Available online at www.sciencedirect.com
ScienceDirect
European Journal of Operational Research 187 (2008) 415–428
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

Order selection and pricing methods using flexible quantity and fuzzy approach for buyer evaluation

Hung-Tso Lin *, Wen-Ling Chang

Department of Distribution Management, National Chin-Yi University of Technology, 35, Lane 215, Chung-Shan Road, Section 1 Taiping City, Taichung Country, Taiwan, Republic of China

Received 19 October 2006; accepted 7 March 2007
Available online 3 April 2007

Abstract

This paper presents the methods for order selection and pricing of manufacturer (supplier) with make-to-order basis when orders exceed production capacity. By quoting the concepts of triangular fuzzy numbers and linguistic variables, a fuzzy approach to evaluating buyers by taking into account both positive and negative criteria is proposed. According to the classified results of buyers, the orders will be produced with priority, declined, or determined by MIP model. The fixed quantity MIP model and flexible quantity MIP model are employed to determine the produced orders along with the production quantity and the reference amount for price reduction. By applying the concept of TOPSIS, the closeness coefficients for satisfaction grades of orders and for ranking values of buyers are used as the adjusting rates in the final pricing MIP model to set segmented price.

Keywords: Production; Order selection; Pricing; Fuzzy sets

1. Introduction

In recent years, supply chain management and the supplier selection problems have received considerable attention. Chen et al. (2006) concluded that supplier selection problems adhere to a group decision-making under multiple criteria, uncertain and imprecise data, and fuzzy sets theory is adequate to deal with them. They proposed a normalization method involving linear scale transformation to transform the benefit and cost criteria into comparable scales in their fuzzy decision-making approach. The drawback of the method is that the fuzzy ratings must not include zero; otherwise, all normalized fuzzy ratings will yield zero. With respect to buyer and supplier relationships in the supply chain, Shin et al. (2000) studied the supply management orientation and concluded that an improvement in the supply management orientation improves the performance of both suppliers and buyers (a win–win situation for the supply chain). Das and Abdel-Malek (2003) stated that the underlying assumption of a good supply chain is that buyers and suppliers are willing to accommodate the

* Corresponding author. Tel.: +886 4 23924505x7805; fax: +886 4 23932065.
E-mail address: htl@mail.ncut.edu.tw (H.-T. Lin).

0377-2217/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2007.03.003

uncertainties and variations in each other's business. They introduced supply chain flexibility as the elasticity in the supply contract negotiated between the buyer and supplier. Calosso et al. (2003) presented a negotiation process and three mixed integer programming (MIP) models in a make-to-order (MTO) environment to deal with interfirm negotiation.

Most researches focus on the viewpoint and decision-making of buyers, but Korpela et al. (2002) presented a frame to focus on those of suppliers. They proposed the analytic hierarchy process and MIP for the manufacturer (supplier) to solve production allocation problems that maximize both strategic importance of customers and preferences of customers but minimize customer-related risks. Choi et al. (2004) proposed an order selection agent that employs a job shop scheduling model to deal with the decision problem of selecting a set of optimal orders to maximize profit under limited production capacity. However, the performance of buyers has not been evaluated or taken into account in their method.

With respect to pricing process, Kingsman and Souza (1997) conducted an empirical research and found that most companies use two-phase activity-based costing methods to estimate cost. An initial price is prepared by cost estimation in the first phase and then adjusted with considerations of the company's characteristics, market conditions and economy in the second phase. The final price formula consists of five elements, which include final estimated cost, risk with cost variances, risk with mistakes by the estimators, mark-up on materials and profit margin. In the case of orders which are considered "very normal"; that is, these orders do not present any significant risk of losses, a pre-specified profit margin for these orders is utilized to set price by some companies. In the accounting literature, some authors, for example, Drury (1992) and Needles et al. (1994) have argued that companies employ a cost-plus method for pricing, where the estimated cost is adjusted according to demand and some market factors. Hinterhuber (2004) proposed a framework using company perspective, customer perspective and competitive perspective to set price. The segmented pricing – by type of customer and distribution channel – is introduced to complement a policy of fixed prices in the research. Shipley and Jobber (2001) suggested the concept of continuous pricing process, that is, the selected elements of the pricing process can be altered by the changes in environment conditions, in marketing strategy and in customer needs.

In this paper, we focus on the viewpoint and decision-making of suppliers. In addition to the production perspective, the customer relationship management (CRM) has also attracted increasing attention from suppliers to analyze information about customer behavior and preference to build close business relationship. Armstrong and Collopy (1996) conducted an empirical research and concluded that companies with a pure competitor-oriented strategy are less profitable and less likely to survive than companies with a strong customer orientation. One of the important facets of CRM is that several studies have shown that not all customers are equally profitable for a company (Storbacka, 2000); and hence, Parvatiyar and Sheth (2001, 2002) pointed out that the company must be selective in tailoring its program and marketing efforts by segmenting and selecting appropriate customers so that a company allocates its resources to those customers it can serve the best in order to create mutual value. According to the customer selectivity idea, we propose a fuzzy approach for evaluating customers (buyers) and use the assessment results to screen orders. By applying the concept of TOPSIS (Hwang and Yoon, 1981), the closeness coefficients of the negative-ideal solution for satisfaction grades of orders and the closeness coefficients of the positive-ideal solution for ranking values of buyers are calculated and used as the adjusting rates in the segmented pricing formula.

This paper is organized as follows. In the next section, we describe the characteristics and considerations of manufacturer for decision-making. In Section 3, we present the framework and methods for evaluating buyers. Section 4 discusses how to select orders and set prices, while an illustrative numerical example is presented in Section 5. The empirical application of the addressed problem is introduced in Section 6. Finally, conclusion is pointed out in Section 7.

2. The characteristics and considerations of manufacturer for decision-making

Possible buyers detect the market demand and then place orders to declare the intention for purchasing the predicted quantity of product. From the standpoint of the manufacturer, the characteristics of the production system include: (i) The product structure belongs to multiple products – low volume type. (ii) It is hard to keep a ready inventory of pre-manufactured or over-manufactured goods, and hence, the supplier's production is a MTO basis. (iii) The demand quantity surpasses the supply quantity, that is, the manufacturer cannot produce all the orders under the limited production capacity of the planning horizon. Briefly speaking, the limited production capacity for manufacturer in MTO environment and consideration of CRM make it imperative to properly select the orders and set prices to attain the pre-specified profit margin.

