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Minimizing the Cost Function of GHG Emission in AS&RS Using Artificial Immune System Algorithm

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Abstract **As increase in the Green House Gas (GHG) leads to global warming, it is our basic duty to protect the environment from GHG. As a small part of it, this paper regard in minimizing the cost function of GHG emission of Automated Storage and Retrieval System (AS&RS) in the industrial process. To study this a mathematical model was constructed based on tax cost, penalty cost and discount cost of GHG emission of AS&RS. An Artificial Immune System (AIS) algorithm is implemented to find the optimum solution of the proposed model. The results obtained are compared with the other existing algorithms in the literature. It is observed that the proposed algorithm yields a better results compared to other algorithms**

Keywords — Green House Gas, Global warming, Automated Storage and Retrieval Systems, Mathematical model , clonal selection principle and Artificiel Immune System Algorithm.

I. Introduction

Storing high volume of goods in less spacious warehouses is a difficult task in the manufacturing process. To overcome this issue an advanced storage system namely Automated Storage and Retrieval System (AS/RS) is introduced in the manufacturing industries. Manufacturing system involving AS/RS are called Flexible Manufacturing System (FMS). These advanced storage system will automatically store and retrieve the goods with control from one place. Two important approaches of AS/RS design and study are analytical optimization and simulations [1] and [2]. Scheduling is one of method used for maximizing the throughput of AS/RS, which sequences the retrieval request by condensing the travel time. Generally first come first serve principle [3] is used to store the items. Benefits of these AS/RS are, reducing the labour cost, floor space saving, reliability and accuracy. It has few drawbacks such as, increase in electricity cost, Greenhouse Gas (GHG) emission and high investment cost and less flexibility etc. [4 and 5]. Due to global awareness of environmental protection, government introduced penalty cost for more amount of GHG emission and discount cost for less amount of GHG emission. As the GHG emission increases, the penalty cost will also increase the total cost of the manufacturing process. Therefore in this paper we are putting an effort to reduce the total cost of GHG emission in AS/RS. A mathematical model is constructed based on actual cost, penalty cost and discount cost of the GHG emission of AR/RS. The recent work of GHG emission of AS/RS using Ant Colony Algorithm and Genetic Algorithm are presented in [6]. The results shown that genetic algorithm yielded a better solution than ant colony algorithm. Therefore in this paper an Artificial Immune System (AIS) algorithm is used to minimize the total cost function of GHG emission in AS/RS. Artificial immune system [7], [8], [9] and [10] is a new research field which attracts many researchers due to its wide range of applications. It is formed on the basis of bio immune system. The importance of our immune system is to protect our body from the antigens. Antigens are foreign and harmful pathogens such as bacteria and viruses. Our immune system consists of special types of cells called T-Lymphocytes and B-Lymphocytes which detects antigens entry to our body. Among these B-Lymphocytes are the best matches the antigens, which clones the antigens and send these cloned cells to plasma cells which are high efficient antibodies which fights against the antigens. Antibodies should fight with the antigen to destroy them. But each antigen has its own multi type of epitope that has to be recognized by the antibodies. To overcome this situation the antibodies undergoes cloning. This process is called clonal selection principle [11]. The cloned antibodies undergo mutation to increase the affinity value to destroy the antigens. These mutations are proportional to the affinity to the antigens. The Artificial immune system mainly consists of two components called antigens and antibodies which made up of string of multiple genes. The principles of artificial immune system are used in complex domain problems [12], [13] and [14].

II. Mathematical Model Formulation

In this paper we are going to study about unit load AS/RS, containing one aisle, two racks a, a robot, a conveyor and an

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S/R machine. The mathematical model is formed based on the following assumptions.

- S/R machine can carry only a unit load.
- The horizontal velocity, vertical velocity, loading time, unloading time and amount of power consumed of S/R machine, robot and the conveyor are predetermined.
- The initial state of each rack is known.
- The due dates of all customer orders are known.
- The item locations of storage and retrieval are unknown.
- Available working time for all facilities are known.
- Distance between input/output and storage/Retrieval locations are known.
- Over utilized and underutilized time are permissible and the corresponding costs are known.
- Total GHG emission by all facilities are known.
- Amount of energy consumed by S/R machine, robot and the conveyor are known.
- The GHG conversion factor [15, 16, 17 and 18] is known and constant
- Tax cost, penalty cost and discount cost are known.

