A MULTI-OPTIMIZATION APPROACH TO FAIR PROFIT DISTRIBUTION PROBLEM FOR A SUPPLY CHAIN NETWORK

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Abstract:

The fair profit distribution problem of a typical supply chain network involving batch production is considered in this article. To implement this concept, we construct a multi-product batch production combined with multi-stage distribution planning model to achieve multiple objectives such as maximizing the customer service level, maximizing the profit of each participant company of the supply chain, and ensuring a fair profit distribution. The fuzzy decision-making method is adopted to attain the compromised solution between these conflicting objectives. Therein each objective function is viewed as a fuzzy goal, and a membership function is used to characterize the transition from the objective value to the degree of satisfaction. A two-phase fuzzy optimization method is applied to obtain the compromised solution between all participant companies of the supply chain. One numerical example is supplied, demonstrating that the proposed two-phase method can provide a better compensatory solution for multi-objective problems in a supply chain network.

Keywords:

Supply chain management, Fair profit distribution, Multiple objectives, Fuzzy optimization

Introduction

Recently, Tsiakis *et al.* (2001) proposed a multi-product and multi-period single objective linear programming model for a supply chain network design problem. The objective function contains production cost, transportation cost, and inventory cost. Although the proposed strategies can create the best result for the entire system, it may also increase costs or decrease profits for some members in the supply chain system. Gjerdrum *et al.* (2001) proposed a mixed-integer linear programming model to solve the fair profit distribution problem by using a Nash type objective function. However, two problems are worth further considering. First, the low-bound of profit of each member may be difficult to determine due to the inherent uncertainty. Second, directly maximizing the Nash type objective may cause unfair profit solution due to different scale of profit. In this article, we simultaneously consider problems of fair profit distribution, customer service, and safe inventory in a supply chain network.

Because the optimization for a multi-objective problem is a procedure looking for a compromise policy, the result, called a Pareto optimal or non-inferior solution, consists of an infinite number of options. Methods for finding a Pareto optimal solution are thus filled with subjective and fuzzy properties. In order to overcome the difficulty of describing fuzzy attributes, we adopt a two-phase fuzzy decision method to guarantee uniqueness of the optimal solution. A numerical example will be supplied, demonstrating effectiveness of the proposed idea.

Problem Statement

This article considers a supply chain consisting of three different level enterprises: the retailer or market, the distribution center or warehouse, and the plant or manufacturer. The system batch-manufactures one product at each period and the time of manufacturing process of each product is one period. The overall problem can be stated as follows:

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Given:

1. Cost parameters,
2. Manufacture data,
3. Transportation data,
4. Inventory data, such as capacity and safe inventory quantity.
5. Forecasting customer demand and product sales price.

Determine:

1. Production plan of each plant.
2. Transportation plan of each distribution center.
3. Sales quantity of each retailer.
4. Inventory level of each enterprise.
5. Each kind of cost.

The targets are to:

1. Integrate a multi-enterprise decision simultaneously which result a fair profit distribution.
2. Increase the customer service level and safe inventory level as possible.

The relevant balance relations and constraints such as inventory capacity limitations, purchase and inventory costs, product sales revenues, and customer service levels for retailers are listed in Table 2 as an illustration. Detailed explanation for these notations and similar formulations for distributors and for plants can be found in Chen *et al.* (2002).The multiple objective optimization problem can thus be formulated as follows, where $\mathbf{x}$ and Ω denote the variable vector and the feasible searching space, respectively:

$$\max_{\mathbf{x}\in\Omega}(J_1,\ldots,J_S)=\left(\begin{array}{l}\sum_t \mathrm{Z}_{rt},\ \ \frac{1}{T}\sum_t \mathrm{CSL}_{rt},\\ \frac{1}{T}\sum_t \mathrm{SIL}_{rt},\\ \sum_t \mathrm{Z}_{dt},\ \ \frac{1}{T}\sum_t \mathrm{SIL}_{dt},\\ \sum_t \mathrm{Z}_{pt},\ \ \frac{1}{T}\sum_t \mathrm{SIL}_{pt};\\ \forall r\in\mathcal{R},\ d\in\mathcal{D},\ p\in\mathcal{P}\end{array}\right)$$

$$\mathbf{x}=\left\{\begin{array}{r}\mathrm{S}^i_{rt},\mathrm{I}^i_{rt},\mathrm{B}^i_{rt},\mathrm{D}^i_{rt},\mathrm{S}^i_{drt},\mathrm{Q}^k_{drt},\mathrm{I}^i_{dt},\mathrm{D}^i_{dt},\mathrm{Y}^k_{drt},\\ \mathrm{S}^i_{pdt},\mathrm{Q}^{k'}_{pdt},\mathrm{I}^i_{pt},\mathrm{D}^i_{pt},\mathrm{Y}^{k'}_{pdt},\alpha^i_{pt},\beta^i_{pt},\gamma^i_{pt},o^i_{pt};\\ i\in\mathcal{I},\ r\in\mathcal{R},\ d\in\mathcal{D},\ p\in\mathcal{P},\\ t\in\mathcal{T},\ k\in\mathcal{K},\ k'\in\mathcal{K},\ n\in\mathcal{N}\end{array}\right\}$$

