Water Cycle and Artificial Bee Colony Based Algorithms for Optimal Order Allocation Problem with Mixed Quantity Discount Scheme

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Abstract. Supplier selection is one of the most important activities in purchasing management. Once the suppliers are determined, the proper allocation of the order among the suppliers can greatly help the company to reduce the raw material and production costs. In this paper, the order allocation with quantity discount of a single product is considered. The product can be offered with either an all unit discount model or an incremental discount one. Since the problem is NP-hard, three metaheuristics are applied to solve the problem. The metaheuristics are water cycle algorithm, artificial bee colony algorithm and hybrid water cycle-artificial bee colony algorithm. The results obtained from these algorithms are then compared.

Keywords: Water cycle algorithm, Hybrid water cycle and artificial bee colony algorithm, Order allocation problem, Quantity discount.

1 Introduction

A large portion of the product cost in many manufacturing industries is from the cost of raw materials. In some cases, this cost can be accounted for 70% of the product cost, and may go up to 80% in hi-tech firms. It is thus important for the management to recognize the importance of reducing the cost of material procurement to improve the competitiveness of the firms [1-4].

Basically, there are two types of the supplier selection problem: single sourcing where only one supplier can satisfy all buyer's requirements and multiple sourcing where one supplier cannot satisfy all buyer's requirements due to supplier capacity limitation or sometimes to reduce the risk of supply interuption [4]. The situation becomes more complicated when the suppliers motivate their customers to buy more by offering quantity discount. Two popular quantity discount schemes are called all unit discount and incremental discount. Moreover, some studies in this area may be

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interested in cases with pure all unit discount or pure incremental discount. It is possible in an actual setting that different suppliers may offer different discount models (or a mixed discount scheme). In addition, the suppliers may impose a fine if the buyer purchases less than a prespecified amount in exchange for preferably allotting their capacities for the buyer as explored in Chotyakul et al. (2012).

The supplier selection and quantity allocation decision problem under quantity discount environment is an NP-Hard problem [5]. In previous studies, there are several methods used in solving this problem, and may be classified into three groups: (i) exact methods, (ii) heuristics, and (iii) metaheuristics algorithm such as genetic algorithm (GA) [1] and artificial bee colony (ABC) [7]. The first two methods sometimes require a long computational time to find the optimal solution, whereas metaheuristics may obtain near optimal solutions within a reasonable amount of time. Thus, this paper adopts metaheuristics to solve the problem [5,6].

Recently, a new algorithm called water cycle algorithm (WCA) was developed and tested on truss structure design problems. Their results showed that the WCA performed better than standard GA and particle swarm optimization [8,9]. Inspired by their success, we apply the WCA on an order allocation problem with mixed quantity discount. We also develop a hybrid water cycle-artificial bee colony algorithm (HWAA) and test it on the same problem. These results are then compared with those from ABC.

This paper is organized as follows. Section 2 presents a mathematical model of the order allocation problem with a mixed quantity discount scheme. Section 3 briefly describes the WCA and HWAA. The numerical experiment is explained in Section 4. Section 5 discusses the results. Finally, Section 6 concludes the paper.

2 Mathematical Model

2.1 Assumptions and Notation

Assumptions:

- The demand for the product is known and may be fulfilled by the suppliers.
- Each supplier offers one of the following quantity discount schemes: all unit discount or incremental discount.
- Each supplier imposes a minimal monetary value (MMV) constraint.
- The supply capacity of each supplier is finite.
- The buyer purchases to fulfill the demand of merely one period.
- The product must be purchased in whole units.