A. *Indices*

I_c Item quantities requested by the customer c, $c = 1,2, \dots C$

I_s Item quantities supplied by the supplier s, $s = 1,2, \dots S$

i Number of item types, $i = 1,2, \dots N$

j Number of vertical locations, $j = 1,2, \dots J$

k Number of horizontal locations, $k = 1,2, \dots K$

m Number of S/R machines, $m = 1,2, \dots M$

R_r Rack r in a warehouse, $r = 1,2, \dots R$

B. *Parameters*

$Rack_{r.(k.j)}$ The item types stored in the locations $(k.j)$ in the rack r

$$Rack_{r.(k.j)} = \begin{cases} 1 & if\ the\ \ otem\ i\ is\ stored\ in\ location\ (k.j) \\ 0 & otherwise \end{cases}$$

H_v Horizontal velocity of AS/RS in m/s

V_v Vertical velocity of AS/RS in m/s

t_{ss} Storage time of an item on location by S/R machine

t_{rs} Retrieval time of an item on location by S/R machine

t_{lc} Loading time of an item on S/R machine by the conveyor

t_{uc} Unloading time of an item on S/R machine by the conveyor

t_{lr} Loading time of an item on conveyor by the robot

t_{ur} Unloading time of an item on conveyor by the robot

T Maximum working time of normal shifts in AS/RS warehouse

P_s Amount of power consumed in kW by S/R machine

P_c Amount of power consumed in kW by conveyor

P_r Amount of power consumed in kW by robots

f_c Conversion factor of greenhouse gas

$tdc_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)}$ Travel time of dc cycle request of the customer c for an item i in rack r

O_t Over time working of AS/RS warehouse (greater than T)

U_t Under time working of AS/RS warehouse (greater than T)

G_p Permissible amount of GHG produced by all facilities

G_o Over GHG produced by all facilities (more than G_p)

G_u Under GHG produced by all facilities (less than G_p)

C_{O_t} Cost for over time working of AS/RS warehouse

C_{U_t} Cost for under time working of AS/RS warehouse

C_T Tax cost for a kg GHG produced.

C_P Penalty cost for a kg GHG produced

C_D Discount cost for a kg GHG produced

TC Total cost by all the facilities

C. *Decision Variables*

$$X_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)} = \begin{cases} 1 & if\ the\ requiest\ of\ customer\ c\ for\ the\ item\ i\ in\ rack\ r \\ & with\ the\ location\ k_1 j_1 (storage)\ and\ k_2 j_2 (retrieval) \\ 0 & otherwise \end{cases}$$

D. *Objective Functions*

$$\begin{aligned} &Min\ TC \\ &= [U_t \times C_{U_t}] + [O_t \times C_{O_t}] + C_T \times f_c \\ &\times \left[\begin{array}{l} P_s \times \left[\sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{i=1}^{n} \sum_{k_1=1}^{K} \sum_{k_2=1}^{K} \sum_{j_1=1}^{J} \sum_{j_2=1}^{J} X_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)} \times tdc_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)} \right] \\ + P_c \times \left[\left(t_{lc} . \sum_{s=1}^{S} I_s \right) + \left(t_{uc} . \sum_{c=1}^{C} I_c \right) \right] + P_c \times \left[\left(t_{lr} . \sum_{s=1}^{S} I_s \right) + \left(t_{ur} . \sum_{c=1}^{C} I_c \right) \right] \end{array} \right] \\ &+ [(G_o \times C_P) - (G_u \times C_d)] \end{aligned} \quad (1)$$

$$\text{Where } tdc_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)} = \max\left\{\frac{k_1}{H_v}.\frac{j_1}{V_v}\right\} + t_{ss} + \max\left\{\frac{|k_1-k_2|}{H_v}.\frac{|j_1-j_2|}{V_v}\right\} + t_{rs} + \max\left\{\frac{k_2}{H_v}.\frac{j_2}{V_v}\right\} \quad (2)$$

