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Selecting an optimal mixed products using grey relationship model

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ABSTRACT

This paper presents an integrated supplier selection and inventory management using grey relationship model (GRM) as well as multi-objective decision making process. The proposed model of this paper first ranks different suppliers based on GRM technique and then determines the optimum level of inventory by considering different objectives. To show the implementation of the proposed model, we use some benchmark data presented by Talluri and Baker [Talluri, S., & Baker, R. C. (2002). A multi-phase mathematical programming approach for effective supply chain design. European Journal of Operational Research, 141(3), 544-558.]. The preliminary results indicate that the proposed model of this paper is capable of handling different criteria for supplier selection.

1. Introduction

Initial buying decisions such as make-or-buy decisions and supplier selection are considered as the most important strategies for companies. The nature of these decisions usually maintains a complex framework and managerial decisions play essential role on making appropriate long-term decisions. Nevertheless, the application of outranking techniques in purchasing decisions has not been reviewed, extensively (Weber et al., 1991; Wray et al., 1994). De Boer et al. (1998) demonstrated through means of a supplier selection instance, that an outranking approach could be very well suited as a decision-making tool for initial purchasing decisions. De Boer et al. (2001) presented a comprehensive review of decision methods reported in the literature for supporting the supplier selection process. They positioned the contributions in a framework that takes the diversity of procurement situations based on complexity and relative importance and covered all phases in the supplier selection process.

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Saen (2008) argued that supplier-selection models used be ranked solely based on cardinal data with less emphasis on ordinal data. However, with the widespread use of manufacturing philosophies such as just-in-time (JIT), emphasis had shifted to the concurrent consideration of cardinal and ordinal data in the supplier-selection process. They explained that the application of data envelopment analysis (DEA) for supplier-selection problems rely on total flexibility of the weights. They proposed a pair of assurance region-imprecise data envelopment analysis (AR-IDEA) technique for choosing the best suppliers in the presence of both weight restrictions and imprecise data. Saen (2009) presented a decision model for ranking suppliers in the presence of cardinal and ordinal data, weight restrictions, and nondiscretionary factors.

Ghodsypour and O’brien (2001) presented a mixed integer non-linear programming model to handle the multiple sourcing problem, which takes into account the total cost of logistics, including net price, storage, transportation and ordering costs. Kahraman et al. (2003) implemented fuzzy analytic hierarchy process (AHP) to choose the best supplier company providing the most satisfaction for the criteria detected. According to Min (1994), international supplier selection is one of the most complicated and risky owing to a variety of uncontrollable and unpredictable factors influencing the decision. These factors may incorporate political situations, tariff barriers, cultural and communication barriers, trade regulations and agreements, currency exchange rates, cultural differences, ethical standards, quality standards and so forth (Pan, 1989; Rosenthal et al., 1995).

Noorul Haq and Kannan (2006) designed of an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain environment. Their work dealt with the development of an integrated supplier selection and multi-echelon distribution inventory model (MEDIM) for the original equipment manufacturing firm in a built-to-order supply chain environment based on fuzzy analytical hierarchy process (FAHP) and a genetic algorithm. The primary objective of their work was to design the integrated qualitative decision-making of the supplier selection model using FAHP with that of the quantitative mathematical model for the distribution inventory supply chain using a metaheuristics method.

Pi and Low (2006) proposed a method for supplier evaluation and selection via Taguchi loss functions and an AHP. Shin et al. (2000) investigated the effect of a supply management orientation (SMO) on the suppliers' operational performance and buyers' competitive priorities including cost, quality, delivery, flexibility. Talluri and Baker (2002) presented a multi-phase mathematical programming approach for effective supply chain design. Wang et al. (2004) integrated product characteristics to supply chain strategy and adopted supply chain operations reference (SCOR) model level I performance metrics as the decision criteria. They also developed an integrated analytic hierarchy process (AHP) and preemptive goal programming (PGP) based multi-criteria decision-making methodology to consider both qualitative and quantitative factors in supplier selection. Wangphanich et al. (2010) presented an analysis of the bullwhip effect in multi-product, multi-stage supply chain systems–a simulation approach. Wu (2002) presented a comparative study of using grey relational analysis in multiple attribute decision making problems.