Notation:

j Index of suppliers ; $j = 1, 2, 3,\ldots,S$
k Index of discount intervals ; $k = 1, 2, 3,\ldots,K_j$
S Total number of suppliers
s_1 Number of suppliers who offer all unit discount scheme

s_2 Number of suppliers who offer incremental discount scheme
K_j Total number of discount intervals of supplier j
x_j Purchased quantity from supplier j who offers all unit discount
y_j Purchased quantity from supplier j who offers incremental discount
$P_k(x_j)$ Cost function of the purchased quantity from supplier j who offers all unit discount in discount interval k
$P_k(y_j)$ Cost function of the purchased quantity from supplier j who offers incremental discount in discount interval k
p_j Unit price of product offered by supplier j before the discount is applied
u_{jk} Upper bound of the quantity discount interval k offered by supplier j
l_{jk} Lower bound of the quantity discount interval k offered by supplier j
d_{jk} Unit price discount rate on discount interval k offered by supplier j
C_j Maximum supply capacity of supplier j
D Total demand of the product
V_j^m Minimum purchase agreed with supplier j
f_j Fine rate applied to the unpurchased amount from supplier j in comparison to the minimum purchase agreed

2.2 Mathematical Formulation

Using the above notation, the problem is formulated as the following.

Objective Function. The objective is to minimize the total purchase cost as shown in Eq. (1). The first term in the objective function consists of the costs incurred by the all unit discount and by the incremental discount, respectively. The second term in the objective function is the cost due to the penalty imposed on the buyer (the fine) if the MMV is not met.

$$\text{Minimize Total Purchase Cost} = \sum_{j=1}^{s_1}\left(\sum_{k=1}^{K_j} P_k(x_j) + f_j \max\left\{V_j^m - \sum_{k=1}^{K_j} P_k(x_j), 0\right\}\right) + \sum_{j=s_1+1}^{S}\left(\sum_{k=1}^{K_j} P_k(y_j) + f_j \max\left\{V_j^m - \sum_{k=1}^{K_j} P_k(y_j), 0\right\}\right) \quad (1)$$

Constraints. *Capacity constraint.* The purchased quantity from each supplier is less than or equal to the supplier's production capacity.

$$x_j \leq C_j \text{ where } j = 1,2,\dots,s_1 \; and \; y_j \leq C_j \text{ where } j = s_1+1, s_1+2,\dots,S \quad (2)$$

Demand constraint. The sum of the quantities purchased from all suppliers must satisfy the demand of the product.

$$\sum_{j=1}^{S} x_j \geq D \quad (3)$$

Discount constraints. The purchased quantity from each supplier who offers all unit discount x_i and incremental discount y_i must be equal to or between there lower and upper bound of the discount interval k. Therefore, the only one of the discount interval k that the purchased quantity from the selected supplier falls within must be selected. The purchase cost of the purchase quantity to be charged by the total price under all-unit, $P_k(x_i)$ and incremental, $P_k(y_i)$ discount can be formulated as:

- All unit discount

$$P_k(x_j) = \begin{cases} x_j p_j(1 - d_{jk}) & ;\ l_{jk} \le x_j \le u_{jk}\ ;\ 1 \le j \le s_1, \forall\ k \\ 0 & ;\ Otherwise \end{cases} \tag{4}$$

- Incremental discount

$$P_k(y_j) = \begin{cases} \left(\sum_{m=1}^{k-1}(u_{jm} - u_{j,m-1})(1 - d_{jm}) + (y_j - u_{j,k-1})(1 - d_{jk})\right) p_j \\ \qquad ;\ l_{jk} \le y_j \le u_{jk}\ \ if\ s_1 + 1 \le j \le S, \forall k \\ 0 \qquad ;Otherwise \end{cases} \tag{5}$$

Nonnegativity constraint. Eq.(6) specifies that the decision variables are nonnegative integers.

$$x_j \ge 0\ where\ j = 1, 2, \dots, s_1\ and\ y_j \ge 0\ where\ j = s_1 + 1, s_1 + 2, \dots, S \tag{6}$$

