_{max} \): Maximum sale price in period \( t \)

\( D_p \): Specific demand of item \( p \) in each period

\( v_p \): Rate of discount of item \( p \)

\( C_{pd} \): Unit shipment cost of item \( p \) to distributer center \( d \)

\( C_{pdc} \): Unit shipment cost of item \( p \) from distributer center \( d \) to customer \( c \)

\( C_{pdct} \): Unit shipment cost of item \( p \) from distributer center \( d \) to distribution center \( d' \)

\( C_p \): Unit shipment cost of item \( p \) in each period

\( H_p \): Unit holding cost of item \( p \) at each distribution center

\( \pi_{pc} \): Unit shortage cost of item \( p \) for the \( c \)th customer

\( DC_p \): Delay cost for one period of item \( p \) (for \( DD \leq t < DL \))

\( SC_p \): Substitution cost of item \( p \)

\( t_d \): Shipment time to distribution center \( d \)

\( t_{dd} \): Shipment time from distribution center \( d \) to distribution center \( d' \)

\( t_c \): Delivery time from distribution center \( d \) to customer \( c \) (consisting of an average time for order consolidation at the distributer, shipment loading/unloading times and sending the items to the customer’s address.

Variables

\( Q_{pdt} \): Quantity of item \( p \) delivered to distribution center \( d \) on date \( t \)

\( Q_{pdc} \): Quantity of \( p \)th item delivered on date \( t \) from distribution center \( d \) for the order of the \( c \)th customer (order or substitute)

\( Q_{pdct} \): Quantity shipment of item \( p \) between distribution center \( d \) and \( d' \) on date \( t \)

\( X_{pdc} \): Quantity of \( p \)th item picked on distribution center \( d \) (on date \( t = DL_d \)) and delivered on date \( t \) to the \( c \)th customer

\( X_{pdc} \): Quantity of \( s \) substituted for \( p \), picked on distribution center \( d \) and delivered on date \( t \) to the \( c \)th customer

\( B_{pdc} \): Final back-order quantity of item \( p \) at distribution center \( d \) for the \( c \)th customer in period \( t \)

\( I_{pt} \): Ending inventory level of item \( p \) at distribution center \( d \) in period \( t \)

\( P_p \): Sale price of \( p \)th item in period \( t \) at each distributer

\( A_{pt} \): Advertising cost per unit of \( p \)th item in period \( t \)

\( Y_{dct} \): 1 if distribution center \( d \) is used for a delivery on date \( t \) for the \( c \)th customer, 0 otherwise

\( OD \): 1 if order delay occurred, 0 otherwise

\( a_p \): 1 if demand of the \( c \)th consumer for item \( p \) is greater than a specific demand, 0 otherwise.

4.2.1 Proposed demand function

Advertising and pricing are two important factors that change market demand considerably. Here, we propose that the demand function changes continuously with price, advertising, and time as follows:

\[
D_p(t, P, A) = P_p^{D_k - v_p} A_p^c exp(t),
\]
where \(0 \leq e_a \leq 1\) is the parameter of advertising, \(0 \leq e_p \leq 1\) is price elasticity, and the scaling constant \((p)\) represents the related factors. The proposed demand function assume that the maximum tendency to pay will be increased as the price of an item decreases and advertising increases, which is proved by the following equations (GhasemYaghin et al., 2012):

\[
\frac{\partial D}{\partial P} = -e_p P^{-e_p-1} A e_c \exp(t) \leq 0
\]  
(2)

\[
\frac{\partial D}{\partial A} = e_p P^{-e_p-1} A e_c \exp(t) \geq 0.
\]  
(3)

### 4.2.2 Customer profile

As expressed before, we consider that the e-tailer aims at legality; thus, we propose a performance measure for the order fulfillment process as the comparison indicator to improve the process by using a conceptual model that was developed by Johansson, McHugh, Pendlebury, and Wheeler (1993) in the following equation:

Total value = quality \times \text{service cost} \times \text{lead time}.

