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Integrated Capacitated Transportation and Production Scheduling Problem in a Fuzzy Environment

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KEYWORDS

Integrated capacitated air transportation and production scheduling;
Fuzzy environment;
Metaheuristics;
Keshtel algorithm;
Virus colony search

ABSTRACT

Nowadays, the production scheduling systems are integrated by different transportation networks, e.g., airplanes, trains, and ships. Although the integrated air transportation and production scheduling problem is modelled with different factors, according to the literature reports, a fuzzy environment along with capacitated transportation systems has been scarcely considered. These facts motivate our attempts to contribute to a new formulation of this problem while considering the aforementioned suppositions. Another contribution of this study is to apply a number of nature-inspired metaheuristics. Accordingly, not only Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are used as famous metaheuristic algorithms existing in the literature, but also two recent ones, namely, Keshtel Algorithm (KA) and Virus Colony Search (VCS), are considered for the first time in the literature. In addition, the Taguchi experimental design method is utilized to tune the algorithms' parameters. By generating different test problems, KA reveals a better performance when solving large-sized samples, in comparison to other metaheuristics.

1. Introduction and Literature Review

The recent decade has seen a rapid development of production scheduling along with different types of transportation systems such as airplanes, trains, and ships. In this regard, Nasiri *et al.* [1] explored the freight consolidation and containerization using ship transportation. Thus, Hajiaghaei-Keshteli et al. [2] firstly proposed integrated production scheduling and rail transportation. Generally, the type of transportation network plays an important role in an integrated business network in terms of production scheduling problem [3-4]. In today's markets, after passing the periods of mass production and customized production, the air transportation provides a chance to achieve the growth of customer satisfaction more efficiently in both academia and industrial practitioners [5]. The importance of air transportation in production scheduling systems has increased dramatically [6]. To get closer to reality, the uncertainty of a set of key parameters in such systems makes this problem

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more practical [7-8]. These facts have motivated our attempts to contribute to an integrated air transportation and production scheduling problem in a fuzzy environment.

As pointed out by Chen [9] in a review paper, coordinated decisions, especially in a supply chain, have been increasingly motivated by both academia and industrial practitioners in the following decades. From another point of view, concerning a coordinated manner, managers seek to make sustainable decisions within the capacitated production scheduling context [10].

Usually, customers understand and accept small deviation of due date. This uncertainty refers to production problems such as damages to raw materials as well as machinery failures and problems such as delay delivery of aircraft, traffic problems, etc. In general, an insignificant distance from the agreed delivery date is considered to be delivery time window. Accordingly, Fig. 1 illustrates the proposed problem, graphically.