Multi-objective Optimization: A Fuzzy Approach

Consider the multiple objective optimization problem mentioned above. We propose a two-phase fuzzy satisfying method to find a best compromised solution, such as summarized in the following.

1. Determine the ideal solution and anti-ideal solution by individually maximizing and minimizing each objective function in sequence (Lee and Li, 1993, Shih and Lee, 2000).

$$\begin{array}{rcll} J_i^* &=& \mathbf{max}\, J_i & \text{(ideal solution of } J_i)\\ J_i^- &=& \mathbf{min}\, J_i & \text{(anti-ideal solution of } J_i)\end{array}$$

2. Define a fuzzy goal $\mathcal{J}_i$ with a linear membership for describing the degree of satisfaction for J_i.

$$\mu_{\mathcal{J}_i}=\begin{cases}1 & \text{for} \quad J_i\geq J_i^*\\ \frac{J_i-J_i^-}{J_i^*-J_i^-} & \text{for} \quad J_i^-\leq J_i\leq J_i^*\\ 0 & \text{for} \quad J_i\leq J_i^-\end{cases}$$

Evaluate membership value for the overall degree of satisfaction, $\mathcal{D}$, by a t-norm, $\mathbb{T}$, where $\mathbb{T}$ can be a minimum or a product operator.

$$\mu_{\mathcal{D}} = \mathbb{T}\left(\mu_{\mathcal{J}_1}[J_1],\cdots,\mu_{\mathcal{J}_S}[J_S]\right)$$

3. (*Phase* 1) Obtain the least degree of satisfaction for all objectives, μ^1, by the minimum operator.

$$\max_{\mathbf{x}\in\Omega}\mu_{\mathcal{D}}=\max_{\mathbf{x}\in\Omega}\mathbf{min}\left(\mu_{\mathcal{J}_1},\ldots,\mu_{\mathcal{J}_S}\right)=\mu^1$$

4. (*Phase* 2) Re-optimize the problem with new constraints.

$$\begin{array}{rcl}\max_{\mathbf{x}\in\Omega^+}\mu_{\mathcal{D}} &=& \max_{\mathbf{x}\in\Omega^+}\mu_{\mathcal{J}_1}\times\cdots\times\mu_{\mathcal{J}_S}\\ \text{where }\ \Omega^+ &=& \Omega\cap\left\{\mu_{\mathcal{J}_i}\geq\mu^1,\ i=1,\cdots,S\right\}\end{array}$$

Numerical Example

Considering a supply chain consists of 1 plant, 2 distribution centers, 2 retailers, and 2 products. The whole planning horizon is 10 periods (weeks) based on a forecasting customer demand. Some of the environment condition parameters are listed in Table 1.

The ideal/anti-ideal solutions for all objectives can be found in Chen et al. (2002). The resulting membership values of using $\mathbb{T}$ = minimum in phase 1 to maximize $\mu_{\mathcal{D}} = \mu^1$ with fair distribution, and $\mathbb{T}$ = product in

Table 1: *The environment condition parameters for the example*

Parameters	Retailer 1	Retailer 2
MIC_r	400	400
$\mathrm{SIQ}_{rt}^{i1}, \mathrm{SIQ}_{rt}^{i2}$	100	100
$\mathrm{I}_{rt0}^{i1}, \mathrm{I}_{rt0}^{i2}$	100	100
$\mathrm{UIC}_{rt}^{i1}, \mathrm{UIC}_{rt}^{i2}$	\$50	\$50
$\mathrm{UHC}_{rt}^{i1}, \mathrm{UHC}_{rt}^{i2}$	\$15	\$15
$\mathrm{USR}_{rt}^{i1}, \mathrm{USR}_{rt}^{i2}$	\$1700	\$1700
FCD_{rt}^{i1}	\$180, \$80	\$180, \$80
FCD_{rt}^{i2}	\$180, \$20	\$180, \$20

phase 2 with additional constraints are depicted in Figure 1. Therein, a membership value closing to 1.0 implies higher degree of satisfaction for associated objective. The figures show that the proposed two-phase optimization method can maximize individual efficiency and keep fair profit distribution.