(4)

The above equation consists of the competitiveness of cost for a lean objective, while customer service level for an agile objective as well as the reliability of quality and delivery efficiency for both lean and agile objectives are the main criteria for evaluating the performance of distributors with respect to customer satisfaction. Since efficiency is inversely proportional to cost (i.e. efficiency increases as cost decreases) and effectiveness and responsiveness are directly proportional to customer service level, Equation (4) can be rewritten conceptually as follows (Okongwu et al., 2012):

\[
\text{Total value} = \text{efficiency} \times \text{effectiveness} \times \text{responsiveness}.
\]  
(5)

According to above performance measurement, the customers’ profile matrix is as follows:

\[
\text{CPM} = [v_{ct}],
\]  
(6)

where \(v_{ct}\) represents total preference value of the \(c\)th customer in period \(t\) with the linguistic term.

### 4.2.3 Qualitative objective function

Owing to the importance of customer satisfaction in the Internet environment, the qualitative objective is proposed as the performance objective including efficiency, effectiveness, and responsiveness in order to enable the e-tailer to adopt its order portfolio strategy. This objective is expressed by a linguistic term similar to the service-oriented objective of GhasemYaghin et al. (2012): ‘The total preference value should be Rather High.

#### 4.2.4 Quantitative objective function

The quantitative objective of the proposed model is to maximize the total profit of the e-tailer, which is equal to the price revenue and the advertising-sensitive demands of customers minus the related costs imposing the following constraints:

\[
\text{MAX } Z = R_{\text{total}} - C_{\text{total}}
\]  
(7)

\[
\tilde{C}_{\text{total}} = \sum_{p} \sum_{d} \sum_{t} (\tilde{C}_{pd} + \tilde{C}_{pd} t) \times Q_{ptd}
\]  

\[+ \sum_{p} \sum_{d} \sum_{t} (\tilde{C}_{pd} + \tilde{C}_{pd} t) \times Q_{ptd}^d
\]  

\[+ \sum_{p} \sum_{d} (H_p \times I_{pt}) + \sum_{p} \sum_{d} \sum_{t} (\tilde{C}_{pd} \times \tilde{C}_{pd} t - \sum_{i} A_{pd} \times D_{pt})
\]  

\[+ \sum_{p} \sum_{d} \sum_{c} (\tilde{C}_{pd} \times X_{pdct}) - \sum_{p} \sum_{d} A_{pt} \times D_{pt}
\]  

\[X_{pdct} + \sum_{s \in S_p} X_{s pdct} = Q_{pdct} \quad \forall t \leq DL
\]  
(8)

\[D_{pt} = \tilde{D}_p \times D_{pt} \quad \forall p, c, t
\]  
(9)

\[Q_{pdct} + B_{pdct} = D_{pt} \times (t + \tau_p) \times \chi_{d(t + \tau_p)} \quad \forall p, d, c, t
\]  
(10)

\[\sum_{p} \sum_{d} \sum_{t \geq DL} Q_{pdct} = OD \times \sum_{p} D_{pt} \quad \forall d, c
\]  
(11)

\[Q_{pd(t - \tau_p)} = \sum_{c} B_{pd(t - \tau_p)} - \sum_{c} Q_{pdct} - \sum_{d} Q_{pdct}
\]  

\[+ \sum_{d} Q_{pd(d(t - \tau_p))} = I_{pd(t + \tau_p)} \quad \forall p, d, \forall t \geq DL
\]  
(12)

\[D_{pt} = \sum_{d} I_{pd} \quad \forall p, t
\]  
(13)

\[\sum_{d} y_{dct} = 1 \quad \forall c, t
\]  
(14)

\[\sum_{d} \tilde{D}R_p \times Q_{pdct} \leq \tilde{D}R_p \times \sum_{d} Q_{pdct} \quad \forall p, c, t
\]  
(15)

\[\sum_{p} \sum_{d} \tilde{S}L \times Q_{pdct} \leq \tilde{S}L_c \times \sum_{p} \sum_{d} Q_{pdct} \quad \forall c, t
\]  
(16)

\[\sum_{p} A_{pt} \times D_{pt} \leq \tilde{A}_{pt} ^{\max} \quad \forall t
\]  
(17)

\[D_{pt} = L \times \omega_p \quad \forall p, c, t
\]  
(18)
\begin{align}
    P_{pt} & \leq \bar{P}_t \quad \forall p, t \\
    P_{pt(t+1)} & \leq P_{pt} \quad \forall p, t \\
    Q_{pdt}, Q_{pddt}, Q_{pddt'}, X_{pdt}, X_{pddt}, B_{pdc}, L_{pdt}, P_{pt}, A_{pt} & \geq 0
\end{align}