Such that

$$\sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{i=1}^{n} \sum_{k_1=1}^{K} \sum_{k_2=1}^{K} \sum_{j_1=1}^{J} \sum_{j_2=1}^{J} X_{(I_c.i).R_r.(k_1 k_2 j_1 j_2)} = 1 \quad (3)$$

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$$\left[\sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{i=1}^{n}\sum_{k_1=1}^{K}\sum_{k_2=1}^{K}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} X_{(I_c.i).R_r.(k_1k_2j_1j_2)} \times tdc_{(I_c.i).R_r.(k_1k_2j_1j_2)}\right] + U_t - O_t = T.m \qquad (4)$$

$$f_c.\left[P_s \times \left[\sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{i=1}^{n}\sum_{k_1=1}^{K}\sum_{k_2=1}^{K}\sum_{j_1=1}^{J}\sum_{j_2=1}^{J} X_{(I_c.i).R_r.(k_1k_2j_1j_2)} \times tdc_{(I_c.i).R_r.(k_1k_2j_1j_2)}\right] + P_c \times \left[\left(t_{lc}.\sum_{s=1}^{S} I_s\right) + \left(t_{uc}.\sum_{c=1}^{C} I_c\right)\right] + P_c \times \left[\left(t_{lr}.\sum_{s=1}^{S} I_s\right) + \left(t_{ur}.\sum_{c=1}^{C} I_c\right)\right]\right] + U_e - O_e = 1 \qquad (5)$$

III. Implementation of Artificial Immune System

In bio immune system antigens are the infecting pathogens such as viruses or bacteria's and antibodies are cells within the human body which destroys the antigen. In employee scheduling the potential solution generated by the algorithm is referred as an antibody and the best solution obtained using AIS is the antigen. The potential solution is calculated as fitness of the solution in terms of cost function. There are three types of libraries in AIS called antigen library, antibody library and Final solution library. Antigen library consists of set of potential solution for the upcoming generation. We generate antibody library through cloning and affinity mutation of the antigen library. The best solutions among all the iterations are accumulated in the final solution library. From this library one of best solution is selected and remaining kept in memory for the future usage.

Steps Involved In the General Artificial Immune System Algorithm

Step 1: Define the problem size and threshold, initialize the random population of strings (represents the possible solution) up to the specified population which becomes an antigen library.

Step 2: We find the objective function value (OFV) and also the affinity value of each string using the relation

$$Affinity = 1/OFV$$

By the above equation affinity value increases as the OFV decreases. Depending on the value of affinity of each string the selection process is done.

Step 3: The rate of cloning of each string is calculated using the formula

$$Rate\ of\ cloning = affiniy\ value\ \times population\ size$$

Step 4: Each cloned cell undergoes mutation in terms of inverse mutation and pair wise mutation.

Step 4a: Inverse Mutation:

We have to generate some random positions between (1, n) of the original string, where n is the number of AGVs in the manufacturing process. Then we have to select two positions randomly for mutation, let it be 1 and 5. Then inverse mutation is obtained by reversing the order of the sequence between the positions 1 and 5 as given below

Original string → 5 1 6 2 7 9 4 8 3 10
Mutated string ← 7 2 6 1 5 9 4 8 3 10

After inverse mutation, OFV of the mutated string is calculated. If the OFV of the mutated string is less than the original string, then the original string is replaced by mutated string, otherwise pair wise mutation is done for the original string.

Step 4b: Pair wise Mutation:

We have to generate some random positions between (1, n) of the original string, where n is the number of AGVs in the manufacturing process. Then we have to select two positions randomly for mutation, let it be 1 and 5. Then pairwise mutation is obtained by reversing the order of the sequence between the positions 1 and 5 as given below

Original string → 5 1 6 2 7 9 4 8 3 10
Mutated string ← 7 2 6 1 5 9 4 8 3 10

After pair wise mutation, OFV of the mutated string is calculated. If the OFV of the mutated string is less than the original string, then the original string is replaced by mutated string, otherwise the original sequence is retained as it is.