The cost of producing the orders is divided into cost directly related to the number of units in the orders, such as direct materials, direct labor, power and machine cost, indirect cost such as the cost of production planning, control, inspection, supervision and material handling, and traditional factory overhead. The indirect cost and factory overhead are allocated to each order proportional to the number of produced units, abbreviated by allocated cost. Under the characteristics of the production system, the minor deviation between the produced quantity and purchase quantity of each order can probably increase total production quantity, which will probably reduce the production cost per unit and increase the number of produced orders. As a result, the price competitiveness and customer relationship will be enhanced. To respond to the underlying assumption of a good supply chain (Das and Abdel-Malek, 2003) and construct the mutual relationship between manufacturer and buyers, the manufacturer has negotiated agreements with some of the buyers, abbreviated by agreed group, to accept the minor quantity deviation and then share the associated price reduction to compensate for the deviation.

The decision-maker of manufacturer takes into account the assessment result of each buyer, purchase quantity of each order along with the allowed quantity deviation, production capacity limit and pre-specified profit margin to determine production plan of a specific horizon, e.g., a daily or weekly production plan, with the objective of maximizing total production quantity. The assessment result of each buyer and actual percentage deviation of quantity for each order are further used in the final pricing process. The computation flow of the proposed methods is shown as Fig. 1.

3. Framework and methods for evaluating buyers

In this section, a fuzzy approach to evaluating and classifying buyers is developed. The importance weights of various criteria and the ratings of buyers for subjective and qualitative criteria are considered as linguistic variables. The judgment values of linguistic data are quantified with triangular fuzzy numbers (TFNs). The reason for using TFNs to capture the vagueness of the linguistic assessments is that TFN is intuitively easy to use (Liang and Wang, 1994). The linguistic variable schemes in the rating set (Cochran and Chen, 2005; Liang and Wang, 1994) and weighting set (Liang and Wang, 1994), shown in Tables 1 and 2, respectively, are used in this study to evaluate the ratings of buyers with respect to different criteria and the importance of the criteria, respectively. The extension principle (Zadeh, 1965) is used to aggregate fuzzy numbers in the following weighted rating model.

As the buyer evaluation is a group multiple-criteria decision-making problem, the following sets are used in our description for convenience:

(i) A set of n possible buyers called $B = \{B_1, B_2, \ldots, B_n\}$.
(ii) A set of K criteria called $C = \{C_1, C_2, \ldots, C_K\}$. Let $C = C' \cup C''$, where C' and C'' are the sets of positive and negative criteria, respectively.
(iii) A set of S decision-makers called $D = \{D_1, D_2, \ldots, D_S\}$.

The steps of the proposed approach are as follows.

Step e1: Form a committee of decision-makers who are concerned and familiar with marketing, selling and CRM. Identify and divide the evaluation criteria into positive criteria (the higher the rating, the greater the preference) and negative criteria (the lower the rating, the greater the preference).

Step e2: Obtain the linguistic rating of each buyer for each criterion and linguistic weight of each criterion from decision-makers. The linguistic judgment values for evaluating the buyers with respect to different criteria and the importance weights of the criteria are quantified with TFNs as shown in Tables 1 and 2, respectively. Let TFNs

$$\widetilde{M}_{jks} = (a_{jks}, b_{jks}, c_{jks}), \quad j = 1, 2, \ldots, n, \quad k = 1, 2, \ldots, K, \quad s = 1, 2, \ldots, S$$

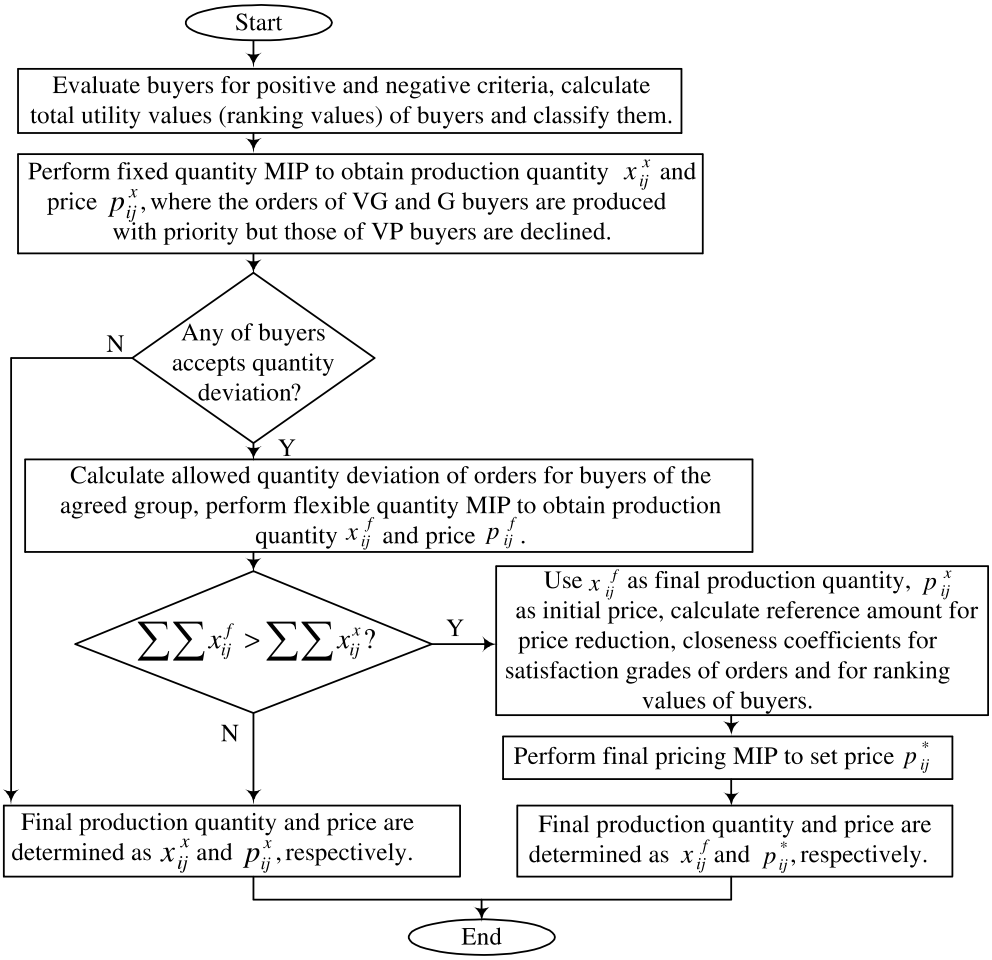

Fig. 1. Flowchart of the proposed methods.