The terms in the total cost represent shipment costs from supplier to distributors, delivery costs from distributors to customers and shipment costs between distributors by considering shipment times and also inventory holding costs, shortage costs, delay costs, substitution costs as well as advertising costs, respectively. Constraint (8) implies that the quantity of the \( p \)th item delivered on date \( t \) from distribution center \( d \) to the \( c \)th customer should be equal to the sum of the quantity of the \( p \)th item and the quantity of item \( s \) substituted for \( p \), picked at distribution center \( d \) and delivered on date \( t \). Constraint (9) reflects the fact that the demand of each customer for each item is greater than a proportion of the demand function. Constraint (10) points out that the demand of each customer for each item is essentially equal to the total quantity delivered plus the backlog demand. Constraint (11) shows that if at least one item is delayed, \( OD \) must be equal to one. Constraint (12) corresponds to inventory balance equations for items at each distributor and period, back-order is delivered at the next period. Constraint (13) ensures that customer orders will be provided by one distributor. Constraints (15) and (16) ensure the minimum acceptable levels of quality and service level, respectively. Constraint (17) indicates the limitation of advertising cost in each period. Constraint (18) shows that if the demand of each customer for each item is greater than the specified demand, customers can use discount. It is noted that \( L \) is a very large positive number. Constraints (19) and (20) ensure that prices are lower than the maximum price and non-decreasing in each period, respectively. Moreover, Constraint (21) guarantees the non-negativity of the corresponding decision variables.

5. Solution methodology

Generally, fuzzy mathematical programming can be classified into two major classes: possibilistic programming and (2) flexible programming. Our proposed model is a combination of both flexible programming to cope with flexibility in the target values of objective functions, which is modeled by subjective or preference-based fuzzy sets (Mula, Poler, & Garcia, 2006) and possibilistic programming to handle the lack of knowledge of objective function’s coefficients and constraints by using available objective data and subjective knowledge/experience of the DM (Inuiuchi & Ramik, 2000). To solve the model, we apply a two-phase approach; at first, an appropriate strategy is adopted to convert the model into an equivalent crisp one. Then, an interactive fuzzy programming approach is used to capture inherent fuzziness in objectives’ aspiration levels along with converting to a single objective crisp formulation for an efficient compromise solution.

5.1 Treating the imprecision of the quantitative objective function

Relying on the theory of possibility, there are different approaches to modeling the coefficients of the objective function and constraints as fuzzy numbers for obtaining compromise solutions. Here, we adopt the methods of Parra, Terol, Gladish, and Rodriguez (2005) and Jimenez, Arenas, Bilbao, and Rodriguez (2007). Since all of the coefficients in the quantitative objective function have trapezoidal possibility distributions, the objective function would have a trapezoidal possibility distribution, which is stated as follows:

\[ Z = (Z^1, Z^2, Z^3, Z^4) \]

According to the Jimenez et al. (2007), the total expected value of \( Z \) is defined as

\[ EV_\delta(Z) = \delta EI(Z)^R + (1 - \delta) EI(Z)^L, \]

where \( EI(Z)^R \) and \( EI(Z)^L \) are the right and left expected values of \( Z \), respectively. The parameter \( \delta \in [0,1] \) represents the DM’s degree of optimism. In this case, the total expected value of the trapezoidal possibility distribution of \( Z \) is replaced as follows:

\[ EV_\delta(Z) = (1 - \delta) \frac{Z_1 + Z_2}{2} + (\delta) \frac{Z_3 + Z_4}{2}. \]

5.2 Treating the fuzzy constraints

In the proposed model, there are fuzzy constraints with hard inequalities. For example, the coefficients of both sides of constraints (15) and (16) and one side of constraints (9), (17), and (19) are imprecise. To convert the fuzzy parameters to crisp ones; we rely on possibility theory based on the method of Parra et al. (2005), where \( \beta \)
represents the minimum acceptable possibility level of occurrence for the corresponding fuzzy data. A suitable value for $\beta$ is determined subjectively from the experience and knowledge of the DM.