2. The proposed model

2.1. Grey Model

The proposed model of this paper considers six major factors for supplier selection including purchasing expenditure, quality of product, on time delivery, customer services, partnership and financial strength. The first factor, purchasing expenditure consists of three factors including product price, transportation and ordering cost. The second factor, quality consists of three factors, which are the ratio of waste materials, returned items and quality of system. The third item, on time delivery, includes two items of time delay and quantity shortage. Customer services include three options of being responsive, time of response and the way of meeting customers’ requests. Partnership is another important factor including partnership in plans or in contracts. Finally, financial strength is the last item, which includes three sub-item including working capital, revenue and cash flow. The proposed model of this paper uses grey relation model (GRM) originally developed by Deng (1989). The method consists of the following steps,

Step 1: In this step, we compute total value of each alternative and normalize them based. Let *m* and *n* be alternative and attribute, therefore, we have,

$$X_0=(x_{01},x_{02},\ldots,x_{0n}) \tag{1}$$
$$X_i=(x_{i1},x_{12},\ldots,x_{in}) \tag{2}$$

Let y_i be the value of each alternative, therefore we have,

$$Yi=(y_{i1},y_{i2},\ldots,y_{in}), \tag{3}$$

where y_{ij} is the value of attribute *i* on alternative *j*. The consistency ratio of $x_{ij}=(x_{i1},x_{i2},\ldots,x_{in})$ is calculated based on the following,

$$X_i(j)^*=\frac{x_i(j)-min\ x_i(j)}{max\ x_i(j)-min\ x_i(j)} \tag{4}$$

$$X_i(j)^*=\frac{max\ x_i(j)-x_i(j)}{max\ x_i(j)-min\ x_i(j)} \tag{5}$$

$$X_{ij}=\frac{|x_i(j)-x_{0b}(j)|}{max\ x_i(j)-x_{0b}(j)} \tag{6}$$

Step 2. Define the reference value as follows,

$$X_0=(x_{01},x_{02},\ldots,x_{0n})=(1,1,\ldots,1) \tag{7}$$

Step 3. Calculate confidence interval

$$Y(x_{0j},x_{ij})=\frac{\Delta_{min+\xi}\Delta_{max}}{\Delta_{ij+\xi}\Delta_{max}} \tag{8}$$

where Δ_{ij} is calculated as follows,

$$\Delta_{ij}=|x_{0j}-x_{ij}|. \tag{9}$$

In addition, Δ_{min} and Δ_{max} are calculated as follows,

$$\Delta_{min}=min\{\Delta_{ij},i=1,\ldots,m,j=1,\ldots,n\} \tag{10}$$
$$\Delta_{max}=max\{\Delta_{ij},i=1,..,m,j=1,\ldots,n\} \tag{11}$$

Step 4. Calculate grey value

$$\Gamma=\sum_{j=1}^{n} w_j Y(X_{0j},X_{ij})\times(X_{0j},X_{ij}) \tag{12}$$

The weights used in Eq. (12) are determined using analytical hierarchy process (AHP).

2.2. Supply chain model

In this section, we present a multi-objective decision making where three objectives of ordering cost, delivery time and quality are considered.

2.2.1 Ordering cost

$$\min z_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij}, \tag{13}$$

where c_{ij} is transportation cost for delivering j^{th} item from resource i and it consists of three components of purchasing cost (p_{ij}), transportation expenditure (F_{ij}) and ordering cost (O_{ij}), respectively.

2.2.2. Cost of quality

Let d_{ij} be the sum of the number of returned and waste materials for delivering j^{th} item from resource i. Therefore, we have,

$$\min z_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} x_{ij}, \tag{14}$$

2.2.3. On time delivery

Let t_{ij} be the delivery time of j^{th} item from resource i. Therefore, we have,

$$\min z_3 = \sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij} x_{ij}, \tag{15}$$

