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供應鏈網路整合性多目標模糊決策規劃研究(1/3)

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計畫主持人：陳誠亮

計畫參與人員：陳誠亮　賴佑年　湯志偉　林立峰

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供應鏈網路整合性多目標模糊決策規劃研究 (1/3)
(NSC93-2214-E-002-025)

陳誠亮
台灣大學化工系

Abatract A multi-product, multi-stage, and multi-period production and distribution planning model is formulated for a typical multi-echelon supply chain network to achieve multiple objectives such as maximizing profit of each participant enterprise, maximizing customer service level, and ensuring fair profit distribution. A two-phase fuzzy decision-making method is proposed to attain compromised solution between all conflict objectives. One numerical case study is supplied, demonstrating that the proposed two-phase fuzzy intersection method can provide a better compensatory solution for multi-objective problems in a supply chain network.

Keywords Supply chain management, fair profit distribution, multi-objective optimization

1. INTRODUCTION

In traditional supply chain management, minimizing costs or maximizing profit as a single objective is often the focus when considering the integration of supply chain network. Recently, Gjerdrum *et al.* [1] proposed a mixed-integer linear programming model for a production and distribution planning problem and solve the fair profit distribution problem by using the Nash-type model as objective function. However, directly maximizing the Nash-type objective may cause the unfair profit distribution due to different scales of profits. Furthermore, today's consumers are demanding better customer service, whether it be the manufacturing or service industry. Customer service should also be taken into consideration when formulating a supply chain system. But in the traditional supply chain management of minimizing costs or maximizing profit as a single objective, it is difficult to quantify customer service into a monetary amount into the objective function. To solve this problem, we attempt to establish a production and distribution planning model that can fairly distribute profits and also take several performance indices such as customer service and safe inventory level into consideration. And this would be turned into a multi-objective programming problem. Then, we proposed a modified two-phase fuzzy intersection method [2] to solve the multi-objective programming problem. So that, we can guarantee each member of the supply chain system can go after their own maximal profit on the basis of the least of required profit.

2. PROBLEM DESCRIPTION

A general multi-echelon supply chain is considered which consists of three different level enterprises. The first level enterprise is retailer from which the products are sold to customer subject to a given low bound of customer service. The second level enterprise is distribution center (DC) which uses different type of transport capacity to deliver products from plant side to retailer side. The third level enterprise is plant which batch-manufactures one product at one period. The overall problem can be stated as follows:

Given: cost parameters, manufacture data, transportation data, inventory data, forecasting customer demand and product sales price.

Determine: production plan of each plant and transportation plan of each distribution center, sales quantity of each retailer and inventory level of each enterprise, and each kind of cost.

The *target* is to integrate the multi-echelon decisions simultaneously, which results in a fair profit distribution, and to increase customer service level and safe inventory level as possible.

3. MATHEMATICAL FORMULATION

3.1. Parameters We divide the parameters into two categories: the cost parameters and other parameters such as inventory capacity, transport lead time, etc., such as shown in Table 1.
3.2. Variables Binary variables, which act as policy decisions to use economies of scale for manufacturing or shipping, and other variables can be found in Table 2.
3.3. Integration of production and distribution models Detailed formulation for constraints and objective functions for retailer r, distribution center d, and for plant p, respectively, can be found in [3].We integrate three different level enterprises to establish a mixed-integer non-linear programming model. The multiple objectives $J_s, s \in \mathcal{S}$, variable vector, $\mathbf{x}$, and the feasible searching space, Ω, are stated in the following.