Consequently, the equivalent auxiliary crisp constraints can be represented as follows:

$$
D_{pcr} = \left[(1 - \beta) \times \left(\frac{D_{p1} + D_{p2}}{2}\right) + \beta \times \left(\frac{D_{p3} + D_{p4}}{2}\right)\right] \times D_{pc}
$$

(24)

$$
\sum_d Q_{pdcr} \times \left[(1 - \beta) \times \left(\frac{D_{p1} + D_{p2}}{2}\right) + \beta \times \left(\frac{D_{p3} + D_{p4}}{2}\right)\right] + (1 - \beta) \times \left(\frac{D_{p1} + D_{p2}}{2}\right) \times \sum_d Q_{pdcr}
$$

(25)

$$
\sum_p A_{pcr} \times D_{pc} \leq \beta \times \left(\frac{A_{1}^{\text{max}} + A_{2}^{\text{max}}}{2}\right) + (1 - \beta) \times \left(\frac{A_{3}^{\text{max}} + A_{4}^{\text{max}}}{2}\right)
$$

(26)

$$
P_{pcr} \leq \beta \times \left(\frac{P_{1}^{\text{max}} + P_{2}^{\text{max}}}{2}\right) + (1 - \beta) \times \left(\frac{P_{3}^{\text{max}} + P_{4}^{\text{max}}}{2}\right).
$$

(27)

$$
\sum_p A_{pcr} \times D_{pc} \leq \beta \times \left(\frac{A_{1}^{\text{max}} + A_{2}^{\text{max}}}{2}\right) + (1 - \beta)
$$

(28)

6. Hybrid fuzzy goal programming model

Zimmermen (1976) first introduced linear programming problems with a fuzzy goal and fuzzy constraints, and Zimmermen (1978) also presented the application of fuzzy set theory to linear programming problems with several objective functions. Narasimhan (1980) first investigated a goal programming framework in a fuzzy environment where equal weights are associated with multiple goals. Subsequently, the solution approach was developed and several auxiliary crisp formulations with different achievement functions were proposed in the literature to aggregate the membership functions of fuzzy goals, such as the simple and weighted additive models, preemptive structure, etc. Hannan (1981) applied fuzzy set theory to goal programming problems to quantify the imprecise aspirations of DMs using piecewise linear and continuous membership functions and presented models for the use of fuzzy goal programming (FGP) with preemptive priorities, with Archimedean weights, and with the maximization of the membership function corresponding to the minimum goal. Since the proposed model includes qualitative objective and quantitative objectives for which all of the coefficients are fuzzy numbers, the DM is not able to estimate the goal exactly. FGP is the most common approach being increasingly applied to solve such problems. In this approach, the DM can take decisions by choosing a preferred efficient solution by introducing membership functions and linguistic statements to specify imprecise aspiration levels as fuzzy goals of each objective function and converting the equivalent multiple objectives into a single objective. According to the literature on fuzzy goal programming, the solution values of a deterministic model are used as a benchmark to construct membership functions for each goal. We use the DM’s judgments to define membership functions (Jamalnia & Soukhakian, 2009). There are three most common types of fuzzy goal programming models for finding an optimal solution $X$ such that all fuzzy goals are satisfied:

$$
G_k(X) \geq g_k \quad k = 1, \ldots, M
$$

$$
G_k(X) \leq g_k \quad k = M + 1, \ldots, n
$$

$$
G_k(X) = g_k \quad k = n + 1, \ldots, l
$$

subject to:

$$
AX \leq b
$$

$$
X \geq 0,
$$

(29)

where $g_k$ is the aspiration level for the $k$th goal, and $AX \leq b$ are the crisp system constraints written as a vector.

6.1 Treating the qualitative objective function

In this section, for converting the qualitative objective into the equivalent quantitative one, we use a fuzzy linguistic variable whose values are characterized by trapezoidal membership functions with the DM’s judgments. We consider a linguistic set similar to that of Jamalnia and Soukhakian (2009): $L = \{VL, L, RL, M, RH, VH\}$, where VL, L, RL, M, RH, and VH denote Very Low, Low, Rather Low, Medium, Rather High, and Very High, respectively, with regard to customer satisfaction in the interval [0,100] as a percentage. The membership functions are illustrated in Figure 1.

6.2 Membership function construction for a quantitative objective

A fuzzy goal (i.e. $EV_a(\tilde{Z}) \geq g$) is characterized by its associated membership function, which is depicted in
where $L$ is the lower tolerance limit for the fuzzy goal and $\mu(V)$ indicates the achievement degree of the fuzzy goal for the given solution vector $V$.

