Mathematical Optimization Algorithm for Minimizing the Cost Function of GHG Emission in AS/RS Using Positive Selection Based Clonal Selection Principle

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Abstract. This paper regards with the minimization of total cost of Greenhouse Gas (GHG) efficiency in Automated Storage and Retrieval System (AS/RS). A mathematical model is constructed based on tax cost, penalty cost and discount cost of GHG emission of AS/RS. A two stage algorithm namely positive selection based clonal selection principle (PSBCSP) is used to find the optimal solution of the constructed model. In the first stage positive selection principle is used to reduce the search space of the optimal solution by fixing a threshold value. In the later stage clonal selection principle is used to generate best solutions. The obtained results are compared with other existing algorithms in the literature, which shows that the proposed algorithm yields a better result compared to others.

1. 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, 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 labor 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, 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 a two stage Positive Selection Based Clonal Selection Principle (PSBCSP) algorithm is used in order to minimize the total cost function of GHG emission in AS/RS. Positive selection algorithm is developed by Seiden and Celeda in 1992 [7]. The main function positive selection algorithm [8] is to distinguish between the good and solutions in order to retain the good solution for future step and discard the bad solution permanently from the system. And the main objective of clonal selection principle [9, 10] is to select the best antibody for cloning and
mutation in order to destroy the antigens. There two types of cells namely B-cells and T-cells for clonal selection principle. B-cell based clonal selection algorithm plays a vital role in solving various scheduling problems [11, 12, 13 and 14]. Both positive selection and clonal selection principle are combined to get a positive selection based clonal selection principle algorithm [15].

2. **Mathematical model**

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 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 [16, 17, 18 and 19] is known and constant
- Tax cost, penalty cost and discount cost are known

2.1. **Indices**

- $I_c$: Item quantities requested by the customer $c$, $c = 1,2, ... C$
- $I_s$: Item quantities supplied by the supplier $s$, $s = 1,2, ... S$
- $i$: Number of item types, $i = 1,2, ... N$
- $j$: Number of vertical locations, $j = 1,2, ... J$
- $k$: Number of horizontal locations, $k = 1,2, ... K$
- $m$: Number of S/R machines, $m = 1,2, ... M$
- $R_r$: Rack $r$ in a warehouse, $r = 1,2, ... R$

2.2. **Parameters**

- $Rack_{r,(k,j)}$: The item types stored in the locations $(k,j)$ in the rack $r$
- $H_v$: 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
- $t_{tr}$: 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
\( t_{dc(l,c),R_r,(k_1k_2j_1j_2)} \) 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

2.3. Decision Variables

\[ X_{(l,c),R_r,(k_1k_2j_1j_2)} = \begin{cases} 1 & \text{if the request of customer } c \text{ for the item } i \text{ in rack } r \\ & \text{with the location } k_1j_1 \text{(storage) and } k_2j_2 \text{(retrieval)} \\ 0 & \text{otherwise} \end{cases} \]

2.4. Objective Function

\[
\begin{align*}
\text{Min } TC & = \left[ U_t \times C_{O_t} \right] + \left[ O_t \times C_{O_t} \right] + C_T \times f_c \\
& = \left[ C_r \times \sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{i=1}^{n} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{j=1}^{J} X_{(l,c),R_r,(k_1k_2j_1j_2)} \times t_{dc(l,c),R_r,(k_1k_2j_1j_2)} \right] \\
& + P_c \times \left[ \left( t_{lc} \times \sum_{r=1}^{S} I_r \right) + \left( t_{uc} \times \sum_{r=1}^{C} I_r \right) \right] + \left[ t_{r} \times \sum_{s=1}^{S} I_s \right] + \left( t_{u} \times \sum_{c=1}^{C} I_c \right) \\
& + \left[ (G_o \times C_p) - (G_u \times C_d) \right]
\end{align*}
\]