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

$$\mathbf{x} = \left\{ \begin{array}{r} \mathrm{S}^i_{rt}, \mathrm{I}^i_{rt}, \mathrm{B}^i_{rt}, \mathrm{D}^i_{rt}, \mathrm{S}^i_{drt}, \mathrm{Q}^k_{drt}, \mathrm{I}^i_{dt}, \mathrm{D}^i_{dt}, \mathrm{Y}^k_{drt}, \mathrm{S}^i_{pdt}, \mathrm{Q}^{k'}_{pdt}, \mathrm{I}^i_{pt}, \mathrm{D}^i_{pt}, \mathrm{Y}^{k'}_{pdt}, \alpha^i_{pt}, \beta^i_{pt}, \gamma^i_{pt}, o^i_{pt}, \\ i \in \mathcal{I},\ r \in \mathcal{R},\ d \in \mathcal{D},\ p \in \mathcal{P},\ t \in \mathcal{T},\ k \in \mathcal{K},\ k' \in \mathcal{K},\ n \in \mathcal{N} \end{array} \right\} \tag{2}$$

4. FUZZY MULTI-OBJECTIVE OPTIMIZATION

By considering the uncertain property of human thinking, it is quite natural to assume that the DM has a fuzzy goal, $\mathcal{J}_s$, to describe the objective J_s with an interval $[J_s^*, J_s^-]$. For the s^{th} maximal objective, it is quite satisfied as the objective value $J_s \geq J_s^*$, and is unacceptable as $J_s \leq J_s^-$. The original multi-objective optimization problem is thus equivalent to look for a

Table 1: *Indices, sets, and parameters*

Index/Set	Dimension	Physical meaning
$r \in \mathcal{R}$	$[\mathcal{R}] = R$	retailers
$d \in \mathcal{D}$	$[\mathcal{D}] = D$	distribution centers
$p \in \mathcal{P}$	$[\mathcal{P}] = P$	plants
$i \in \mathcal{I}$	$[\mathcal{I}] = I$	products
$t \in \mathcal{T}$	$[\mathcal{T}] = T$	periods
$k \in \mathcal{K}$	$[\mathcal{K}] = K$	transport capacity level, DC to retailer
$k' \in \mathcal{K}'$	$[\mathcal{K}'] = K'$	transport capacity level, plant to DC
Parameter	$* \in$	Physical meaning
USR_*^i	$\{pd, dr, r\}$	Unit Sale Revenue of i, p to d, *etc.*
UIC_*^i	$\{p, d, r\}$	Unit Inventory Cost of i for p, d, r
UHC_*^i	$\{p, d, r\}$	Unit Handling Cost of i for p, d, r
$\mathrm{UTC}_*^{k'}$	$\{pd\}$	k'th level Unit Transport Cost, p to d
UTC_*^k	$\{dr\}$	kth level Unit Transport Cost, d to r
$\mathrm{FTC}_*^{k'}$	$\{pd\}$	k'th level Fix Transport Cost, p to d
FTC_*^k	$\{dr\}$	kth level Fix Transport Cost, d to r
UMC_*^i	$\{p\}$	Unit Manufacture Cost of i
OMC_*^i	$\{p\}$	Overtime unit Manuf. Cost of i
FMC_*^i	$\{p\}$	Fix Manuf. Cost changed to make i
FIC_*^i	$\{p\}$	Fix Idle Cost to keep p idle
FCD_*^i	$\{r\}$	Forecast Customer Demand of i
TLT_*	$\{pd, dr\}$	Transport Lead Time, p to d (d to r)
SIQ_*^i	$\{p, d, r\}$	Safe Inventory Quantity in p, d, r
MIC_*	$\{p, d, r\}$	Max inventory capacity of p, d, r
$\mathrm{TCL}_*^{k'}$	$\{pd\}$	k'th Transport Capacity Level, p to d
TCL_*^k	$\{dr\}$	kth Transport Capacity Level, d to r
MITC_*	$\{d\}$	Max Input Transport Capacity of d
MOTC_*	$\{d\}$	Max Output Transport Capacity of d
FMQ_*^i	$\{p\}$	Fix Manufacture Quantity of i
OMQ_*^i	$\{p\}$	Overall fix Manufacture Quantity
MTO_*	$\{p\}$	Max Total Overtime manuf. period

Table 2: *Binary variables and other continuous variables for $t \in \mathcal{T}$*