### 6.3 The equivalent crisp model

In our model, owing to more importance having been given to profit maximization than customer satisfaction, the approach of Chen and Tsai (2001) is adopted which allows the DM to determine preemptive priority for achieving goals. The hybrid model will be converted to a crisp one as follows:

$$\text{Max } \sum_i \mu_i$$

subject to:

- all the crisp constraints
- the membership functions ($\mu_i, i = 1, 2$)
- $\mu_1 \geq \mu_{RH}$

### 7. Numerical example

To demonstrate the applicability and usefulness of the proposed model and solution method, the following numerical example is presented. We assume the online retailer has one supplier, three distributors located in different customer zones, and five customers.

Moreover, the main assumptions are as follows:

1. There is a 6-period planning horizon (e.g., each period is 24 hours) and each customer is assumed to order at the first 3-period, therefore the due date and deadline are assumed to be 1 and 2, respectively.
2. There is no initial inventory and the ending inventory is at the end of period 6.
3. There are three different items: M, N, and O. Item MS is added as substitute for M.
4. All customers are satisfied with the substitute items.
5. We set the minimal acceptable possibility degree of imprecise data as $\beta = 0.8$ and $\delta = 0.7$ as a rather optimistic DM.
6. The holding cost of items is assumed to be $H_p = (0.5, 0.55, 0.6)$.
7. The average service level and the acceptable service level of all customers are assumed to be $SL = (0.9, 0.92, 0.95)$ and $SL_c = (0.9, 0.92, 0.95)$, respectively.
8. In the demand function, the scaling constant $\rho = 1$, the parameter of advertising $e_a = 0.3$, and price elasticity $e_p = 0.5$.

Because of unavailability as well as the lack of required data, we generate data randomly in such a way that they will be close to the real data. Without loss of generality and just to simplify the generation of fuzzy parameters, we use a symmetrical triangular possibility distribution for our numerical test. Table 2 summarizes the information about the source of random data generation.

Furthermore, according to Jamalnia and Soukhakian (2009) we use the DM’s judgments to define the membership functions of both quantitative and qualitative objectives. In this example, based on the DM’s judgments, $L = 220,000,0$ and $g = 450,000,0$.

The membership function of the qualitative objective was defined in Section 6.1 and the quantitative objective is...
Corresponding random distribution | Parameter | Corresponding random distribution
--- | --- | ---
\(CP\) | \(U(10,50)\) | \(U(0,1)\)
\(C_{pd}\) | \(U(40,100)\) | \(U(0,5.10)\)
\(C_{pdc}\) | \(U(70,160)\) | \(U(0.5,2)\)
\(C_{pdcr}\) | \(U(5,25)\) | \(U(0.01,0.03)\)
\(DC_p\) | \(U(130,270)\) | \(DR_p\) | \(U(0.02,0.05)\)
\(SC_C\) | \(U(90,150)\) | \(D_{pc}\) | \(U(0,10)\)
\(\pi_{pc}\) | \(U(150,300)\) | \(\pi_{p}\) | \(U(1)\)
\(A_{\text{max}}\) | \(U(100,250)\) | \(d_p\) | \(U(0,10)\)

\[\mu_c(V) = \begin{cases} 
1 & \text{EV}_{0.7}(\tilde{Z})(V) \geq g \\
\frac{\text{EV}_{0.7}(\tilde{Z})(V) - L}{g - L} & L \leq \text{EV}_{0.7}(\tilde{Z})(V) \leq g \\
0 & \text{EV}_{0.7}(\tilde{Z})(V) \leq L
\end{cases}\]

Consequently, the following constraints are added to model:

\[\begin{align*}
\mu_1 &\leq 4.34 \times 10^{-7} \times (\text{EV}_{0.7} - 220,000,0) \\
\mu_2 &\leq 0.13 \times X - 7.6 \\
\mu_3 &\leq 16 - 0.2 \times X.
\end{align*}\]

7.1 Sensitivity analysis and discussion

In order to analyze behavior of the proposed model, sensitivity analysis on \(\beta\)-levels and \(\delta\)-value has been conducted. The main results of all test problems are shown in Tables 3 and 4.