2.2.4. Budget constraint

The next constraint is associated with the amount of budget for ordering goods as follows,

$$\sum_{i=1}^{m} p_{ij} x_{ij} \le \beta_j, j = 1, \cdots, n \tag{16}$$

2.2.5. Demand constraint

The next constraint is associated with demand (D_j) for ordering goods as follows,

$$\sum_{i=1}^{m} x_{ij} \le D_j, j = 1, \cdots, n \tag{17}$$

2.2.6. Supply constraint

Supply constraints are stated as follows,

$$\sum_{i=1}^{m} x_{ij} \ge S_j, j = 1, \cdots, n \tag{18}$$

2.2.7. Waste constraint

Let Q_{ij} be the amount of waste reported for j^{th} item from resource i. In addition, let α_i be the amount of allowable waste purchased from each supplier. Therefore, we have,

$$\sum_{i=1}^{m} Q_{ij} x_{ij} \ge \alpha_i D_j, j = 1, \cdots, n \tag{19}$$

2.2.8. Inventory constraint

Let A_j and L_j be the average amount of inventory and lead time for product j item. In addition, let I_i^0 be the amount of inventory at the beginning of each period. Therefore, we have,

$$\sum_{i=1}^{m} x_{ij} \geq L_i A_j - I_i^0, \; j = 1, \cdots, n \tag{20}$$

2.3. A mixed integer programming approach

The proposed mixed integer programming approach uses grey technique to choose appropriate suppliers. Let y_i be an integer variable, which is one when supplier j is selected and zero, otherwise. Therefore, we propose a new objective function as follows,

$$\max z_0 = \sum_{i=1}^{m}\sum_{j=1}^{n} w_j y_i, \tag{21}$$

where w_j is the relative weight of supplier j obtained using grey technique. Therefore, the first objective function specified in Eq. (13) is stated as follows,

$$\min z_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} (p_{ij} x_{ij} + F_{ij} y_i + O_{ij} y_i) \tag{22}$$

In addition, the supply constraint is also defined as follows,

$$\sum_{i=1}^{m} x_{ij} \geq S_{ij} y_i, \; j = 1, \cdots, n \tag{18}$$

The other constrains hold for the new mixed integer programming problem as stated earlier.

3. The case study

The proposed model of this paper uses the data from the literature (Talluri & Baker, 2002). Table 1 shows the input data where D represents the distance, SR indicates the supplier credit, TC specifies the total cost, NB is the total number of orders received from the supplier with no error, NOT represents the total number of on time delivery and SV specifies the number of parts.

Table 1
The input number for the case study of the proposed model

	TC	SR	D	NOT	NB	SV
S1	253	5	249	187	90	2
S2	268	10	643	194	130	13
S3	259	3	714	220	200	3
S4	180	6	1809	160	100	3
S5	257	4	238	204	173	24
S6	248	2	241	192	170	28
S7	272	8	1404	194	60	1
S8	330	11	984	195	145	24
S9	327	9	641	200	150	11
S10	330	7	588	171	90	53
S11	321	16	241	174	100	10
S12	329	14	567	209	200	7
S13	281	15	567	165	163	19
S14	309	13	967	199	170	12
S15	291	12	635	188	185	33
S16	334	17	795	168	85	2
S17	249	1	689	177	130	34
S18	216	18	913	167	160	9
Index	180	18	238	220	200	53

Note that the last row of Table 1 represents the min/max of the numbers from each column, which is used in Step 1 of the proposed model. Therefore, we have X_0=(180,18,238,220,200,53). Table 2 demonstrates details of the implementation of the second step of GRM method as follows,

Table 2
The results of the second step of the proposed GRM method

	TC(-)	SR(+)	D(-)	NOT(+)	NB(+)	SV(+)
s1	0.525974	0.235294	0.992998	0.45	0.214286	0.019231
s2	0.428571	0.529412	0.742202	0.566667	0.5	0.230769
s3	0.487013	0.117647	0.697008	1	1	0.038462
s4	1	0.294118	0	0	0.285714	0.038462
s5	0.5	0.176471	1	0.733333	0.807143	0.442308
s6	0.558442	0.058824	0.99809	0.533333	0.785714	0.519231
s7	0.402597	0.411765	0.257798	0.566667	0	0
s8	0.025974	0.588235	0.525143	0.583333	0.607143	0.442308
s9	0.045455	0.470588	0.743475	0.666667	0.642857	0.192308
s10	0.025974	0.352941	0.777212	0.183333	0.214286	1
s11	0.084416	0.882353	0.99809	0.233333	0.285714	0.173077
s12	0.032468	0.764706	0.790579	0.816667	1	0.115385
s13	0.344156	0.823529	0.790579	0.083333	0.735714	0.346154
s14	0.162338	0.705882	0.535964	0.65	0.785714	0.211538
s15	0.279221	0.647059	0.747295	0.466667	0.892857	0.615385
s16	0	0.941176	0.645449	0.133333	0.178571	0.019231
s17	0.551948	0	0.712922	0.283333	0.5	0.634615
s18	0.766234	1	0.570337	0.116667	0.714286	0.153846

In addition, Table 3 demonstrates the results of the implementation of the third step of the proposed model.