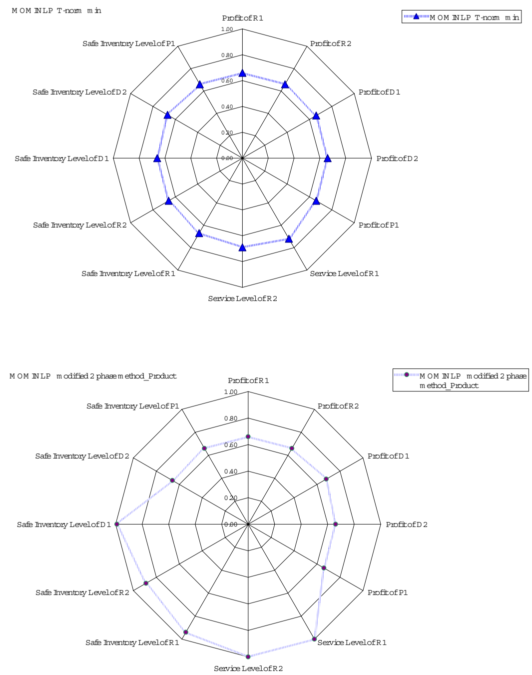

Figure 1: *Resulting membership values when using $\mathbb{T}$ = minimum only (above) and the proposed two-phase optimization (below)*

Conclusions

This paper study the fair profit distribution problem of a typical supply chain network involving batch production. We construct a multi-product batch production combined with a multi-stage distribution planning model to achieve objectives such as maximizing customer service level, maximizing profit of each participant company of the supply chain, and ensuring fair profit distribution. A two-phase fuzzy optimization procedure is proposed to maximize efficiency in production and distribution planning and to guarantee a fair profit distribution. One numerical example is supplied to illustrate the proposed idea.

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Table 2: *Constraints and objectives relevant to retailers (for other equations, see Chen et al., 2002)*

Retailers	Constraints	Inventory balance	$\mathrm{I}^i_{rt} = \mathrm{I}^i_{r,t-1} + \sum_d \mathrm{S}^i_{dr,t-\mathrm{TLT}_{dr}} - \mathrm{S}^i_{rt}$ $\mathrm{I}^i_{rT} \geq \mathrm{SIQ}^i_{rT}$ $\mathrm{B}^i_{rt} = \mathrm{B}^i_{r,t-1} + \mathrm{FCD}^i_{rt} - \mathrm{S}^i_{rt}$ $\mathrm{B}^i_{rT} = 0$
		Max inventory capacity	$\sum_i \mathrm{I}^i_{rt} \leq \mathrm{MIC}_r$
		Safe inventory quantity	$\mathrm{SIQ}^i_{rt} - \mathrm{I}^i_{rt} \leq \mathrm{D}^i_{rt} \leq \mathrm{SIQ}^i_{rt}$ $\mathrm{D}^i_{rt} \geq 0$
	Cost	Purchase cost	$\mathrm{TPC}_{rt} = \sum_d \sum_i \mathrm{USR}^i_{drt} \mathrm{S}^i_{drt}$
		Inventory cost	$\mathrm{TIC}_{rt} = \sum_i \mathrm{UIC}^i_{rt} \mathrm{I}^i_{rt}$
		Handling cost	$\mathrm{THC}_{rt} = \sum_i \mathrm{UHC}^i_{rt} (\sum_d \mathrm{S}^i_{dr,t-\mathrm{TLT}_{dr}} + \mathrm{S}^i_{rt})$
	Revenue	Product sales	$\mathrm{PSR}_{rt} = \sum_i \mathrm{USR}^i_{rt} \mathrm{S}^i_{rt}$
	Service level	Customer service level	$\mathrm{CSL}_{rt} = \frac{\sum_i (\frac{\mathrm{S}^i_{rt}}{\mathrm{FCD}^i_{rt} + \mathrm{B}^i_{r,t-1}})}{\sum_i 1} \times 100\%$
	Inventory level	Safe inventory level	$\mathrm{SIL}_{rt} = \frac{\sum_i (1 - \frac{\mathrm{D}^i_{rt}}{\mathrm{SIQ}^i rt})}{\sum_i 1} \times 100\%$
	Objective functions	Overall profit	$\max_{x \in \Omega} \sum_t \mathrm{Z}_{rt} = \sum_t \mathrm{PSR}_{rt} - \sum_t \mathrm{TPC}_{rt} - \sum_t \mathrm{TIC}_{rt} - \sum_t \mathrm{THC}_{rt}$
		Avg. customer service level	$\max_{x \in \Omega} \sum_t \mathrm{CSL}_{rt}/T$
		Avg. safe inventory level	$\max_{x \in \Omega} \sum_t^T \mathrm{SIL}_{rt}/T$