Step 5: After cloning and mutation process, we reselect the improved strings to maintain the original population. The solution with highest OFV in the population is replaced by randomly generated solutions with lowest OFV, which forms an antibody library.

Step 6: Evaluate the fitness value of the antibodies.

Step 7: If the fitness value is less than the threshold value, select and move the solution to Final solution library, otherwise go to step 1.

Step 8: The Steps 1-7 is repeated for multiple runs till we get a desired solution.

Flow chart for the proposed algorithm is given in the figure 1.

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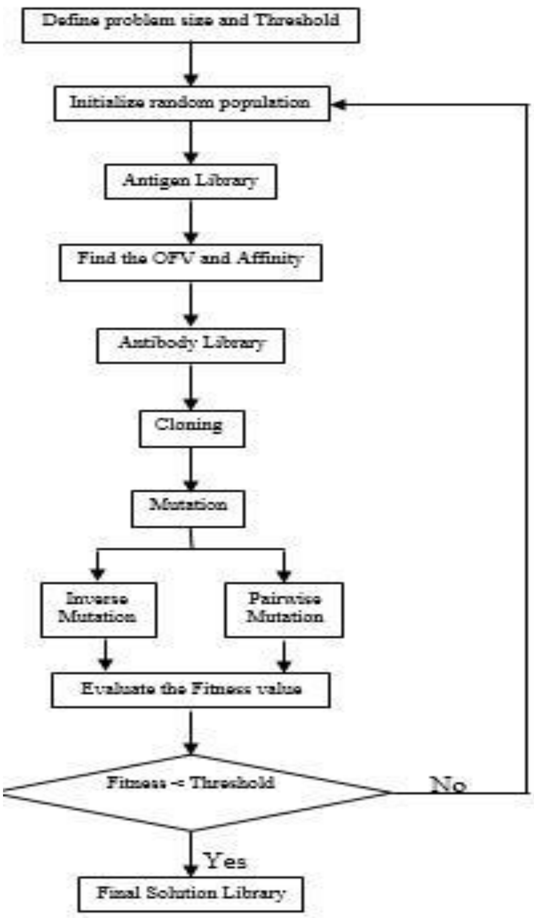

Figure 1: Flow chart of proposed algorithm

IV. COMPUTATIONS AND RESULTS

The initial data of AS/RS system are given as follows

- Number of rack = 2
- Number of Aisles = 1
- Number of S/R machines, $m = 1$
- Number of locations in a row = 10
- Number of locations in a column = 20
- Number of item types in each rack = 20
- Number of customers, $c = 4$
- Number of Supplier, $s = 4$
- Horizontal velocity of S/R machine, $H_v = 4$
- Vertical velocity of S/R machine, $V_v = 0.9$
- Loading/Unloading time of facilities, $t_{ss}.t_{rs} = 8$, $t_{lc}.t_{uc} = 9$ and $t_{lr}.t_{ur} = 4$
- Amount of power consumed in kW by all the equipment, $P_s = 1172$, $P_c = 5.4$ and $P_r = 4$
- Time performance cost($/s), $C_{O_t} = 0.002$ and $C_{U_t} = 0.001$
- GHG emission cost($/s), $C_T = 0.1$, $C_P = 0.15$ and $C_D = 0.08$
- Permissible amount of GHG, $G_p = 200(kg)$
- GHG conversion factor, $f_c = 1.0508 \times 10^5$

The proposed algorithm has to be coded in the MATLAB R2012a (7.14.0.739), 64-bit (win64). All the tests were performed on an Intel core i5 processor with the Microsoft Windows 7 (64-bit) operating system.

The obtained results are tabulated in the table 1. A comparison analysis is given in the table 2, 3, and 4 and also established in the figures 3, 4, 5 and 6.

Table1: The detailed result of AIS for Total cost of GHG, CPU time and cost produced by emission of GHG.