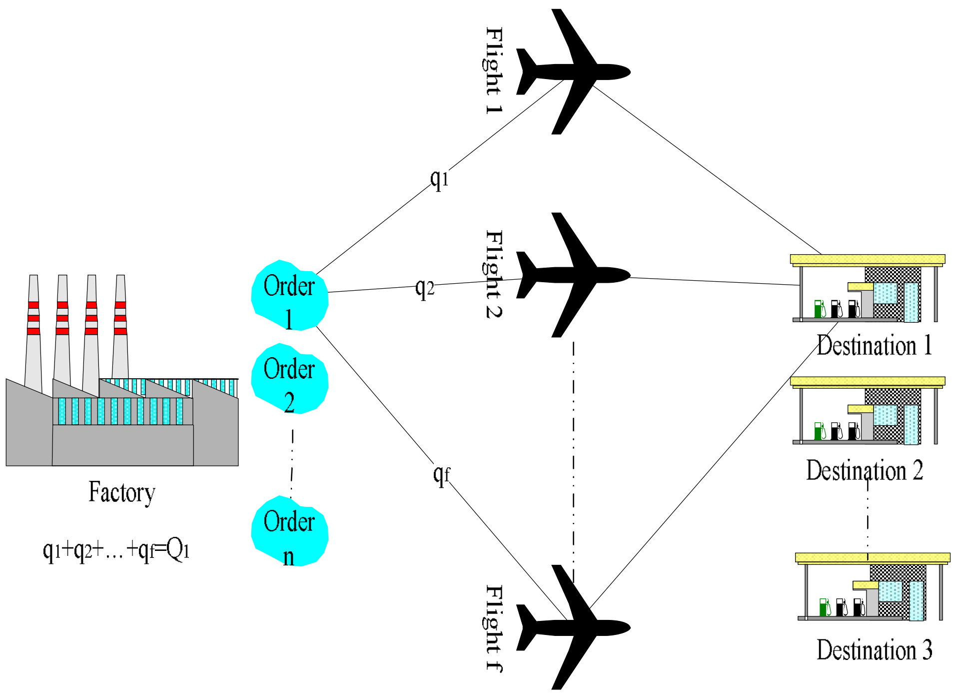

Fig. 1. The graphical illustration of the proposed problem

In the following, a set of recent and important studies is explained. In 2013, Fu *et al*. [11] studied the coordination of the production scheduling and delivery under two main restrictions: time windows and delivery capacity. In 2014, Low *et al*. [12] proposed a non-linear model to minimize the total costs, including transportation cost, vehicle arrangement cost, and penalty cost. They also assumed that goods delivery takes place in the time window. In 2015, Kang *et al.* [13] also modelled an integrated production and transportation problem by considering some suppositions to minimize the total production and transportation cost in each planned period. In a small-sized problem, MILP approach was used. Due to the difficulty of large-sized test problems, a Genetic Algorithm (GA) was presented. Similarly, Li *et al*. [14] addressed the integrated production on parallel batching machines and the delivery scheduling problem in order to maximize the revenue with a proposed heuristics. In 2016, Karaoğlan and Kesen [15] considered integration production and transportation of short-lived products and developed a branch-and-cut algorithm. Recently, Tavakkoli-Moghaddam et al. [16] proposed an integrated air transportation and production scheduling problem. They applied GA and Particle Swarm Optimization (PSO) to tackle their introduced problem.

Zandieh and Molla-Alizadeh-Zavardehi [17] and Rostamian Delavar et al. [18] proposed some main mathematical models with different suppositions. They considered different types of capacities and solved their problem with two GA approaches. Afterwards, Mortazavi *et al*. [10] addressed the model of Rostamian Delavar *et al*. [18] with a new version of Imperialist Competitive Algorithm (ICA). Usually, the production and distribution-scheduling problem is considered as a problem that minimizes several costs such as production cost, transportation cost, and the earliness and tardiness penalty costs. Their problem was also considered as a non-deterministic polynomial hard problem [9].

To fill the aforementioned gaps and get closer to the real-world applications, this study formulates and solves an integrated capacitated air transportation and production-scheduling problem in a fuzzy environment. This paper also contributes to a number of recent nature-inspired metaheuristics, which have been proposed recently, to solve complex and large-scale test problems. The rest of this paper is summarized as follows. Section 2 explains the proposed problem exactly along with its characteristics in detail. Section 3 probes the encoding plan of algorithms' representation and their details to tackle the problem. The outputs of experiments with different criteria are presented in Section 4. At the end, the conclusion and future works are presented in Section 5.

2. Problem Formulation

This section provides fundamental basics of the model. Herein, orders are allocated to existing capacities of air transportation and are sequenced within the site of production centers in order to minimize the total cost of the whole chain. The developed model is based on the study of Rostamian Delavar *et al*. [18]. The assumptions of the developed problem have been defined based on study of Rostamian Delavar *et al*. [18], too. Accordingly, a set of key parameters, including the capacity and quantity of order, is uncertain and formulated by fuzzy numbers. The indices, parameters, and decision variables of the problem presented are given in Tables 1 to 3, respectively.

Tab. 1. Indices used in problem

Indices	Description
$i, i', \; i, i' = 1,2,\ldots,N$	Order / job index
$f, f', \; f, f' = 1,2,\ldots,F$	Ordinary flight index
$k, \; k = 1,2,\ldots,K$	Destination index
$p, p', \; p, p' = 1,\ldots,N$	Position or sequence of order i

Tab. 2. Parameters used in problem

Parameters	Description
N	Order / job quantity
F	Ordinary flight
K	Destination quantity
Qi	Quantity of order i
li	The latest delivery time of order i;
ei	The earliest delivery time of order i;
ai	Early delivery penalty cost (/unit/h) of order i;
$a'i$	Early departure time penalty cost (/unit/h) of order i
bi	Delivery tardiness penalty cost (/unit/h) of order i;
$Desi$	Destination of order i
$desf$	Destination of ordinary flight f
Df	Departure time of ordinary flight f at the local airport
tf	Duration of flight f
$Capf$	capacity of ordinary flight f
Tcf	Transportation cost of each product unit when allocated to ordinary flight f;
$b'i$	Departure time tardiness penalty cost (/unit) of order i
Af	Arrival time of ordinary flight f at the destination
$MDei$	Maximum departure time of charter flight for order i that can reach the earliest due date (it is equal to the earliest delivery time of order i subtracted from the time of charter flight for order i)
$MDli$	Maximum departure time of charter flight for order i that can reach the latest due date (it is equal to the latest delivery time of order i subtracted from the time of charter flight for order i)
Pi	Processing time of order i (/unit)
LN	A large positive number

Tab. 3. Variables used in the problem

Variables	Description
qif	Quantity of portion of order i allocated to ordinary flight f;
q(T+1)i	Quantity of portion of order i allocated to its charter flight;
Ci	Completion time of order *i*;
Uip	1 if order i is in position *p*, 0 otherwise;