Binary	$* \in$	Meaning when having value of 1
$\mathrm{Y}_{*t}^{k'}$	$\{pd\}$	k'th transport capacity level, p to d
Y_{*t}^{k}	$\{dr\}$	kth transport capacity level, d to r
α_{*t}^{i}	$\{p\}$	manufacture with regular time workforce
β_{*t}^{i}	$\{p\}$	setup plant p to manufacture i
γ_{*t}^{i}	$\{p\}$	p changeover to manufacture i
o_{*t}^{i}	$\{p\}$	manufacture with overtime workforce
Real	$* \in$	**Physical meaning**
S_{*t}^{i}	$\{pd, dr, r\}$	Sales quantity of i, p to d *etc.*
$\mathrm{Q}_{*t}^{k'}$	$\{pd\}$	k'th level transport quantity, p to d
Q_{*t}^{k}	$\{dr\}$	kth level transport quantity, d to r
Q_{*t}	$\{pd, dr\}$	total transport quantity, p to d or d to r
I_{*t}^{i}	$\{p, d, r\}$	Inventory level of i in p, d, r
B_{*t}^{i}	$\{r\}$	Backlog level of i in r at end of t
D_{*t}^{i}	$\{p, d, r\}$	Short safe inventory level in p, d, r
TMC_{*t}	$\{p\}$	Total Manufacture Cost of p
TPC_{*t}	$\{d, r\}$	Total Purchase Cost of d, r
TIC_{*t}	$\{p, d, r\}$	Total Inventory Cost of p, d, r
THC_{*t}	$\{p, d, r\}$	Total Handling Cost of p, d, r
TTC_{*t}	$\{d; pd, dr\}$	Total Transport Cost of d; p to d or d to r
PSR_{*t}	$\{p, d, r\}$	Product Sales Revenue of p, d, r
SIL_{*t}	$\{p, d, r\}$	Safe Inventory Level of p, d, r
CSL_{*t}	$\{d\}$	Customer Service Level of r
Z_{*t}	$\{p, d, r\}$	Net profit of p, d, r

suitable decision that can provide the maximal overall degree-of-satisfaction for the multiple fuzzy objectives. Under incompatible objective circumstances, a DM must make a compromise decision that provides a maximal degree-of-satisfaction for all of these conflict objectives. The new optimization problem can be interpreted as the synthetic notation of a conjunction statement (maximize jointly all objectives). The result of this aggregation, $\mathcal{D}$, can be viewed as a fuzzy intersection of all fuzzy goals $\mathcal{J}_s,\ s \in \mathcal{S}$, and is still a fuzzy set. The final degree-of-satisfaction resulting from certain variable set, $\mu_{\mathcal{D}}(\mathbf{x})$ can be determined by aggregating the degree-of-satisfaction for all objectives, $\mu_{\mathcal{J}_s}(\mathbf{x})$, $s \in \mathcal{S}$, via specific t-norms such as minimum or product operators. The procedure of the fuzzy satisfying approach for the multi-objective optimization problem, Eq.(1), are summarized as follows.

Step 1. Determine the ideal solution and anti-ideal solution by directly maximizing and minimizing each objective function, respectively.

$$\begin{aligned} \mathbf{max}\, J_s &= J_s^* \quad \text{(Ideal solution of } J_s, \text{ totally acceptable value)} \\ \mathbf{min}\, J_s &= J_s^- \quad \text{(Anti-ideal solution of } J_s, \text{ unacceptable value)} \end{aligned} \tag{3}$$

Step 2. Define each membership function. Without loss of generality, we will adopt linear function for all fuzzy objectives.

$$\mu_{\mathcal{J}_s} = \begin{cases} 1; & J_s \geq J_s^* \\ \frac{J_s - J_s^-}{J_s^* - J_s^-}; & J_s^- \leq J_s \leq J_s^* \\ 0; & J_s \leq J_s^- \end{cases} \qquad \forall\, s \in \mathcal{S} \tag{4}$$

Step 3. (**Phase** I) To maximize the degree of satisfaction for the worst objective by selecting minimum operator for fuzzy aggregation.