Table 1
Linguistic variables for rating of buyer

Linguistic data (Positive criteria/Negative criteria)	TFN
Very Good/Very High	(0.8, 1, 1)
Good/High	(0.6, 0.8, 1)
Fair/Medium	(0.3, 0.5, 0.7)
Poor/Low	(0, 0.2, 0.4)
Very Poor/Very Low	(0, 0, 0.2)

Table 2
Linguistic variables for importance weight of each criterion

Linguistic data	TFN
Very High	(0.7, 1, 1)
High	(0.5, 0.7, 1)
Medium	(0.2, 0.5, 0.8)
Low	(0, 0.3, 0.5)
Very Low	(0, 0, 0.3)

be the linguistic ratings assigned to B_j for C_k by D_s. Let TFNs

$$W_{ks} = (d_{ks}, h_{ks}, z_{ks}), \quad k = 1, 2, \ldots, K, \quad s = 1, 2, \ldots, S$$

be the linguistic weights given to C_k by D_s.

Step e3: Transform the various criteria scales into comparable scales. In our paper, the set of criteria are divided into positive and negative criteria. With respect to the transformation methods, the normalization method involving linear scale transformation (Chen et al., 2006) cannot be used here since the assessed fuzzy ratings may include zero in this paper, which will probably lead all normalized ratings to zero; the methods of inverse normalized amount (Ghodsypour and O'Brien, 1998) cannot be applied here since it is proposed for crisp number. We propose the following arithmetic operations to transform the assessed ratings for positive and negative criteria into comparable scales:

$$\begin{aligned} M_{jks} &= \widetilde{M}_{jks} \,\Theta\, (a_{\min}, a_{\min}, a_{\min}) \\ &= (a_{jks} - a_{\min}, b_{jks} - a_{\min}, c_{jks} - a_{\min}), \quad C_k \in C', \end{aligned} \tag{1}$$

$$\begin{aligned} M_{jks} &= (c_{\max}, c_{\max}, c_{\max}) \,\Theta\, \widetilde{M}_{jks} \\ &= (c_{\max} - c_{jks}, c_{\max} - b_{jks}, c_{\max} - a_{jks}), \quad C_k \in C'', \end{aligned} \tag{2}$$

where $a_{\min}$ and $c_{\max}$ are the minimal and maximal numbers used in the rating scale, respectively.

Step e4: Aggregate the fuzzy assessments of the decision-makers. According to the idea of Golden Mean, the aggregated fuzzy assessment should not be influenced by the largest and smallest values. Hence, the maximal and minimal linguistic judgment values of the decision-makers for evaluating B_j with respect to C_k and for evaluating the importance weight of C_k are trimmed off. By using the trimmed mean aggregation rule to pool the decision-makers' opinions, the TFNs of B_j for C_k will be

$$M_{jk} = (a_{jk}, b_{jk}, c_{jk}), \quad j = 1, 2, \ldots, n, \quad k = 1, 2, \ldots, K, \tag{3}$$

where

$$a_{jk} = \left(\sum_{s=1}^{S} a_{jks} - \max_s\{a_{jks}\} - \min_s\{a_{jks}\} \right) \Big/ (S-2),$$

$$b_{jk} = \left(\sum_{s=1}^{S} b_{jks} - \max_s\{b_{jks}\} - \min_s\{b_{jks}\} \right) \Big/ (S-2),$$

$$c_{jk} = \left(\sum_{s=1}^{S} c_{jks} - \max_s\{c_{jks}\} - \min_s\{c_{jks}\} \right) \Big/ (S-2).$$

The importance weight of C_k will be

$$W_k = (d_k, h_k, z_k), \quad k = 1, 2, \ldots, K, \tag{4}$$

where

$$d_k = \left(\sum_{s=1}^{S} d_{ks} - \max_s\{d_{ks}\} - \min_s\{d_{ks}\} \right) \Big/ (S-2),$$

$$h_k = \left(\sum_{s=1}^{S} h_{ks} - \max_s\{h_{ks}\} - \min_s\{h_{ks}\} \right) \Big/ (S-2),$$

$$z_k = \left(\sum_{s=1}^{S} z_{ks} - \max_s\{z_{ks}\} - \min_s\{z_{ks}\} \right) \Big/ (S-2).$$

Further, M_{jk} and W_k are aggregated by averaging the products between the criteria ratings and the corresponding importance weights. The fuzzy suitability index, G_j, of B_j can be obtained using the fuzzy sum and fuzzy multiplication as follows:

$$G_j = (1/K) \otimes [(M_{j1} \otimes W_1) \oplus (M_{j2} \otimes W_2) \oplus \cdots \oplus (M_{jK} \otimes W_K)].$$

Here, G_j is not a TFN. For simplicity, we use the approximation formula (Liang and Wang, 1994) to approximate the aggregated TFN

$$G_j \cong \left(\sum_{k=1}^{K} a_{jk} d_k / K, \sum_{k=1}^{K} b_{jk} h_k / K, \sum_{k=1}^{K} c_{jk} z_k / K \right). \tag{5}$$

Step e5: Calculate the total utility values, or ranking values, of the aggregated fuzzy assessment, which can be used to rank and classify the buyers. The total utility function developed by Chen (1985) is used against G_j to obtain a number, $U_T(B_j)$, for each buyer. By using the definitions and formulas of right utility value, $U_R(B_j)$, derived from the associated maximizing set and of left utility value, $U_L(B_j)$, derived from the associated minimizing set (Hsieh and Chen, 1999; Cochran and Chen, 2005), the total utility value $U_T(B_j)$ of G_j are calculated as follows and will be used in the segmented pricing formula to set the final price:

$$U_T(B_j) = [U_R(B_j) + 1 - U_L(B_j)]/2. \tag{6}$$

Step e6: Calculate the utility similarity between each buyer's fuzzy assessment value and each linguistic data in Table 1. Choose the corresponding best linguistic data of each buyer with largest utility similarity to classify the buyers. The classified results will be used in the order selection process. Denote the total utility value of the fuzzy assessment of B_j and of linguistic data L_i by $U_T(B_j)$ and $U_T(L_i)$, respectively. By using the utility similarity method proposed by Hsieh and Chen (1999), the utility similarity between the fuzzy assessments of B_j and L_i, $U_S(B_j, L_i)$, can be calculated as

$$U_S(B_j, L_i) = \frac{\min\{U_T(B_j), U_T(L_i)\}}{\max\{U_T(B_j), U_T(L_i)\}}. \tag{7}$$