3 Algorithms

3.1 Water Cycle Algorithm

The water cycle algorithm (WCA) is a relatively new algorithm proposed by Eskandar et al. in 2012. The algorithm is inspired by observation of water cycle and how rivers and streams flow downhill towards the sea in the real world. The initial population in the algorithm is called raindrops. The best (in term of the objective function value) of the raindrops is chosen as the sea. Then some top raindrops are chosen as rivers and the rest are streams. Like in the nature, streams are created from raindrops and flow downhill from one place to another and join each other to form new rivers and end up in the sea (the best point). The WCA is adapted to solve the optimal order allocation problem under a mixed quantity discount scheme with the following details:

Step 1: Randomize the initial raindrops by Eq. (7)

$$x_{ij} = rand(0,1) * x_j^{max}\ ;\ i = 1, 2, 3, \dots, N_{pop}\ and\ j = 1, 2, 3, \dots, N_{var} \tag{7}$$

Where x_{ij} is the product quantity purchased from supplier *j* at raindrop number *i*, x_j^{max} is the maximum capacity of supplier *j* and *rand(0,1)* is a random number between 0 and 1. We denote N_{pop} as the initial population of raindrops and $N_{var} = S$ or the number of suppliers.

Step 2: Calculate the objective function value (total purchase cost) of each raindrop

$$Cost_i = f(x_{ij}) \tag{8}$$

The best of the raindrops is chosen as the sea, some few top raindrops are chosen as the rivers and the rest are streams.

Step 3: Calculate the intensity of flow (NS_n) using Eq. (9) to assign the streams to rivers and rivers to sea

$$NS_n = round\left\{\left|\frac{Cost_n}{\sum_{i=1}^{Nsr} Cost_i}\right| \times N_{Raindrops}\right\}\ ;\ \ n = 1,2,\ldots,N_{sr} \tag{9}$$

Where N_{sr} is the number of rivers and sea

Step 4: Streams are created from raindrops and flow to join each other to form new rivers and sea. The new positions of streams and rivers is determined by Eqs. (10) and (11).

$$v_{ij}^{Stream} = x_{ij}^{Stream} + rand(0,1) \times C \times \left(x_{ij}^{River} - x_{ij}^{Stream}\right) \tag{10}$$

$$v_{ij}^{River} = x_{ij}^{River} + rand(0,1) \times C \times \left(x_{ij}^{Sea} - x_{ij}^{River}\right) \tag{11}$$

Where C is the value between 1 and 2 (near to 2). The best value for C may be chosen as 2. If the solution given by a stream is better than its connecting river, the positions of river and stream are exchanged (i.e. the stream becomes the river and vice versa). Such exchange can similarly happen for rivers and sea.

Step 5: The evaporation process is proposed to avoid getting trapped in local optima. The following pseudo code shows how to determine whether or not river flows to the sea.

$$if \quad \left|x_i^{Sea} - x_i^{River}\right| < d_i^{max} \qquad i = 1,2,3,\ldots,N_{sr} - 1$$

Evaporation and raining process
End if

Where d_i^{max} is a small number close to zero and use for control the search intensity near the sea. Reduce the value of d_i^{max} by Eq. (12)

$$d_{i+1}^{max} = d_i^{max} - \frac{d_i^{max}}{max\ iteration} \tag{12}$$

Step 6: After the evaporation process, the raining process is executed by:

$$x_{new}^{Stream} = x_j^{min} + rand(0,1) \times \left(x_j^{max} - x_j^{min}\right) \tag{13}$$

3.2 Hybrid Water Cycle-Artificial Bee Colony Algorithm

The hybrid water cycle-artificial bee colony algorithm (HWAA) integrates two nature-inspired metaheuristics: WCA and artificial bee colony (ABC) algorithm. More details of the ABC algorithm can be found in the literature such as [11,12]. The main structure of HWAA is based on WCA except for the step of finding new positions of streams in Eq. (10). We replace this step by a step when a new candidate food source position in ABC algorithm is determined. The new step is:

$$v_{ij}^{Stream} = x_{ij}^{River} + rand(0,1) \times \left(x_{ij}^{River} - x_{rj}^{Stream}\right) \tag{14}$$

Where r is new random candidate of existing food source

4 Numerical Experiment

From the model in Section 2, several parameters are set with the following values.