Size of the problem	Number of S/R orders	Total cost of GHG model	CPU time of GHG model	Cost produced by the emission of GHG
Small	100	25.38	75.48	3.03
	200	28.35	148.25	7.35
	300	35.27	236.45	15.52
	400	40.29	315.28	25.34
	500	46.17	385.65	35.54
Medium	600	51.28	477.25	42.95
	700	60.36	526.25	49.65
	800	65.56	627.54	57.62
	900	70.36	725.26	70.24
	1000	102.54	800.25	85.45

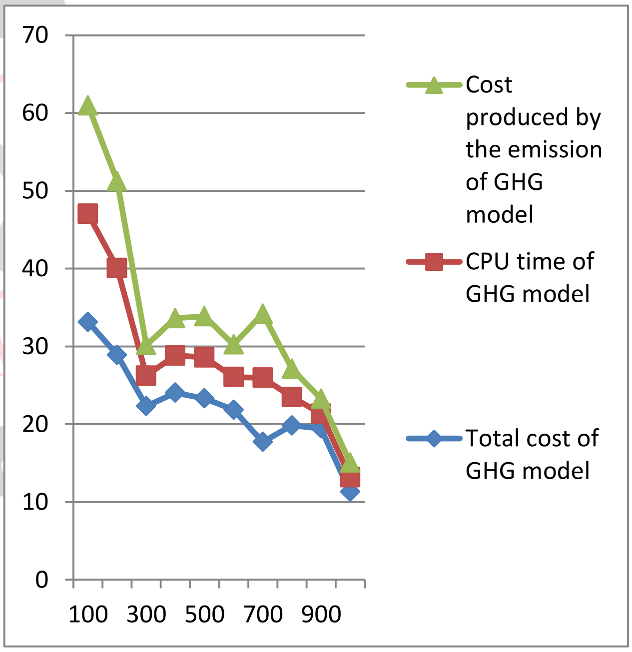

Figure 3: Improvements of AIS

Table 2: Total cost of GHG model

Size of the problem	Number of S/R orders	Total Cost ($)			Improvement
		ACO	GA	AIS	
Small	100	38.63	30.48	25.38	33.1364829
	200	44.39	33.27	28.35	28.9149384
	300	53.11	39.21	35.27	22.3157358
	400	61.43	46.46	40.29	24.0421868
	500	68.35	53.69	46.17	23.3190538
Medium	600	75.08	59.8	51.28	21.8561873
	700	83.33	67.4	60.36	17.7299703
	800	93.13	75.57	65.56	19.8491465
	900	108.8	81.73	70.36	19.4543007
	1000	144.1	115.6	102.5	11.32255

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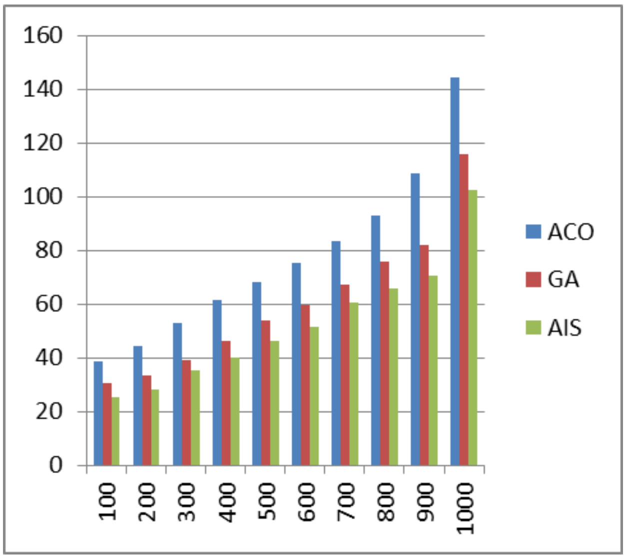

Figure 4: Total cost comparison of AIS with ACO and GA

Table 3: CPU time of GHG model

Size of the problem	Number of S/R orders	CPU time (s)			Improvement
		ACO	GA	AIS	
Small	100	92.48	81.87	75.48	13.9123
	200	185.49	160.4	148.2	11.171475
	300	253.37	242.9	236.4	3.92213351
	400	339.72	322.7	315.2	4.79318358
	500	412.27	401.8	385.6	5.27324308
Medium	600	525.89	492.9	477.2	4.19920884
	700	606.97	568.0	526.2	8.24032673
	800	678.58	646.1	62	3.65245922
	900	749.84	734.2	725.2	1.90801749
	1000	802.25	810.3	800.2	1.86460339