4. Methods for order selection and pricing

To adopt the essence of customer (buyer) relationship orientation, the orders placed by the buyers who were classified into VG or G are produced with priority to enhance customer relationship, whereas the orders of those who were classified into VP are declined to avert the potential transaction risk, and the orders of the remaining buyers are determined by the MIP model. As the orders are screened according to the classified results of buyers who placed the orders and the production plan is of short horizon; that is, the update cost information is used in the decision-making process. The production plan can be viewed as one that does not present any significant mark-up on materials and risks with cost variances and mistakes by estimators, which makes the production cost less variable and simpler for estimation. Hence, the pricing model proposed by Kingsman and Souza (1997) can be simplified as the process of making the production cost estimate and then adding some pre-specified profit margin, which will be used in this paper. The initial price of each produced order is set by estimating the production cost and adding a pre-specified profit margin. Then, the initial price is adjusted in accordance with the actual percentage deviation of quantity for the orders and the ranking values of the buyers who placed the orders. The larger the percentage deviation of quantity, the lower the satisfaction grade of the order; and hence, the lower the final price will be. Moreover, the higher the ranking values, the greater the preference of the buyer; and hence, the lower the final price will be. A lower final price means a larger value of price reduction in the pricing formula (12).

A stepwise description of the order selection and pricing process is given in the following.

Step s1: Determine the produced orders along with the production quantity and price per unit by performing the fixed quantity MIP model, MIP^x, where none of the buyers has agreed to accept quantity deviation. For the notations used, see Table 3.

MIP^x is formulated as follows:

Table 3
Notations

Index
Y_i: product type i, $i = 1, 2, \ldots, m$
B_j: possible buyer j, $j = 1, 2, \ldots, n$
O_{ij}: order placed by B_j for purchasing Y_i
Input parameters
q_{ij}: purchase quantity of O_{ij}
t_i: processing time per unit of Y_i
β: hour rates of direct labor, power and machine cost, etc.
r_i: direct material cost per unit of Y_i
T_L: maximal production time in a day
F_C: indirect cost and factory overhead in a day
π: rate of pre-specified profit margin of a production plan
Decision variables
x^x_{ij}: production quantity of O_{ij} in MIP^x
p^x_{ij}: price per unit of O_{ij} in MIP^x
$\lambda_{ij} = 1$, if O_{ij} is produced; otherwise $\lambda_{ij} = 0$

$$\text{Maximize} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} x^x_{ij} \tag{c0}$$

$$\text{Subject to} \quad \lambda_{ij} = 1, \quad B_j \in \{VG, G\}$$
$$= 0, \quad B_j \in \{VP\}$$
$$= (0, 1), \quad \text{otherwise}, \tag{c1}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} t_i x^x_{ij} \leqslant T_L, \tag{c2}$$

$$p^x_{ij} = \left(F_C \middle/ \sum_{i=1}^{m} \sum_{j=1}^{n} x^x_{ij} + r_i + \beta t_i \right) (1 + \pi), \tag{c3}$$

$$x^x_{ij} = \lambda_{ij} q_{ij}. \tag{c4}$$

The objective function (c0) is to maximize total production quantity to reduce the allocated cost per unit of product and increase the number of produced orders as far as possible. Constraint (c1) restricts the orders placed by the buyers who were classified as VG or G to be produced with priority, whereas the orders placed by those who were classified as VP are declined. The actual production time is restricted within capacity limit by Constraint (c2). Constraint (c3) sets the price per unit to satisfy the pre-specified profit margin using the cost-plus method. Constraint (c4) identifies O_{ij} to be produced or declined. The purchase quantity and produced quantity are restricted to integers for convenience in our model.

Step s2: If none of the buyers is of the agreed group, terminate the algorithm. The final production quantity and price are determined as x^x_{ij} and p^x_{ij}, respectively. Otherwise, calculate the allowed quantity deviation of O_{ij} for buyers of the agreed group as $\widehat{\varepsilon} \cdot q_{ij}$, where $\widehat{\varepsilon}$ is the pre-set percentage deviation. For convenience, $\widehat{\varepsilon} \cdot q_{ij}$ is rounded to the smallest integer, which is greater than or equal to it, denoted by E_{ij}. Then, the minimal and maximal production quantities of O_{ij} will be $q^l_{ij} = q_{ij} - \mathrm{E}_{ij}$ and $q^u_{ij} = q_{ij} + \mathrm{E}_{ij}$, respectively. MIP^x is then modified to formulate the flexible quantity MIP model, MIP^f, where some of the buyers are of the agreed group. The notations p^x_{ij} and x^x_{ij} are replaced by p^f_{ij} and x^f_{ij}, respectively, and Constraint (c4) is replaced by $\lambda_{ij} q^l_{ij} \leqslant x^f_{ij} \leqslant \lambda_{ij} q^u_{ij}$ for the orders placed by buyers of the agreed group.

Step s3: Perform MIP^f to determine the produced orders along with the production quantity, x^f_{ij}, and price per unit, p^f_{ij}.

Step s4: If $\sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij}^{x} \geqslant \sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij}^{f}$, terminate the algorithm. Otherwise, calculate the cost reduction per unit as

$$c^{\Delta} = F_C \bigg/ \sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij}^{x} - F_C \bigg/ \sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij}^{f},$$

which is the difference between the allocated cost per unit in $\mathrm{MIP}^{\mathrm{x}}$ and $\mathrm{MIP}^{\mathrm{f}}$. Then, the reference amount for price reduction per unit is calculated as $p^{\Delta} = c^{\Delta}(1+\pi)$.

Step s5: Calculate actual percentage deviation of quantity for the produced order O_{ij} as

$$\varepsilon_{ij} = (|x_{ij}^{f} - q_{ij}| \times 100\%)/q_{ij} \tag{8}$$

and then derive the associated satisfaction grade with respect to quantity as

$$\Omega_{ij} = 1 - \varepsilon_{ij}. \tag{9}$$

Theoretically, the maximum of Ω_{ij} is 1.