It should be noted that the main difference of this model with the mentioned works in the literature is the two types of delivery times (the earliest and latest delivery times are considered). The following equations are defined as follows:

$$\min \sum_{t=1}^{N}\sum_{i=1}^{F}\left(\left(\left(\frac{\min\left(0, c_i - D_f - \frac{1}{LN}\right)}{c_i - D_f - \frac{1}{LN}}\right)\left(\left(Tc_f * q_{if}\right)+\left(\alpha_i' *\left(D_f - c_i\right)* q_{if}\right)+\left(\left(\alpha_i * \max\left(0, e_i - A_f\right)* q_{if}\right)+\left(\beta_i * \max\left(0, A_f - l_i\right)* q_{if}\right)\right)\right)\right)+\left(\left(1-\left(\frac{\min\left(0, c_i - D_f - \frac{1}{LN}\right)}{c_i - D_f - \frac{1}{LN}}\right)\right)\left(\left(\beta_i' * q_{if}\right)+\left(\min(\alpha_i', \alpha_i)*\max\left(0, MDE_i - c_i\right)* q_{if}\right)+\left(\beta_i * \max\left(0, c_i - MDL_i\right)* q_{if}\right)\right)\right)\right)+\sum_{i=1}^{N}\left(\left(\beta_i' * q_{(T+1)i}\right)+\left(\min(\alpha_i', \alpha_i)*\max(0, MDE_i - c_i)* q_{(T+1)i}\right)+\left(\beta_i * \max\left(0, c_i - MDL_i\right)* q_{(T+1)i}\right)\right) \tag{1}$$

s.t.

$$q_{if} *(Des_i - des_f) = 0 \qquad i = 1,\ldots, N; f = 1,\ldots, F \tag{2}$$

$$\sum_{i=1}^{N} q_{if} \leq Cap_f \qquad f = 1,\ldots,F \tag{3}$$

$$\sum_{f=1}^{F} q_{if} + q_{(T+1)i} = Q_i \qquad i = 1,\ldots,N \tag{4}$$

$$\sum_{p=1}^{N} u_{ip} = 1 \qquad i = 1,\ldots, N \tag{5}$$

$$\sum_{i=1}^{N} u_{ip} = 1 \qquad p = 1,\ldots,N \tag{6}$$

$$\sum_{p=1}^{N}\left(u_{ip}\left(p_i Q_i + \sum_{p'=1}^{p-1}\sum_{i'=1}^{N} u_{i'p'} P_{i'} Q_{i'}\right)\right) = c_i \qquad i = 1,\ldots, N \tag{7}$$

$$u_{ip} \in \{0,1\} \qquad i = 1,\ldots, N; p = 1,\ldots, N \tag{8}$$

$$q_{if}, q_{(T+1)i} = \text{Non-negative integer variable} \tag{9}$$

As noted earlier, the proposed model considers both of transportation and production centers. The first objective function aims to dedicate the orders that coordinate the ordinary flight. In addition, the second one stands for the orders that cannot satisfy the ordinary flight. Eventually, the allocated orders of each chapter are computed in the last term of objective function. Constraint (2) ensures that order *i* and ordinary flight *f* have the same destinations. Constraint (3) ensures that the allocated quantities to flight *f* are less than the capacity of flight *f*. Constraint (4) ensures that order *i* is fully allocated. A set of constraints (5) and (6) states the allocation constraints of a single machine. Constraint set (7) computes the completion time of jobs.

3. Solution Method

As can be seen in the literature, since this problem is NP-*hard* [10-18], a number of recent studies have focused mainly on developing efficient metaheuristic approaches to solve this problem. Similar to these studies, the main contribution of this study is to propose a number of nature-inspired algorithms to probe this problem more efficiently. In this regard, four metaheuristics are used in this paper: Genetic Algorithm (GA) as a famous evolutionary algorithm, Particle Swarm Optimization (PSO) as a well-known swarm intelligence, nature-inspired meta-heuristics Virus Colony Search (VCS), and Keshtel Algorithm (KA).

3-1. Encoding scheme

Similar to another metaheuristic solution planning when solving the discrete mathematical formulation, a representation plan of designing the encoding and decoding of algorithms is required [4-8]. Accordingly, the order of each comfortable ordinary flight should be assigned with the same destinations. The allocation matrix is divided into K sub-matrices. All of processes in algorithms are applied to each sub-matrix. Accordingly, an example is illustrated in Fig. 2. Order 2 has destination 2 and, then, can be transported by both flights 1 and 4. Generally, the input allocation of transportation is firstly shown in Fig. 2. In addition, Fig. 3 gives the assigned transportation matrix.

	Des_i		2	2	1	1	2	1
Des_f	f \ i		2	3	4	5	6	7
2	1	0	5					5
1	2						0	9
1	3					5		5
2	4	3				6		10

Fig. 2. Orders transportation cost

	Des_i	1	1	1	1	2	2	2
Des_f	f \ i	1	4	5	7	2	3	6
1	2	9	4	9	9			
1	3	6	7	15	5			
2	1					15	8	6
2	4					3	5	7

Fig. 3. Transportation allocation sub-matrices

3-2. Keshtel algorithm (KA)