Table 3
The summary of the results of Table 3

	TC(-)	SR(+)	D(-)	NOT(+)	NB(+)	SV(+)
s1	0.474026	0.764706	0.007002	0.55	0.785714	0.980769
s2	0.571429	0.470588	0.257798	0.433333	0.5	0.769231
s3	0.512987	0.882353	0.302992	0	0	0.961538
s4	0	0.705882	1	1	0.714286	0.961538
s5	0.5	0.823529	0	0.266667	0.192857	0.557692
s6	0.441558	0.941176	0.00191	0.466667	0.214286	0.480769
s7	0.597403	0.588235	0.742202	0.433333	1	1
s8	0.974026	0.411765	0.474857	0.416667	0.392857	0.557692
s9	0.954545	0.529412	0.256525	0.333333	0.357143	0.807692
s10	0.974026	0.647059	0.222788	0.816667	0.785714	0
s11	0.915584	0.117647	0.00191	0.766667	0.714286	0.826923
s12	0.967532	0.235294	0.209421	0.183333	0	0.884615
s13	0.655844	0.176471	0.209421	0.916667	0.264286	0.653846
s14	0.837662	0.294118	0.464036	0.35	0.214286	0.788462
s15	0.720779	0.352941	0.252705	0.533333	0.107143	0.384615
s16	1	0.058824	0.354551	0.866667	0.821429	0.980769
s17	0.448052	1	0.287078	0.716667	0.5	0.365385
s18	0.233766	0	0.429663	0.883333	0.285714	0.846154

Finally, Table 4 demonstrates the results of the implementation of grey method as follows,

Table 4
The priority of different suppliers

	TC(-)	SR(+)	D(-)	NOT(+)	NB(+)	SV(+)	Priority
s1	0.678414	0.566667	0.993047	0.645161	0.56	0.504854	0.658024
s2	0.636364	0.68	0.79504	0.697674	0.666667	0.565217	0.673494
s3	0.660944	0.53125	0.767465	1	1	0.509804	0.74491
s4	1	0.586207	0.5	0.5	0.583333	0.509804	0.613224
s5	0.666667	0.548387	1	0.789474	0.838323	0.641975	0.747471
s6	0.693694	0.515152	0.998094	0.681818	0.823529	0.675325	0.731269
s7	0.626016	0.62963	0.573986	0.697674	0.5	0.5	0.587884
s8	0.506579	0.708333	0.678032	0.705882	0.717949	0.641975	0.659792
s9	0.511628	0.653846	0.795846	0.75	0.736842	0.553191	0.666892
s10	0.506579	0.607143	0.817803	0.550459	0.56	1	0.673664
s11	0.522034	0.894737	0.998094	0.566038	0.583333	0.547368	0.685267
s12	0.508251	0.809524	0.826842	0.84507	1	0.530612	0.753383
s13	0.603922	0.85	0.826842	0.521739	0.79096	0.604651	0.699686
s14	0.54417	0.772727	0.683043	0.740741	0.823529	0.55914	0.687225
s15	0.581132	0.73913	0.798272	0.652174	0.903226	0.722222	0.732693
s16	0.5	0.944444	0.738252	0.535714	0.54902	0.504854	0.628714
s17	0.690583	0.5	0.776954	0.582524	0.666667	0.732394	0.658187
s18	0.810526	1	0.699466	0.530973	0.777778	0.541667	0.726735
wj	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667	

In summary, the order of suppliers can be specified as follows,

S12>S5>S3>S15>S6>S18>S13>S14>S11>S10>S2>S9>S8>S17>S1>S16>S4>S7.

4. Conclusion

In this paper, we have presented a new mixed integer multi-objective programming technique to determine the level of order materials from various suppliers. The proposed model of this paper uses grey method to rank different suppliers in terms of various attributes and using the proposed mix integer programming technique it is possible to determine the desirable level of inventory ordered from each supplier. The proposed model of this paper can be extended for problems that are more realistic. In addition, for large-scale problems, it is possible to use multi-objective metaheuristics methods to generate Pareto-optimal solutions and we leave it for interested researchers as future studies.

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