Step s6: By applying the concept of TOPSIS, calculate the closeness coefficient of the produced order O_{ij} with respect to Ω_{ij}, denoted by CN_{ij}, and use it as the adjusting rate in pricing process to compensate for the quantity deviation. The larger the ε_{ij}, the lower the Ω_{ij}, and the larger the price reduction will be. The positive-ideal solution and the negative-ideal solution with respect to Ω_{ij} are set as 1 and $\min_{i,j}\{\Omega_{ij}\}$, respectively. We calculate the relative closeness to negative-ideal solution as the closeness coefficient:

$$CN_{ij} = \frac{1-\Omega_{ij}}{1-\min_{i,j}\{\Omega_{ij}\}}. \tag{10}$$

Step s7: Calculate the closeness coefficient of B_j with respect to $U_T(B_j)$, denoted by CP_j, and use it as the adjusting rate in pricing process. The larger the $U_T(B_j)$, the greater the preference of B_j, and the larger the price reduction will be. The positive-ideal solution and the negative-ideal solution with respect to $U_T(B_j)$ are set as 1 and 0, respectively. We calculate the relative closeness to positive-ideal solution as the closeness coefficient:

$$CP_j = \frac{U_T(B_j)-0}{1-0} = U_T(B_j). \tag{11}$$

Step s8: By using x_{ij}^{f} as the final production quantity of O_{ij}, p_{ij}^{x} as initial price per unit of O_{ij} and p^{Δ} as reference amount for price reduction, the final price per unit of O_{ij}, p_{ij}^{*}, is set in accordance with CN_{ij} and CP_j as the following segmented pricing formula:

$$p_{ij}^{*} = p_{ij}^{x} - \rho \cdot p^{\Delta} \cdot (w_1 \cdot CN_{ij} + w_2 \cdot CP_j), \tag{12}$$

where w_1 and w_2 are the importance placed on CN_{ij} and CP_j by the decision-maker, respectively, and ρ is an elastic factor used to adjust the rates of price reduction in equality of scale to obtain the best solution for attaining the pre-specified profit margin as far as possible. The final prices per unit of the produced orders are set by the following model, MIP^{*}:

$$\begin{aligned} \text{Minimize} \quad & Z = G^{-} + G^{+} \\ \text{Subject to} \quad & p_{ij}^{*} = p_{ij}^{x} - \rho \cdot p^{\Delta} \cdot (w_1 \cdot CN_{ij} + w_2 \cdot CP_j) \\ & \sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij}^{*} \cdot x_{ij}^{f} + G^{-} - G^{+} = \left[F_C + \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}^{f} \cdot (r_i + \beta \cdot t_i)\right](1+\pi)G^{-}, \quad G^{+} \geqslant 0. \end{aligned}$$

5. Numerical example

Suppose a manufacturing firm that desires to deal properly with the 17 orders placed by 10 buyers has to propose the one-day production plan. The relevant data of the orders are shown in Table 4. The products

Table 4
Relevant data of the orders

	r_i (\$/unit)	t_i (m/unit)	q_{ij}									
			B_1[a]	B_2	B_3[a]	B_4[a]	B_5[a]	B_6	B_7	B_8	B_9	B_{10}[a]
Y_1	600	3.0	60[a]						40			
Y_2	550	2.0		25			35[a]				20	
Y_3	460	1.5					30[a]					
Y_4	320	4.0	80[a]									
Y_5	150	3.5			50[a]					35	30	
Y_6	200	2.5				20[a]						
Y_7	180	2.6		60					30			
Y_8	350	3.0					55[a]	25				
Y_9	250	1.0				50[a]						40[a]

[a] Indicates that percentage deviation of quantity within about 5% is acceptable.

purchased by the orders are divided into nine types. The production capacity required to produce all the orders is estimated to be 1935.5 minutes, which exceeds the maximal production capacity of 960 minutes each day ($T_L = 960$). Hence, the buyers' evaluation for the order selection and pricing process is conducted. The estimated production cost reveals that $\beta = 8$ dollars/minute and $F_C = 50,000$ dollars/day. π is set as 10% of the production cost. Five out of 10 buyers have agreed to accept the percentage deviation of quantity within about 5%.

Steps e1 and e2: Suppose that a committee of seven decision-makers has been formed to evaluate the buyers. Three positive criteria and two negative criteria are considered to evaluate the buyers. The positive criteria include relationship closeness (C_1), coordination and conflict resolution (C_2) and buyer's position and influence in the industry (C_3). The negative criteria contain likelihood of canceling order without agreement (C_4) and likelihood of risk at an uncollectible account (C_5). The evaluation results are shown in Table 5.

Step e3: As the maximal and minimal numbers used in the rating scale are one and zero, respectively, the assessed ratings for positive and negative criteria are transformed into comparable scales by formulas (1) and (2), respectively, as follows:

$$M_{jks} = \widetilde{M}_{jks} \ \Theta \ (0,0,0) = \widetilde{M}_{jks}, \quad \text{for } C_k = C_1, C_2, C_3.$$
$$M_{jks} = (1,1,1) \ \Theta \ \widetilde{M}_{jks}, \quad \text{for } C_k = C_4, C_5.$$

For example, the linguistic data assigned to B_2 for negative criterion C_4 by D_1 is Low (L), the fuzzy rating is $\widetilde{M}_{241} = (0, 0.2, 0.4)$, which represents the expansion interval of dislike.

Table 5
Ratings of the buyers and importance weights for various criteria

Decision-maker	Buyer/weight	Positive criteria			Negative criteria	
		C_1	C_2	C_3	C_4	C_5
D_1	B_1	VG	G	G	VL	L
	B_2	G	F	VG	L	VL
	⋮	⋮	⋮	⋮	⋮	⋮
	B_{10}	VP	VP	P	VH	VH
	Weight	H	VH	M	VH	M
⋮	⋮	⋮	⋮	⋮	⋮	⋮
D_7	B_1	VG	G	VG	VL	VL
	⋮	⋮	⋮	⋮	⋮	⋮
	B_{10}	VP	P	P	VH	VH
	Weight	M	VH	M	H	M

The transformed rating is $M_{241} = (1, 1, 1)\,\Theta\,(0, 0.2, 0.4) = (0.6, 0.8, 1)$, which represents the expansion interval of preference.

Step e4: The pooled ratings and weights of the decision-makers are calculated by formulas (3) and (4), respectively. Then, the aggregated fuzzy suitability indices are calculated by formula (5) as shown in Table 6.

Steps e5 and e6: By using formula (6) to calculate the total utility values as shown in Table 7, then the utility similarity values are calculated by formula (7) and each buyer is classified according to the corresponding linguistic data, as seen in Table 8.