One of recent nature-inspired algorithms proposed in this study is Keshtel Algorithm (KA). This metaheuristic developed by Hjiaghaei-Keshteli and Aminnayeri [19] is inspired by an amazing feeding behavior of a dabbling dock, namely Keshtel, in *Anas* family. To clarify the counterpart of the proposed algorithm, the user generates an initial population, called Keshtel, and divides them into three types (*i.e.*, N_1, N_2, and N_3). N_1 includes some Keshtels that have found good food for the first time, called lucky Keshtels. In addition, N_3 includes the worst solutions. The lucky Keshtels search for more food around them. When better food is found around a lucky Keshtel, a new lucky one is replaced; if not, the swirling will continue. For N_2 population, they move between the two other Keshtels. In addition, for N_3 population, they are regenerated randomly for each generation. The steps of KA are detailed in Fig. 4.

```
Initialize Keshtels population.
Calculate the fitness and sort them in three types: N1, N2 and N3
X*=the best solution.
while (t< maximum number of iteration)
   for each N1
     Calculate the distance between this lucky Keshtel and all Keshtels.
     Select the closest neighbor.
     S=0;
     while (S< maximum number of swirling)
       Do the swirling.
       if the fitness of this new position is better than prior
         Update this lucky Keshtel.
           break
       endif
       S=S+1
     endwhile
   endfor
   for each N2
     Move the Keshtel between the two Keshtels.
   endfor
   for each N3
     Create a random solution.
   endfor
   Merge the N1, N2 and N3
   Sort the Keshtels and form N1, N2 and N3 for next iteration.
   Update the X* if there is better solution.
   t=t+1;
end while
return X*
```

Fig. 4. The pseudo-code of KA

3-3. Virus colony search (VCS)

Virus Colony Search (VCS) presented by Dong Li *et al.* [20] simulates the diffusion and infection strategies for host cells adopted by virus to survive in the cell environment. It starts with a random initial population. These solutions are divided into two types: Viruses and Host Cells. The better ones are selected as viruses. Each virus in the diffusion process creates a new random individual. Then, each virus infects only one host cell. The algorithm is summarized by pseudo-code, as seen in Fig. 5.

Initialize random population and set parameters.

Calculate the fitness and sort them in two types: V_{pop} *and* H_{pop}

X*=the best solution.

while (t<maximum number of iteration)

for each virus

Do the diffusion process.

$V_{pop'} = Guassion(\mathrm{X}^*, \delta) + (\mathrm{rand} \times \mathrm{X}^* - \mathrm{rand} \times \mathrm{V_{pop}});$

Check the boundary.

endfor

Update V_{pop} with $V_{pop'}$.

for each host cell

Do the infection process.

Create the new virus ($V_{pop''}$).

$V_{pop''} = \mathrm{X}^* + \mathrm{H_{pop}} \times \mathrm{N}(0, \mathrm{C});$

Check the boundary.

Response of immune system.

if p<rand

$V_{pop''} = V_{pop} - rand \times (H_{pop} - V_{pop});$

else

$V_{pop''} = V_{pop};$

endif

endfor

Update V_{pop} and H_{pop}.

Update the X* if there is better solution.

t=t+1;

endwhile

Fig.5. The pseudo-code of VCS

3-4. Genetic algorithm (GA)

Genetic Algorithm (GA) developed by Holland [21] is known as one of the well-known evolutionary algorithms. GA inspired by genetics defines an array of variables named chromososme. Two operators change chromosomes: mutation and crossover [1]. Since this metaheuristic is well known and has been investigated by several earlier studies, the interested readers can refer to related studies in this regard [2-5].

3-5. Particle swarm optimization (PSO)

Eberhart and Kennedy [22] firstly proposed PSO. The social behavior of individuals or particle in nature, like flocks of birds or schools of fish, motivates the creators to develop the algorithm. In the PSO, any solution in a search space is a counterpart of a particle nature. Each particle selects a direction to move using a combination of its current location information, the best place where previously had, and the best experience of all the particles. This process is repeated until the termination criteria are met. Similar to GA, the interested readers can refer to [6-8] to see more illustrations and descriptions of this well-known metaheuristics.

4. Computational Results

Herein, first, the data have been generated by an approach benchmarked from the literature. Consequently, the presented metaheuristics are tuned by the Taguchi method to set the best set of algorithms' parameters. Finally, a comparative study is adopted to assess the performance of metaheuristics in different criteria.

4-1. Generating data

To investigate the behavior of the solution approaches, a plan to generate the test data is shown in Table 4. To generate experimental problems, a dataset by considering *J-F-K* indices is benchmarked from [14]. The value of *N* is considered equal to 5×*F* for each problem. Then, nine problems with different sizes are generated for the experimental study. We show the total number of flights with the same destination by *TFk*. The corresponding flights are assigned to an ordinary flight number *FNf*, starting from 1 to *TFk*. Each flight's departure time is then generated using uniform distribution from [24 * (*FNf* -1)/*TFk*, 24 * *FNf* /*TFk*]. It should be noted that some parameters, i.e., the capacity and quantity of order, are valued by fuzzy numbers, i.e., fuzzy triangle, as seen in Table 4.