$$\mathop{\mathbf{max}}_{\mathbf{x}\in\Omega} \mu_{\mathcal{D}} = \mathop{\mathbf{max}}_{\mathbf{x}\in\Omega} \mathbf{min}(\mu_{\mathcal{J}_1}, \mu_{\mathcal{J}_2}, \cdots, \mu_{\mathcal{J}_S}) = \mu^1 \tag{5}$$

Step 4. (**Phase** II) Considering satisfaction of all objectives, re-optimize the problem by selecting the product operator with guaranteed minimum degree-of-satisfaction for all objectives.

$$\begin{aligned} \mathop{\mathbf{max}}_{\mathbf{x}\in\Omega^+} \mu_{\mathcal{D}} &= \mathop{\mathbf{max}}_{\mathbf{x}\in\Omega^+} (\mu_{\mathcal{J}_1} \times \mu_{\mathcal{J}_2} \times \cdots \times \mu_{\mathcal{J}_S}) \\ \Omega^+ &= \Omega \cap \{\mu_{\mathcal{J}_s} \geq \mu^1,\ \forall\, s \in \mathcal{S}\} \end{aligned} \tag{6}$$

5. NUMERICAL EXAMPLE

Considering a multi-echelon supply chain consists of 1 plant, 2 distribution centers, 2 retailers, and 2 products. Numerical values of all parameters can be found in [3]. we solve the multi-objective mixed-integer non-linear programming problem by using the fuzzy approach procedure, and the results are summarized in Table 3. Table 3 shows that by selecting minimum as the fuzzy intersection operator, we can get a more balanced satisfaction among all objectives where the degrees of satisfaction are all around 0.66. By using product operator directly to guarantee a unique solution, however, the results are unbalanced with the lower degree of satisfaction for $d = 2$'s profit and safe inventory level, and $p = 1$'s profit. On the other

Table 3: Results of using minimum operator, product operator and two-phase method

	minimum operator		product operator		two-phase method	
Objectives	Obj Value	Satisfaction	Obj Value	Satisfaction	Obj Value	Satisfaction
Profit $r = 1$	$859,582$	0.66	$970,556$	0.73	$845,754$	0.66
Profit $r = 2$	$1,066,607$	0.66	$1,208,310$	0.75	$1,053,162$	0.66
Profit $d = 1$	$566,217$	0.66	$824,620$	0.89	$593,598$	0.68
Profit $d = 2$	$1,959,172$	0.66	$1,515,645$	0.49	$1,935,237$	0.66
Profit $p = 1$	$4,507,340$	0.66	$4,231,931$	0.54	$4,486,048$	0.66
CSL $r = 1$	0.92	0.72	0.99	1.00	0.99	1.00
CSL $r = 2$	0.91	0.69	0.99	1.00	0.99	1.00
SIL $r = 1$	0.63	0.67	0.91	0.97	0.88	0.94
SIL $r = 2$	0.63	0.66	0.91	0.95	0.85	0.89
SIL $d = 1$	0.66	0.66	1.00	1.00	0.99	0.99
SIL $d = 2$	0.65	0.67	0.57	0.59	0.64	0.66
SIL $p = 1$	0.65	0.66	0.77	0.79	0.65	0.66

CSL: Customer Service Level, SIL: Safe Inventory Level

hand, the high performance objectives or goals are given a very high emphasis. To overcome the drawbacks of single phase method, the proposed modified two-phase method can combine advantages of these two popular fuzzy intersection operators. The minimum operator is used in phase I to find the least degree of satisfaction, and the product operator is applied in phase II with guaranteed least membership value for all fuzzy objectives as additional constraints.

6. CONCLUSION

In this paper, we investigate the fair profit distribution problem of a typical multi-echelon supply chain network. The fuzzy set theory is used to attain the compromised solutions. We proposed a modified two-phase fuzzy intersection method by combining the advantages of two popular t-norms to solve the fair profit distribution problem. One case study is supplied, demonstrating that the proposed two-phase method can provide a better compensatory solution for multi-objective problems in a supply chain network.

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