Step s1: Note that B_1 and B_9 are classified as G, whereas B_{10} is classified as VP in Table 8. Hence, λ_{11}, λ_{41}, λ_{29} and λ_{59} are set as one, and $\lambda_{9,10}$ is set as zero in Constraint (c1). The production information, x^x_{ij} and p^x_{ij}, is depicted in Table 9.

Step s2: For the nine orders placed by the five buyers of the agreed group, calculate q^l_{ij} and q^u_{ij} and then modify the formula of Constraint (c4). For example, the allowed quantity deviation of order O_{25} is $E_{25} = \lceil 5\% \times 35 \rceil = 2$, then $q^l_{25} = 35 - 2 = 33$, $q^u_{25} = 35 + 2 = 37$. The associated formula is modified as $\lambda_{25} \cdot 33 \leqslant x^f_{25} \leqslant \lambda_{25} \cdot 37$.

Steps s3 and s4: The production information, x^f_{ij} and p^f_{ij}, is depicted in Table 9. The increments of total production quantity and number of produced orders attained by $\mathrm{MIP}^{\mathrm{f}}$ are 13 (=373 − 360) and 1 (=10 − 9), respectively. Calculate $c^\Delta = 50{,}000/360 - 50{,}000/373 = 4.8406$ and $p^\Delta = 4.8406 \times 1.10 = 5.3247$.

Steps s5, s6 and s7: Calculate ε_{ij} and Ω_{ij} by formulas (8) and (9), respectively. Then, calculate CN_{ij} using formula (10) with $\min\{\Omega_{ij}\} = 94.29\%$. By using formula (11), CP_j can be drawn from Table 7. The computational results are shown in Table 10, where CP_j is depicted to match the order placed by B_j.

Table 6
Pooled ratings and weights and aggregated fuzzy suitability indices

	C_1	C_2	C_3	C_4	C_5	G_j
B_1	(0.72, 0.92, 1)	(0.54, 0.74, 0.94)	(0.64, 0.84, 1)	(0.68, 0.88, 1)	(0.64, 0.84, 1)	(0.30, 0.62, 0.92)
B_2	(0.58, 0.78, 0.94)	(0.42, 0.62, 0.82)	(0.72, 0.92, 1)	(0.64, 0.84, 1)	(0.68, 0.88, 1)	(0.27, 0.58, 0.89)
B_3	(0.54, 0.74, 0.94)	(0.36, 0.56, 0.76)	(0.06, 0.26, 0.46)	(0.36, 0.56, 0.76)	(0.58, 0.78, 0.94)	(0.18, 0.43, 0.73)
B_4	(0.36, 0.56, 0.76)	(0.54, 0.74, 0.94)	(0.30, 0.50, 0.70)	(0.54, 0.74, 0.94)	(0.36, 0.56, 0.76)	(0.21, 0.47, 0.77)
B_5	(0.30, 0.50, 0.70)	(0.42, 0.62, 0.82)	(0.06, 0.26, 0.46)	(0.42, 0.62, 0.82)	(0.30, 0.50, 0.70)	(0.16, 0.38, 0.66)
B_6	(0.12, 0.32, 0.52)	(0.36, 0.56, 0.76)	(0, 0.16, 0.36)	(0.12, 0.32, 0.52)	(0.06, 0.26, 0.46)	(0.08, 0.26, 0.50)
B_7	(0.18, 0.38, 0.58)	(0, 0.08, 0.28)	(0.06, 0.22, 0.42)	(0.06, 0.22, 0.42)	(0, 0.12, 0.32)	(0.03, 0.15, 0.38)
B_8	(0.30, 0.50, 0.70)	(0.24, 0.44, 0.64)	(0.58, 0.78, 0.94)	(0, 0.16, 0.36)	(0.12, 0.32, 0.52)	(0.10, 0.31, 0.59)
B_9	(0.64, 0.84, 1.00)	(0.68, 0.88, 1)	(0.72, 0.92, 1)	(0.72, 0.92, 1)	(0.30, 0.50, 0.70)	(0.30, 0.61, 0.89)
B_{10}	(0, 0, 0.20)	(0, 0.04, 0.24)	(0, 0.16, 0.36)	(0, 0.04, 0.24)	(0.06, 0.18, 0.38)	(0.00, 0.05, 0.26)
W_k	(0.54, 0.76, 1.00)	(0.66, 0.94, 1)	(0.26, 0.54, 0.84)	(0.62, 0.88, 1)	(0.26, 0.54, 0.84)	

Table 7
Total utility values of buyers and of linguistic data

Buyer	$U_T(B_j)$	Linguistic data	$U_T(L_i)$
B_1	0.6221	Very Good	0.9167
B_2	0.5931	Good	0.7500
B_3	0.4794	Fair	0.5000
B_4	0.5120	Poor	0.2500
B_5	0.4410	Very Poor	0.0833
B_6	0.3276		
B_7	0.2334		
B_8	0.3768		
B_9	0.6147		
B_{10}	0.1387		

Step s8: Suppose decision-makers set $w_1 = 2$ and $w_2 = 1$. By using MIP*, the final price per unit along with the final price reduction, calculated as $\rho \times 5.3247 \times (2 \times CN_{ij} + CP_j)$, is obtained with $\rho = 0.5820$, as shown in Table 10. The reason for O_{25} sharing the maximal

Table 8
Utility similarity values and the classified results of each buyer

	VG	G	F	P	VP	Classified results
B_1	0.6786	*0.8294*	0.8038	0.4019	0.1340	G
B_2	0.6470	0.7908	*0.8431*	0.4215	0.1405	F
B_3	0.5230	0.6392	*0.9588*	0.5215	0.1738	F
B_4	0.5585	0.6826	*0.9766*	0.4883	0.1628	F
B_5	0.4811	0.5880	*0.8819*	0.5669	0.1890	F
B_6	0.3574	0.4368	0.6552	*0.7631*	0.2544	P
B_7	0.2546	0.3112	0.4668	*0.9336*	0.3570	P
B_8	0.4111	0.5024	*0.7536*	0.6635	0.2212	F
B_9	0.6706	*0.8196*	0.8134	0.4067	0.1356	G
B_{10}	0.1513	0.1849	0.2773	0.5547	*0.6010*	VP