Tab. 4. Data generation

Parameters	Values
N	*20, 30, 40, 50, 60, 70, 80, 90, 100*
F	*4, 6, 8, 10, 12, 14, 16, 18, 20*
K	*2, 2, 3, 3, 3, 4, 4, 4, 5*
Qi	*(50, 125, 200)**
li	*Uniform [1,6]*(Qi*pi)+0.1*
ei	*Uniform [1,6]*(Qi*pi)-0.1*
ai	*Uniform [3,5]*
a'i	*Uniform [2,4]*
bi	*Uniform [5,8]*
tf	*Uniform [2,10]*
Desi	*Uniform [1,K]*
desf	*Uniform [1,K]*
Df	*Uniform [24*(FNf-1)/TFk , 24*FNf /TFk]*
Capf	*(200, 500, 800)**
Tcf	*Uniform [60+20 desf, 80+20 desf]*
b'i	*Uniform [150+20 desf, 200+20 desf]*
Af	*Df + tf*

MDei	*ei – ti*
MDli	*li – ti*
Pi	*pi=Uniform [0.5,1.5]/(∑Qip'i)* uniform [1.2,2]/24*

**Fuzzy numbers*

4-2. Parameter setting

Since the algorithms employed and proposed in this work have several controlling parameters, the best value should be chosen to provide an unbiased comparison [23-24]. To do this, the Taguchi method presented by Genichi Taguchi [25] is employed, in which the signal-to-noise (*S/N*) ratio indicates the variation amount in response variable. The higher value brings better quality of this metric. *S/N* ratio in the minimizing objective functions should be formulated as follows:

$$S/N = -10\log_{10}\left(objective\ function\right)^2 \quad (10)$$

The parameters listed for each algorithm are given in Table 5. Due to the randomization of these employed nature-inspired algorithms, another metric in this method, called the Percentage of Relative Deviation (*PRD*) approach, is employed to evaluate the performance of algorithms. *PRD* in the minimizing objectives can be assumed by this formula:

$$RPD = \frac{Alg_{sol} - Min_{sol}}{Min_{sol}} \quad (11)$$

where Min_{sol} is the best solution among all solutions, and Alg_{sol} is the output of algorithm. The lower value of this metric brings better quality. According to Table 5, the Taguchi method for GA and VCS has proposed L_9 and L_{27} for PSO. At least, for KA, L_{32} is proposed. Consequently, ratio *S/N* and mean *PRD* for each algorithm are considered in Figs. 6 to 13.

Tab. 5. The meta-heuristics algorithms parameters and their levels.

Algorithm	Parameter	Levels			
		Level 1	Level 2	Level 3	Level 4
GA	Maximum iteration (*Maxit*)	300	500	800	-
	Population size (n_{pop})	100	200	300	-
	Percent of crossover (pc)	0.5	0.6	0.7	-
	Percent of mutation (pm)	0.05	0.1	0.2	-
PSO	Maximum iteration (*Maxit*)	300	500	800	-
	Population size (n_{pop})	100	200	300	
	inertia weight (*W*)	0.65	0.8	0.9	-
	Acceleration coefficient (C_1)	1.2	1.5	2	-
	Acceleration coefficient (C_2)	1.2	1.5	2	-
KA	Maximum iteration (*Maxit*)	300	600	-	-
	Population size (n_{pop})	100	150	200	250
	percentage of N_1 Keshtel (PN_1)	0.02	0.05	0.08	0.1
	percentage of N_2 Keshtel (PN_2)	0.25	0.30	0.35	0.40
	Maximum Swirling (S_{max})	2	4	5	6
VCS	Maximum iteration (*Maxit*)	300	500	600	-
	Population size (n_{pop})	100	200	250	-
	Input variable of search function (*a*)	0.1	0.2	0.35	-