1. The total demand is 35,000 units
2. Possible discount rates that determine discount intervals (d_k): 0% 3% 10%, 0% 5% 10%, 0% 5% 7%
3. The penalty rate (f_j) of the unmet MMV: 20%
4. There are two cases considered here. The first one is composed of 10 suppliers and the other 20 suppliers
5. Six cases of different ratios of the number of suppliers who offer the all unit discount vs. the incremental discount over the total number of suppliers are: 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100

Details of the discount intervals of the suppliers are shown in Table 1 and 2.

Table 1. Lower bound and upper bound of quantity discount for 10 suppliers

k		Supplier (j)									
		1	2	3	4	5	6	7	8	9	10
1	l_{ik}	0	0	0	0	0	0	0	0	0	0
	u_{ik}	799	499	1,679	1,719	579	859	1,099	1,639	419	699
2	l_{ik}	800	500	1,680	1,720	580	860	1,100	1,640	420	700
	u_{ik}	2,799	1,749	5,879	6,019	2,029	3,009	3,829	5,739	1,469	2,449
3	l_{ik}	2,800	1,750	5,880	1,020	2,030	3,010	3,850	5,740	1,470	2,450
	u_{ik}	4,000	2,500	8,400	8,600	2,900	4,300	5,500	8,200	2,100	3,500

Table 2. Lower bound and upper bound of quantity discount for 20 suppliers

k		Supplier (j)									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	l_{ik}	0	0	0	0	0	0	0	0	0	0
	u_{ik}	380	480	860	740	280	360	300	760	440	340
2	l_{ik}	381	481	861	741	281	361	301	761	441	341
	u_{ik}	1,330	1,680	3,010	2,590	980	1,260	1,050	2,660	1,540	1,190
3	l_{ik}	1,331	1,681	3,011	2,591	981	1,261	1,051	2,661	1,541	1,191
	u_{ik}	1,900	2,400	4,300	3,700	1,400	1,800	1,500	3,800	2,200	1,700
k		**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	l_{ik}	0	0	0	0	0	0	0	0	0	0
	u_{ik}	420	400	800	300	260	240	960	320	460	900
2	l_{ik}	421	401	801	301	261	241	961	321	461	901
	u_{ik}	1,470	1,400	2,800	1,050	910	840	3,360	1,120	1,610	3,150
3	l_{ik}	1,471	1,401	2,801	1,051	911	841	3,361	1,121	1,611	3,151
	u_{ik}	2,100	2,000	4,000	1,500	1,300	1,200	4,800	1,600	2,300	4,500

Table 3. Supply information of the 10 suppliers case

Supplier (j)	Capacity C_j (units)	Unit Price P_j (\$)	MMV V_j^m (\$)	Supplier (j)	Capacity C_j (units)	Unit Price P_j (\$)	MMV V_j^m (\$)
1	4,000	106	84,800	6	4,300	94	80,840
2	2,500	91	45,500	7	5,500	107	117,700
3	8,400	92	154,560	8	8,200	99	162,360
4	8,600	106	182,320	9	2,100	91	38,220
5	2,900	109	63,220	10	3,500	95	66,500

Table 4. Supply information of the 20 suppliers case

Supplier (j)	Capacity C_j (units)	Unit Price P_j (\$)	MMV V_j^m (\$)	Supplier (j)	Capacity C_j (units)	Unit Price P_j (\$)	MMV V_j^m (\$)
1	1,900	106	40,280	11	2,100	98	41,160
2	2,400	91	43,680	12	2,000	93	37,200
3	4,300	92	79,120	13	4,000	104	83,200
4	3,700	106	78,440	14	1,500	107	32,100
5	1,400	109	30,520	15	1,300	103	26,780
6	1,800	94	33,840	16	1,200	105	25,200
7	1,500	107	32100	17	4,800	100	96000
8	3,800	99	75,240	18	1,600	105	33,600
9	2,200	91	40,040	19	2,300	95	43700
10	1,700	95	32,300	20	4,500	93	83,700