As it can be seen from Table 3, more balanced solutions are achieved with \(\beta\)-levels 0.8 and 0.9, and the method pays more attention to more important objectives than the minimum satisfaction level.

The parameter \(\delta\) represents the DM’s degree of optimism. Higher values of \(\delta\) indicate a higher degree of optimism. Thus, \(\delta = 0\) and \(\delta = 1\) represent a pessimistic and optimistic DM’s viewpoint, respectively (Li & Lai, 2001). For a moderately optimistic DM, \(\delta = 0.5\) is similar to the method of Jimenez et al. (2007).

The results show that impact of changing the above parameters on the qualitative objective function value is negligible in our experiment. The values of \(\mu_2\) are in the interval specified by Rather High and the model is able to achieve greater values of \(\mu_1\) with fixed \(\mu_2\). Overall, the main objective of the sensitivity analysis is to investigate the robustness of the proposed model due to variations in expert opinions regarding assigning weights during comparison.

For more discussion, the leanness and agility of the case of an online retailer supply chain is tested. Improved supply chain performance implies that a supply chain is capable of responding quickly to variations in customer demand with effective cost reduction. Leanness maximizes profits through cost reduction while agility maximizes profit through improving customer expectations. The leagile supply chain enables the upstream part of the chain to be cost-effective and the downstream part to achieve higher service levels in a volatile marketplace. As a result, the model is capable of taking into consideration both conflicting qualitative and quantitative information. The aim of the qualitative objectives based on the performance framework is to study the most important criteria of customer satisfaction, which explores the relationship between lead time, cost, quality, and service level. The results show that service level and lead time are essential metrics for leagile supply chains, so the main focus should be on the improvement of service level and lead time reduction.

Moreover, the flexible strategies, by allowing the substitution of products and using a second distribution
center, produce very impressive results. Although the efficiency strategy is based on the minimization of total cost, the responsiveness strategies imply speed and aim to deliver all the ordered quantity as soon as the products are available. The solution obtained turns out to be the most economic in this experiment, and other strategies enable one to obtain better solutions with the best value. In other words, the efficiency strategy turns out to be outstanding compared to the effectiveness and responsiveness strategies. Nevertheless, these two strategies can be adopted under specific circumstances where the speed and completeness of delivery of the customer order is much more important than the cost of delivering the order.

Following this discussion, we can conclude that the four hybrid strategies can give different or similar solutions depending on the data set, as well as on the constraints imposed by the customer. Overall, the results suggest that there is consistency in the policy. Managers are faced with the problem of maximizing customer satisfaction while taking into consideration conflicting objectives on the supply and demand sides of the order fulfillment process. Therefore, it could be argued that selecting appropriate order fulfillment is effective in producing successful e-tailing systems.

8. Conclusion
In this paper, we present a model of joint pricing and online fulfillment assignment for a distribution system aimed at leagility under the possibility of using substitute items with customer satisfaction. The model is formulated as a hybrid fuzzy bi-objective multi-period multi-item problem including both quantitative and qualitative objectives. We consider order fulfillment, substitution, delay and shortage quantity, acceptable levels of quality, on-time delivery, and service levels as the important factors for customers, and on the other hand, order quantity, sale price, and advertising expenditure as significant factors for the e-tailer.

The fuzzy parameters and goals are represented by appropriate linear membership functions and, after the defuzzification process, a fuzzy goal programming method is used to solve the equivalent crisp one through an interactive solution procedure.

Finally, in order to assess the performance and usefulness of the proposed model and its solution, a numerical example is provided. The numerical results indicate the significant effect of price on customer demand. Moreover, it can be concluded that utilization of transshipment and substitution strategies in the distribution system would be appropriate in order to increase both total profit and customer satisfaction levels.

This study can be extended to the following areas for future research:

- The development of an efficient heuristic and or exact solution algorithm for solving the corresponding nonlinear model in real size instances.
- Development of the model for the dual-channel of combined retail/e-tail systems and other supply chain structures.

- The evaluation of alternative online fulfillment policies, such as pickup and return policies for the e-tailer that allow customers to pickup/return online purchases from/to the distributor.
- The development and evaluation of adopting a differential pricing strategy in online sales channels, and the investigation of the impact on the pickup option.
- The adoption of other alternate incentive schemes, such as discounting and advertising, in order to increase profit and customer satisfaction.

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References