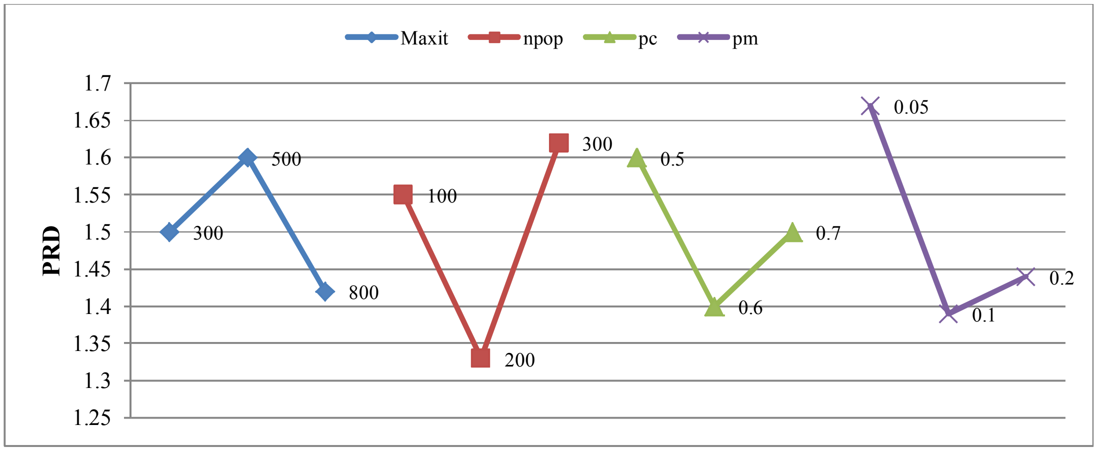

Fig. 6. The PRD for GA

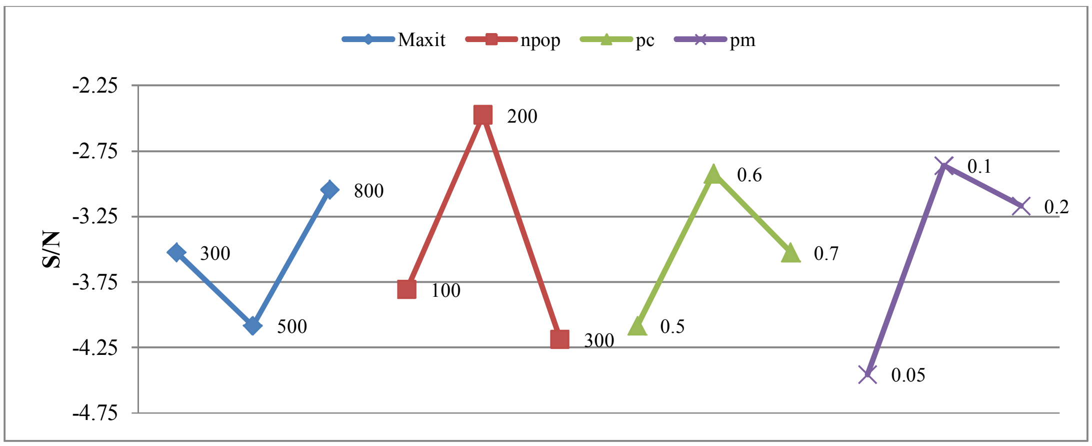

Fig. 7. The S/N for GA

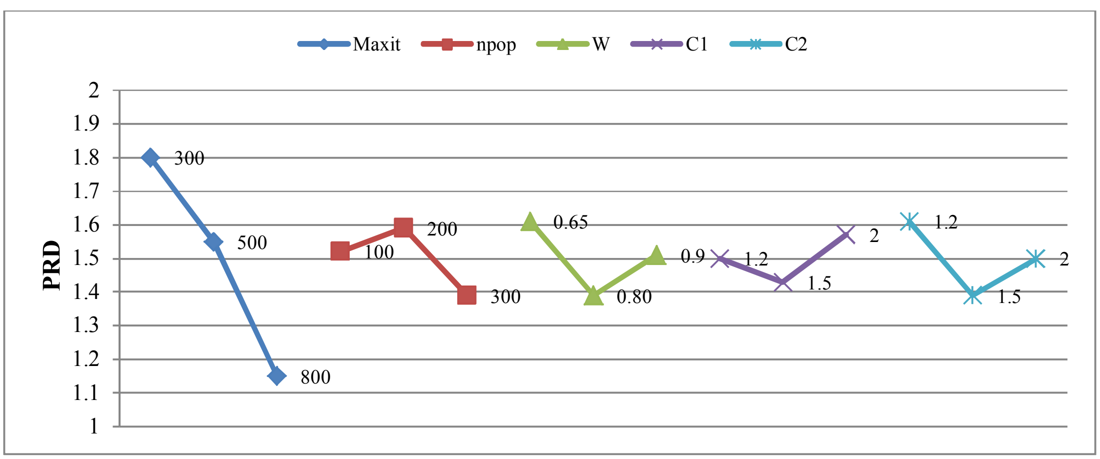

Fig. 8. The PRD for PSO

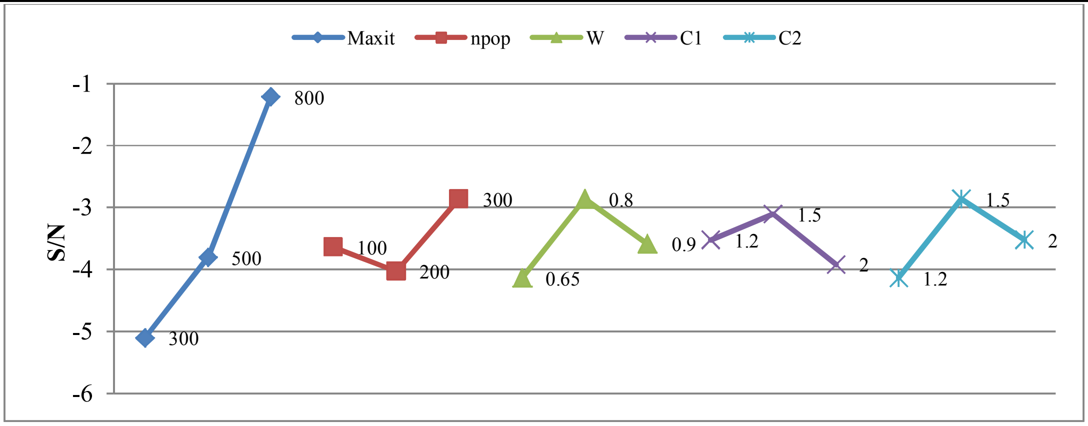

Fig. 9. The S/N for PSO

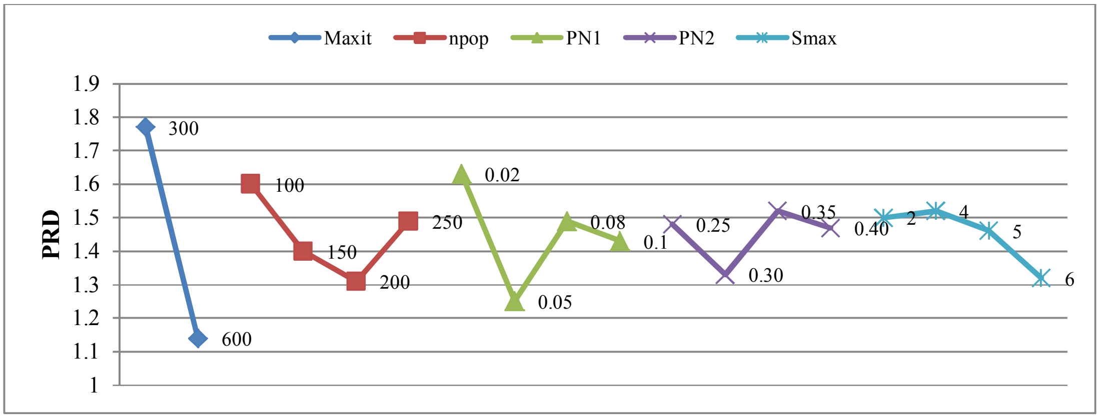

Fig. 10. The PRD for KA

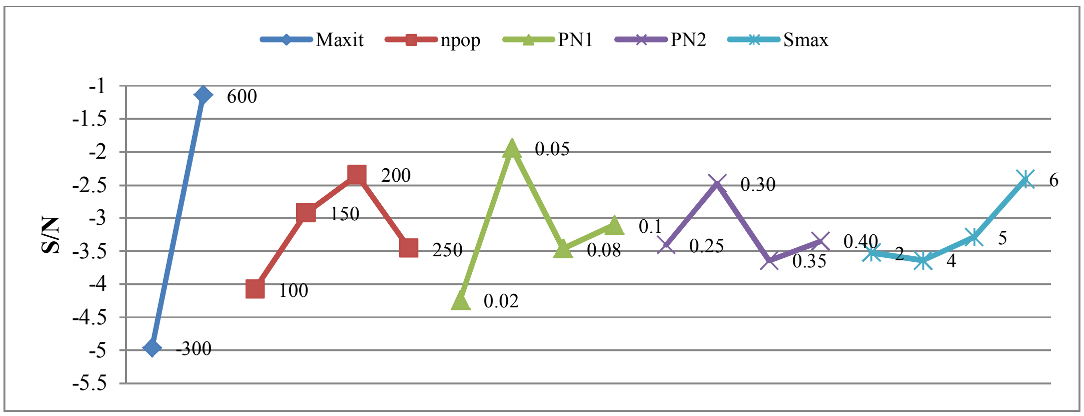

Fig. 11. The S/N for KA

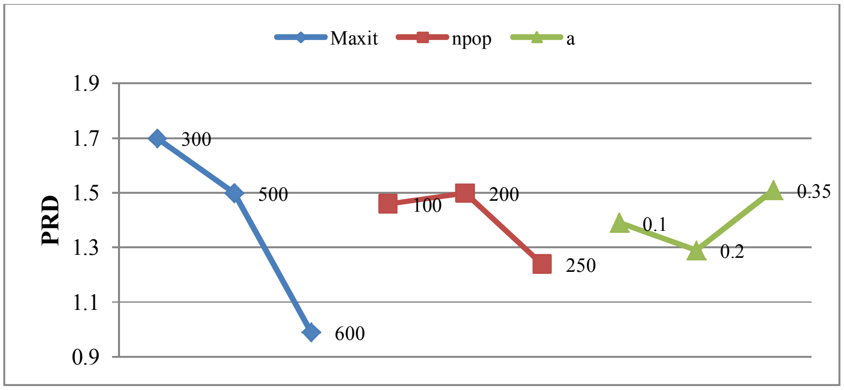

Fig. 12. The PRD for VCS

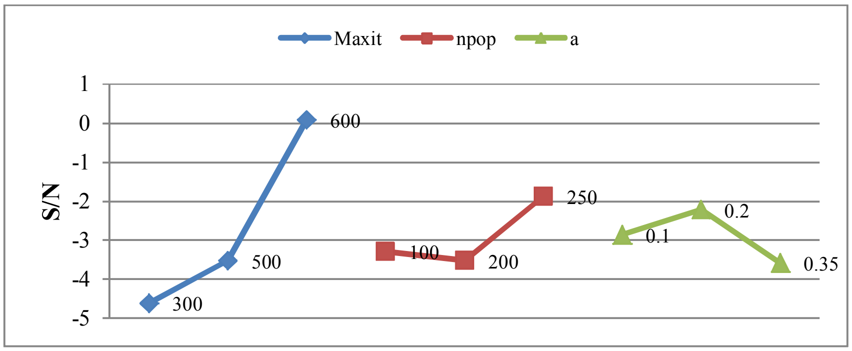

Fig. 13. The S/N for VCS

4-3. Experiments results

This section aims to conduct the analysis in terms of solution time and quality for the presented algorithms. It should be mentioned that each algorithm is run for thirty run times, and the average of outputs is proved reliable. Herein, the obtained results of solving the problems by the developed algorithms have been examined in the previous section. These results are visible in Table 6. Moreover, to study the speed of the algorithms in different problem sizes, a new term "hitting time" is introduced. Hitting time is the first positive time that algorithm meets the best solution (hits). These times are shown in Table 6.

Tab. 6. Comparative results for solution quality and hitting time (second) GAP=(Sol-Best)/Best

Instance	GA			KA			PSO			VCS		
	Sol	Hit	GAP	Sol	Hit	GAP	Sol	Hit	GAP	Sol	Hit	GAP