The WCA and HWAA described in the previous section were then applied to solve the above problem. Both algorithms were written in C++ programming language and run on a computer with Intel® Core™ i5 2.50GHz and 4GB RAM. We set N_{pop}, N_{sr} and d^{max} to be equaled to 100, 5 and 1×10-5 for the WCA, and to 100, 25 and 1×10-5 for HWAA. Each experiment setting was run 30 times (30 trials). The results are compared with those obtained by Chotyakul et al. (2012).

5 Results and Discussion

The results obtained from all three algorithms can be shown in Table 5 to Table 8. For the case of 10 suppliers, the best and the mean value of the objective function are shown in Table 5 and 6. Table 7 and 8 show the results for the case of 20 suppliers. In each table, the first column gives the percentage ratio of the number of supplier offering all unit discount and incremental discount. The next column shows the discount rate of the initial unit prices given in Table 3 and 4. The next part of the table shows the best or the mean value of the objective function obtained in 30 trials from each of the algorithms. Taking the difference between the results of any pair of the algorithms we obtain the results as shown in the last part the table. The computation time required for all 30 trials is less than 2 minutes for the case of 10 suppliers, and for 20 suppliers the time needed is less than 11 minutes.

For the case of 10 suppliers when consider the best objective function value, the HWAA tends to perform better than the other algorithms in the scenarios of 100:0 and 80:20 ratios of the number of suppliers offering the all unit discount and incremental discount, and yields similar results to the ABC algorithm for the 20:80 ratios. The overall performance in this case, the WCA gives better results than the ABC algorithm from the best value perspective, but the ABC is better from the mean value perspective.

When consider the case of the best values for 20 suppliers, the HWAA gives the best results when the ratios of the number of suppliers offering all unit discount and incremental discount are 100:0, 80:20, 60:40, 40:60, and 20:80. For the scenarios under the 0:100 ratio, HWAA gives the same results to those of the ABC algorithm. For this particular case the ABC algorithm finds better results than the WCA in most scenarios. Similar results can be seen when there are 20 suppliers involve and consider the mean values from the 30 trials. However, the ABC algorithm yields slightly little better results than the HWAA in four scenarios. The WCA performs the worst among the three algorithms in all scenarios.

Table 5. Summary of the best value of the total purchase cost in 10 suppliers case

% All Unit Discount : % Incremental Discount	Discount	Best (USD)			Difference (USD)		
		ABC	WCA	HWAA	WCA - ABC	WCA-HWAA	ABC - HWAA
100:0	0%, 3%, 10%	3,069,090	3,067,620	3,067,604	-1469	16	1485
	0%, 5%, 10%	3,062,521	3,060,344	3,060,333	-2177	11	2188
	0%, 5%, 7%	3,152,498	3,150,833	3,150,831	-1665	1	1667
80:20	0%, 3%, 10%	3,097,888	3,096,419	3,096,402	-1469	17	1485
	0%, 5%, 10%	3,086,083	3,083,899	3,083,895	-2184	4	2188
	0%, 5%, 7%	3,165,064	3,163,402	3,163,398	-1662	4	1667
60:40	0%, 3%, 10%	3,142,916	3,142,919	3,142,916	3	3	-1
	0%, 5%, 10%	3,127,771	3,126,299	3,126,298	-1472	1	1473
	0%, 5%, 7%	3,189,877	3,188,759	3,188,756	-1118	2	1121
40:60	0%, 3%, 10%	3,167,551	3,167,552	3,167,551	1	1	0
	0%, 5%, 10%	3,148,677	3,147,639	3,147,634	-1038	5	1043
	0%, 5%, 7%	3,202,383	3,201,608	3,201,607	-775	1	777
20:80	0%, 3%, 10%	3,216,638	3,216,639	3,216,638	0	0	0
	0%, 5%, 10%	3,191,514	3,191,515	3,191,514	1	1	0
	0%, 5%, 7%	3,229,261	3,229,262	3,229,261	0	0	0
0:100	0%, 3%, 10%	3,249,721	3,249,721	3,249,721	0	0	0
	0%, 5%, 10%	3,218,506	3,218,506	3,218,506	0	0	0
	0%, 5%, 7%	3,243,165	3,243,165	3,243,165	0	0	0