Table 9
Production information

Order	q_{ij}	MIP^x		MIP^f	
		x_{ij}^x	p_{ij}^x	x_{ij}^f	p_{ij}^f
O_{11}	60	60	839.1778	57	833.8531
O_{17}	40	0	–	0	–
O_{22}	25	25	775.3778	25	770.0531
O_{25}	35	35	775.3778	33	770.0531
O_{29}	20	20	775.3778	20	770.0531
O_{35}	30	30	671.9778	31	666.6531
O_{41}	80	80	539.9778	76	534.6531
O_{53}	50	0	–	0	–
O_{58}	35	0	–	0	–
O_{59}	30	30	348.5778	30	343.2531
O_{64}	20	0	394.7778	19	389.4531
O_{72}	60	0	–	0	–
O_{77}	30	30	373.6578	30	368.3331
O_{85}	55	0	–	0	–
O_{86}	25	0	–	0	–
O_{94}	50	50	436.5778	52	431.2531
$O_{9,10}$	40	0	–	0	–
Total		360	–	373	–

Table 10
Computational results of pricing process

Produced order	ε_{ij} (%)	Ω_{ij} (%)	CN_{ij}	CP_j	p_{ij}^*	Final price reduction
O_{11}	5	95	0.8750	0.6221	831.8261	7.3517
O_{22}	0	100	0.0000	0.5931	773.5397	1.8381
O_{25}	5.71	94.29	1.0000	0.4410	767.8126	7.5652
O_{29}	0	100	0.0000	0.6147	773.4727	1.9051
O_{35}	3.33	96.67	0.5833	0.4410	666.9955	4.9823
O_{41}	5	95	0.8750	0.6221	532.6261	7.3517
O_{59}	0	100	0.0000	0.6147	346.6727	1.9051
O_{64}	5	95	0.8750	0.5120	387.7674	7.0104
O_{77}	0	100	0.0000	0.2334	372.9344	0.7234
O_{94}	4	96	0.7000	0.5120	430.6521	5.9257

price reduction is that it takes the maximal percentage deviation of quantity and its ranking value is passable, whereas O_{77} sharing the minimal price reduction is because it takes no percentage deviation of quantity and its ranking value is not good enough. The cost of production plan along with the associated revenue is 200,060 and 220,066, where the rate of pre-specified profit margin, 10%, is attained.

6. The empirical application

Examples of industries where this problem arises fall into small and medium firms who manufacture and sell packed lunch/dinner/provisions, denoted by packed food, in Taiwan. The capacity of a firm is limited by the work force and facility. For convenience, it is regular for most of the conferees, participants, workers, officers, and students, etc., to consume packed food in Taiwan. The purchasers are concerned with flavor and price. Especially in the government offices and public schools, the unit price is restricted to be less than a certain value by the accounting and audit regulations. For some of the seminars, symposiums, workshops, student subsidiary courses or extracurricular activities, etc., the number of participants or members relevant to working group are unable to be determined exactly; and hence, a minor quantity deviation is accepted sometimes in practice. For the firm with excellent cookery and using good material, the received orders from local buyers or organizations in the vicinity always surpass the supply quantity.

As there are more than ten kinds of packed food, in general, providing buyers to pick and choose and with the considerations of hygiene and safety; hence, the method of keeping a ready inventory of pre-manufactured or over-manufactured goods is forbid, which led the supplier's production to a MTO basis. As the demand and delivery date is specified by the orders and cannot be shifted to other days, the manufacturer should conduct order selection to propose a daily production plan. As there is a large secondary choice of suppliers for the buyers, it is common and ordinary for the buyers whose orders are declined to purchase elsewhere.

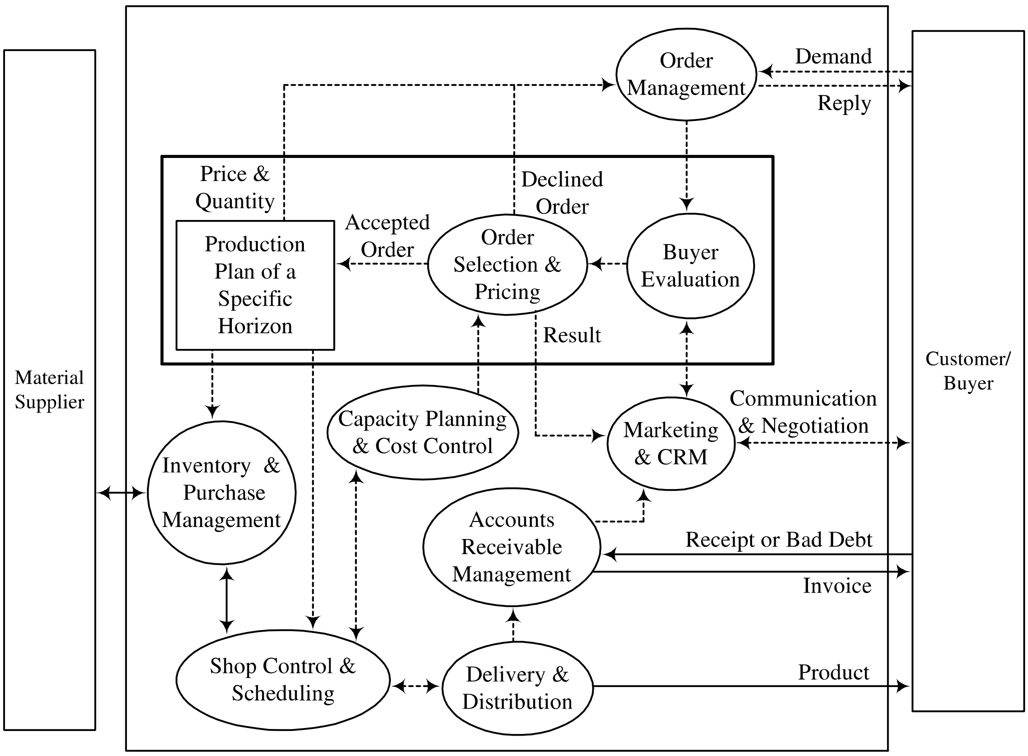

Fig. 2. Linkage and communication between the proposed scheme and related core business processes.