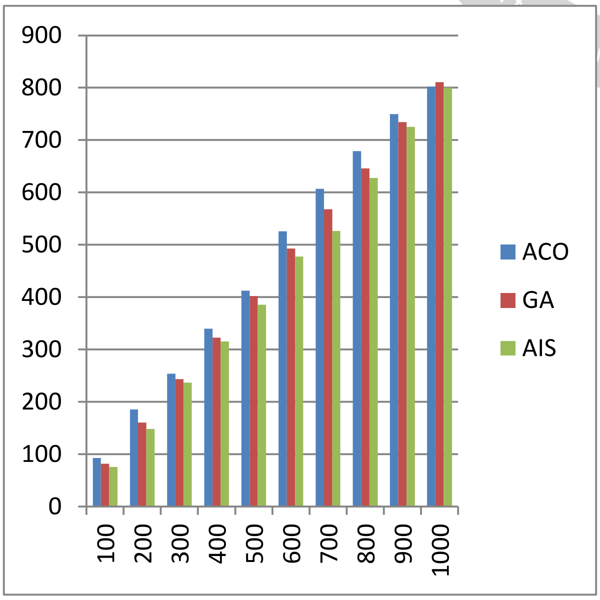

Figure 5: CPU time comparison of AIS with ACO and GA

Table 4: Cost produced by the emission of GHG model

Size of the problem	Number of S/R orders	Cost produced by GHG			Improvement
		ACO	GA	AIS	
Small	100	11.84	4.08	3.03	50.73529
	200	20.1	9.47	7.35	44.561774
	300	33.67	20.52	15.52	38.986354
	400	46.09	30.77	25.34	33.896652
	500	56.2	41.59	35.54	26.568886
Medium	600	66.7	50.55	42.95	28.882294
	700	77.52	62.02	49.65	31.231860
	800	92.85	74.45	57.62	32.008059
	900	103.82	81.5	70.24	19.950920
	1000	125.29	102.1	85.45	21.166095

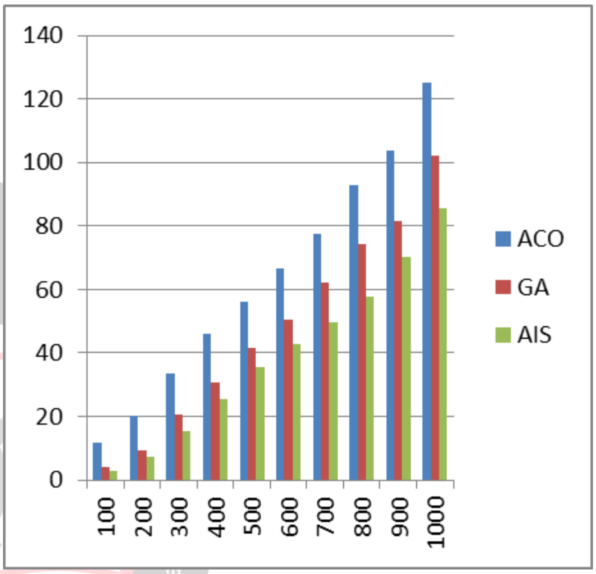

Figure 6: Total cost produced by GHG emission comparison of AIS with ACO and GA

A comparison analysis is shown in the figure 4, 5 and 6, which shows that AIS reduces the Total cost, CPU time and Cost produced by GHG compared to other two algorithms namely GA and ACO.

V. CONCLUSION

The paper mainly concentrated on GHG emission produced by automated storage and retrieval systems. The main intention is to reduce the cost of GHG emission. A mathematical model was framed consisting of tax cost, penalty cost, discount cost and time constraints of loading and unloading of S/R machines, robots and conveyors. To analyse the model, an Artificial Immune System method is used. The results were simulated using Mat lab and compared with other two algorithms, namely Ant Colony and Genetic Algorithm. It was observed that the proposed algorithm yields a better result for small, medium and large number of requested orders but merely same results for the Extra-large number of requested orders. Therefore the same model can be solved using other hybrid algorithm to get a best result.

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