Table 6. Summary of the mean value of the total purchase cost in 10 suppliers case

% All Unit Discount : % Incremental Discount	Discount	Mean (USD)			Difference (USD)		
		ABC	WCA	HWAA	WCA - ABC	WCA-HWAA	ABC - HWAA
100:0	0%, 3%, 10%	3,069,090	3,075,163	3,070,108	6073	5055	-1018
	0%, 5%, 10%	3,062,521	3,063,755	3,062,079	1234	1676	442
	0%, 5%, 7%	3,152,531	3,153,600	3,151,667	1069	1933	864
80:20	0%, 3%, 10%	3,097,888	3,103,786	3,099,657	5898	4129	-1769
	0%, 5%, 10%	3,086,083	3,089,034	3,085,583	2951	3452	500
	0%, 5%, 7%	3,165,160	3,165,958	3,164,094	797	1863	1066
60:40	0%, 3%, 10%	3,143,052	3,143,336	3,143,229	284	108	-176
	0%, 5%, 10%	3,127,771	3,131,452	3,128,207	3681	3245	-435
	0%, 5%, 7%	3,189,885	3,190,975	3,188,927	1090	2048	957
40:60	0%, 3%, 10%	3,167,551	3,167,579	3,167,552	28	27	-1
	0%, 5%, 10%	3,148,677	3,152,427	3,148,892	3751	3535	-215
	0%, 5%, 7%	3,202,420	3,202,541	3,201,607	121	935	814
20:80	0%, 3%, 10%	3,216,638	3,216,770	3,216,638	132	132	0
	0%, 5%, 10%	3,191,514	3,191,661	3,191,514	146	146	0
	0%, 5%, 7%	3,229,261	3,229,578	3,229,261	317	317	0
0:100	0%, 3%, 10%	3,249,721	3,249,724	3,249,721	3	3	0
	0%, 5%, 10%	3,218,506	3,218,507	3,218,506	1	1	-1
	0%, 5%, 7%	3,243,165	3,243,168	3,243,165	3	2	-1

From the overall performance in all 36 scenarios each consider from the best value and the mean value perspectives, or 72 subcases, the HWAA gives better or similar results compared to the other algorithms in 57 subcases. When compare the WCA with the ABC algorithm, the WCA tend to yield better solutions from the best value perspective, whereas the ABC algorithm is better if the mean value criterion is used.

Table 7. Summary of the best value of the total purchase cost in 20 suppliers case