20j4f2d	213,187	0.24	0.03	206,775	6.8	0	308,216	23.48	0.49	431,071	14.9	1.085
30j6f2d	352,864	0.34	0.08	327,138	11.7	0	475,843	28.38	0.45	674,964	20.0	1.063
40j8f3d	729,231	0.44	0.09	669,655	13.5	0	907,373	37.21	0.35	1,228,405	27.0	0.834

50j10f	648,99	0.	0.1	552,77	16	0	868,05	45.1	0.	1,147,4	32.	1.0
3d	8	53	7	3	.3		2	0	57	13	6	76
60j12f	767,05	0.	0.1	689,59	20	0	1,034,4	60.9	0.	1,297,3	37.	0.8
3d	5	66	1	4	.4		17	0	50	37	3	81
70j14f	1,221,6	0.	0.2	1,002,4	22	0	1,582,3	74.1	0.	1,951,9	49.	0.9
4d	51	77	2	27	.2		72	4	58	45	4	47
80j16f	1,433,3	0.	0.2	1,159,5	27	0	1,846,8	91.8	0.	2,168,4	52.	0.8
4d	61	89	4	23	.7		42	0	59	00	8	70
90j18f	1,971,4	1.	0.2	1,553,5	31	0	2,427,7	106.	0.	2,775,0	61.	0.7
4d	13	02	7	69	.3		57	79	56	76	8	86
100j20	2,101,7	1.	0.2	1,679,4	34	0	2,638,2	102.	0.	2,911,4	64.	0.7
f5d	56	10	5	66	.0		37	81	57	94	3	34

To select the best metaheuristic in this study, an analysis of variance (ANOVA) is used to accurately analyze the results in order to measure the validity of results. It is clear that the performances of algorithms are not same. In this regard, the means plot and LSD intervals (at the 95% confidence level) for algorithms are depicted in Fig. 14. According to this figure, KA is more successful than other methods are.

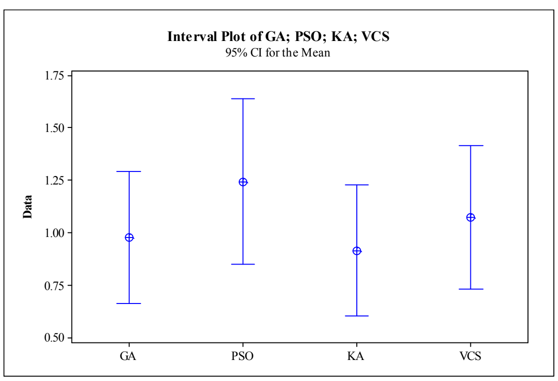

Fig. 14. Means plot and LSD intervals for the algorithms

5. Conclusion and Future Lines

In this paper, an integrated capacitated air transportation and production scheduling problem was highlighted in a fuzzy environment. Accordingly, the coordinated production and air transportation problem with time window for due date and not permitted idle time was considered. Four different metaheuristics were used in this study. Two old and well-known methods, including GA and PSO, and also two recent nature-inspired algorithms, including KA and VCS, were considered. The proper values for algorithms' parameters were selected by the Taguchi approach. Finally, the algorithms were compared with respect to different criteria. As a result, from Table 6 and Fig. 14, KA reached a better value and showed better performance in comparison to other algorithms when solving large-sized samples.

Generally, there are several opportunities for the future studies to develop the proposed model and solution approaches such as:

- ✓ Considering idle time in production site
- ✓ Considering machines downtime
- ✓ Considering another transportation type such as rail or water transportation
- ✓ Considering setup time or compressible processing time.
- ✓ Considering the recent metaheuristics and hybridized ones.

Proposing heuristic methods to solve the problem.

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