Recently, organizations have invested considerable resources to implement manufacturing and information technologies, such as JIT, QR, MRP II and ERP systems, to integrate and coordinate distinct functions within a firm. However, as Chen and Chen (2005) pointed out, many production decision-making processes do not take marketing's dynamic nature into account, and hence, the dynamic aspects of pricing and other marketing related variables tend to be ignored in the computerized manufacturing planning systems. To reform the drawbacks, Hu and Munson (2002) presented an incremental quantity discount model to rectify the unrealistic assumption of fixed prices for lot-sizing planning. Chen and Chen (2005) developed the coordinated and decentralized decision-making policies that solve the production lot-size/scheduling problem taking into account the dynamic aspects of customer's demand as well as the restriction of finite capacity in a plant. Anjos et al. (2005) opined that although a fixed pricing policy is an attractive proposition, it is nonetheless important to update current pricing in response to fluctuations in demand, and possibly also to changes in the price that customers are prepared to pay. They presented a continuous pricing methodology which is particularly well suited for application in the context of an increasing role for the Internet as a means to market goods and services. Most small and medium firms in Taiwan lack appropriate resources in funds, personnel and a cost-effective management technology to respond to demand advantageously and quickly. As the proposed scheme can be solved easily with Excel and LINGO package, it can be used to link and communicate with the related core business processes to construct a small-sized ERP framework, which is depicted in Fig. 2.

7. Conclusion

In this paper, we proposed the methods for order selection and pricing process of manufacturer (supplier) with MTO basis and limited production capacity. By quoting the concepts of TFNs and linguistic variables, a fuzzy set approach for evaluating buyers with respect to positive and negative criteria is conducted. According to the classified results of buyers, the orders are produced with priority, declined, or determined by the MIP model, which realizes the essence of customer (buyer) relationship orientation.

This paper introduced the concept of flexible quantity, where the supplier has negotiated agreements with some of the buyers to accept the minor quantity deviation and then share the associated price reduction to compensate for the deviation. Under the characteristics of MTO and limited production capacity, the flexible quantity model can probably increase the total production quantity, thus reducing the allocated cost per unit. A segmented pricing formula is proposed to set the final price in accordance with the actual percentage deviation of quantity for the orders and the ranking values of the buyers to cope with the dynamic and long-term relationships between supplier and buyers.

In order to set competitive price, the manufacturers should dedicate their efforts to reduce cost by improving and reengineering the manufacturing processes/methods, among which, reduce the allocated cost per unit by increasing production quantity is a managerial topic. Moreover, the manufacturers should take into account the marketing strategy, economic trend, customer need and so on to adjust the pre-specified profit margin.

The proposed scheme can deal with the order selection and pricing process more objectively with customer relationship orientation. It can be used to link and communicate with the related core business processes.

Acknowledgements

The authors thank the reviewers whose comments added significantly to the paper's clarity.

References

Anjos, M.F., Cheng, R.C.H., Currie, C.S.M., 2005. Optimal pricing policies for perishable products. European Journal of Operational Research 166, 246–254.

Armstrong, J.S., Collopy, F., 1996. Competitor orientation – effects of objectives and information on managerial decisions and profitability. Journal of Marketing Research 33, 188–199.

Calosso, T., Cantamessa, M., Vu, D., Villa, A., 2003. Production planning and order acceptance in business to business electronic commerce. International Journal of Production Economics 85, 233–249.

Chen, S.H., 1985. Ranking fuzzy numbers with maximizing set and minimizing set. Fuzzy Sets and systems 17 (2), 113–129.

Chen, J.M., Chen, L.T., 2005. Pricing and production lot-size/scheduling with finite capacity for a deteriorating item over a finite horizon. Computers & Operations Research 32, 2801–2819.
Chen, C.T., Lin, C.T., Huang, S.F., 2006. A fuzzy approach for supplier evaluation and selection in supply chain management. International Journal of Production Economics 102, 289–301.
Choi, H.R., Kim, H.S., Park, B.J., Park, Y.J., Whinston, A.B., 2004. An agent for selecting optimal order set in EC marketplace. Decision Support Systems 36, 371–383.
Cochran, J.K., Chen, H.N., 2005. Fuzzy multi-criteria selection of object-oriented simulation software for production system analysis. Computers and Operations Research 32, 153–168.
Das, S.K., Abdel-Malek, L., 2003. Modeling the flexibility of order quantities and lead-times in supply chains. International Journal of Production Economics 85, 171–181.
Drury, C., 1992. A survey of management accounting practices in UK manufacturing companies. ACCA Research Occasional Paper, Chartered Association of Certified Accountants.
Ghodsypour, S.H., O'Brien, C., 1998. A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. International Journal of Production Economics 56–57, 199–212.
Hinterhuber, A., 2004. Towards value-based pricing – An integrative framework for decision making. Industrial Marketing Management 33, 765–778.
Hsieh, C.H., Chen, S.H., 1999. A model and algorithm of fuzzy product positioning. Information Sciences 121, 61–82.
Hu, J., Munson, C.L., 2002. Dynamic demand lot-sizing rules for incremental quantity discounts. Journal of the Operational Research Society 53, 855–863.
Hwang, C., Yoon, K., 1981. Multiple Attribute Decision Making: Methods and Application. Springer, New York.
Kingsman, B.G., Souza, A.A., 1997. A knowledge-based decision support system for cost estimation and pricing decisions in versatile manufacturing companies. International Journal of Production Economics 53, 119–139.
Korpela, J., Kylaheiko, K., Lehmusvaara, A., Tuominen, M., 2002. An analytic approach to production capacity allocation and supply chain design. International Journal of Production Economics 78, 187–195.
Liang, G.S., Wang, M.J., 1994. Personnel selection using fuzzy MCDM algorithm. European Journal of Operational Research 78, 22–33.
Needles, B.E., Anderson, H.R., Caldwell, J.C., 1994. Financial and Managerial Accounting. Houghton Mifflin Company, USA.
Parvatiyar, A., Sheth, J.N., 2001. Customer relationship management: Emerging practice, process, and discipline. Journal of Economic and Social Research 3 (2), 1–34, 2002 (preliminary issue).
Shin, H., Collier, D.A., Wilson, D.D., 2000. Supply management orientation and supplier/buyer performance. Journal of Operations Management 18 (3), 317–333.
Shipley, D., Jobber, D., 2001. Integrative pricing via the pricing wheel. Industrial Marketing Management 30, 301–314.
Storbacka, K., 2000. Customer profitability: Analysis and design issues. In: Sheth, J.N., Parvatiyar, A. (Eds.), Handbook of Relationship Marketing. Sage Publications, Thousand Oaks, CA, pp. 565–586.
Zadeh, L.A., 1965. Fuzzy sets. Information and Control 8, 338–353.