% All Unit Discount : % Incremental Discount	Discount	Best (USD)			Difference (USD)		
		ABC	WCA	HWAA	WCA - ABC	WCA-HWAA	ABC - HWAA
100:0	0%, 3%, 10%	3,052,077	3,052,532	3,050,855	456	1677	1222
	0%, 5%, 10%	3,045,200	3,044,425	3,043,314	-776	1111	1887
	0%, 5%, 7%	3,133,961	3,133,143	3,132,626	-819	517	1335
80:20	0%, 3%, 10%	3,099,573	3,099,291	3,098,949	-282	342	624
	0%, 5%, 10%	3,089,313	3,088,466	3,088,301	-848	165	1012
	0%, 5%, 7%	3,162,335	3,161,783	3,161,105	-552	678	1230
60:40	0%, 3%, 10%	3,111,186	3,111,286	3,111,056	100	230	130
	0%, 5%, 10%	3,103,547	3,103,461	3,103,357	-86	104	190
	0%, 5%, 7%	3,170,159	3,169,679	3,169,443	-480	236	716
40:60	0%, 3%, 10%	3,152,629	3,152,670	3,152,499	41	171	130
	0%, 5%, 10%	3,137,455	3,137,472	3,137,257	17	214	198
	0%, 5%, 7%	3,188,243	3,187,734	3,187,527	-509	208	716
20:80	0%, 3%, 10%	3,184,461	3,184,509	3,184,461	48	47	-1
	0%, 5%, 10%	3,164,894	3,164,998	3,164,907	104	91	-13
	0%, 5%, 7%	3,204,167	3,203,882	3,203,728	-285	154	439
0:100	0%, 3%, 10%	3,228,975	3,229,067	3,228,975	92	92	0
	0%, 5%, 10%	3,198,676	3,198,758	3,198,676	83	83	0
	0%, 5%, 7%	3,224,385	3,224,498	3,224,385	114	114	0

Table 8. Summary of the mean value of the total purchase cost in 20 suppliers case

% All Unit Discount : % Incremental Discount	Discount	Mean (USD)			Difference (USD)		
		ABC	WCA	HWAA	WCA - ABC	WCA-HWAA	ABC - HWAA
100:0	0%, 3%, 10%	3,052,079	3,058,430	3,052,089	6351	6341	-10
	0%, 5%, 10%	3,045,200	3,049,655	3,043,664	4455	5991	1536
	0%, 5%, 7%	3,133,961	3,134,726	3,132,638	764	2088	1323
80:20	0%, 3%, 10%	3,099,595	3,105,104	3,099,450	5509	5655	146
	0%, 5%, 10%	3,089,439	3,092,244	3,088,734	2806	3510	704
	0%, 5%, 7%	3,162,335	3,163,696	3,161,149	1361	2546	1185
60:40	0%, 3%, 10%	3,111,293	3,111,970	3,111,163	677	807	130
	0%, 5%, 10%	3,103,737	3,105,203	3,103,506	1466	1697	231
	0%, 5%, 7%	3,170,159	3,170,264	3,169,443	105	821	716
40:60	0%, 3%, 10%	3,152,706	3,154,795	3,152,563	2089	2232	143
	0%, 5%, 10%	3,137,660	3,139,015	3,137,517	1355	1498	143
	0%, 5%, 7%	3,188,243	3,188,478	3,187,527	235	951	716
20:80	0%, 3%, 10%	3,184,461	3,186,784	3,184,466	2323	2318	-6
	0%, 5%, 10%	3,165,086	3,166,259	3,164,977	1173	1282	109
	0%, 5%, 7%	3,204,167	3,204,502	3,203,728	335	774	439
0:100	0%, 3%, 10%	3,228,975	3,229,546	3,228,975	571	570	-1
	0%, 5%, 10%	3,198,676	3,199,259	3,198,676	584	583	-1
	0%, 5%, 7%	3,224,385	3,224,943	3,224,385	559	559	0

6 Conclusion

In this paper, the order allocation with mixed quantity discount schemes is considered. The problem is formulated and a numerical example is set for cases of 10 and 20 suppliers with different mixes of all unit discount and incremental discout, as well as discount rates. Since the problem is NP-hard, we choose to apply the water cycle algorithm (WCA) and hybrid water cycle-artificial bee colony algorithm (HWAA) to find the optimal solutions. To HWAA developed in this research utilizes the core methodology from the WCA but replacing a step in the WCA with an exploration step (finding a new candidate food source) of the ABC algorithm. The results obtained from the ABC algorithm of this silimar problem appeared in the literature are also considered. Among the three algorithms, the results show that the HWAA tends to find the best solutions in most scenarios. When compare only the WCA and ABC algorithm, the WCA yields better results if the best value criterion is used, but the ABC is better from the mean value perspective.

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