Where \( t_{dc(l,c),R_r,(k_1k_2j_1j_2)} = \max \left[ \frac{k_1}{H_p}, \frac{j_1}{V_p} \right] + t_{ss} + \max \left[ \frac{|k_1-k_2|}{H_p}, \frac{|j_1-j_2|}{V_p} \right] + \\
t_{rs} + \max \left[ \frac{k_2}{H_p}, \frac{j_2}{V_p} \right] \] (1)

\[
\left[ \sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{i=1}^{n} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{j=1}^{J} X_{(l,c),R_r,(k_1k_2j_1j_2)} \times t_{dc(l,c),R_r,(k_1k_2j_1j_2)} \right] \\
+ U_t - O_t = T \cdot m
\] (4)

Such that

\[
\sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{i=1}^{n} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{j=1}^{J} X_{(l,c),R_r,(k_1k_2j_1j_2)} = 1
\] (3)
\[
f_c = P_s \times \left[ \sum_{c=1}^{C} \sum_{r=1}^{R} \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{j_2=1}^{J} X(i_{c,0}, R_r(k, k_2, j_1, j_2)) \times \text{tdc}(i_{c,0}, R_r(k, k_2, j_1, j_2)) \right] \\
+ P_c \times \left[ \left( t_{ic} \sum_{s=1}^{S} l_s \right) + \left( t_{uc} \sum_{c=1}^{C} l_c \right) \right] + P_r \times \left[ \left( t_{ir} \sum_{s=1}^{S} l_s \right) + \left( t_{ur} \sum_{c=1}^{C} l_c \right) \right] \\
+ U_e - O_e = 1
\]

3. Implementation of Positive Selection Based Clonal Selection Principle

The method is explained in two stages. In the first stage, positive selection algorithm is used and in the second stage, clonal selection principle is applied.

3.1. Positive Selection Algorithm

Upon the generation of the initial solution to the problem, the main function of positive selection principle algorithm is to distinguish between the good and bad solution in order to discard bad solution from the system. In the human body, good solutions represent the antibodies which recognizes and overcomes the antigen. The following figure 1 represents the working rule of positive selection principle in the human body.

![Figure 1: Positive Selection Algorithm](image)

Consider a case of infection (viral, bacterial) attacking the human body. The string \( S \) is the set of antigens attacking the human body which has to be destroyed. Potential Repertoire (P) represents the potentially T-cells in human immune system. To destroy the antigens, we need the cells which can overcome the antigen. Therefore all cells in the human body are tested to find whether they recognize the antigen or not. The cells which possess capacity of recognition of the antigens are called Available Repertoire (A), which will be retained for further usage of destroying the antigens. The remaining cells which fails in the recognition of antigens are discarded from the system. The positive selection algorithm is applied for filtering purposes. Those solutions satisfying certain criteria is retained, other solutions are completely discarded from the system. To check the satisfaction level of the solution, we are fixing a threshold value. A solution is retained if the optimal value of the solution is less than the threshold, otherwise it is completely discarded from the system.

3.2. Clonal Selection Algorithm

The clonal selection algorithm is based on the working principle of human immune system. B-cells along with the T-cells will destroy the various viruses and bacteria which attacks the human body. But it has been observed that B-cells has unique tendency to clone those cells which are capable of destroying...
antigens attacking the human body. Upon the attack of antigen a particular string formation of B-cells are done to overcome the infection. The cell will clone for a large amount to produce high capacity antibodies to overcome the antigen. Usually B-cells themselves under goes process of cloning and mutation repeatedly to recognize the right solution to destroy the antigens. The flow for the positive selection based clonal selection principle algorithm is given in the figure 2.

Figure 2: Flow chart of the proposed Algorithm
4. Result and Discussion
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, \( t_{sr}, t_{rs} = 8, t_{ic}, t_{uc} = 9 \) and \( t_{ir}, t_{ur} = 4 \)
- 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_{Ot} = 0.002 \) and \( C_{Ut} = 0.001 \)
- GHG emission cost($/s), \( C_{r} = 0.1, C_{p} = 0.15 \) 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 PSBCSP 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 GHG emission |
|---------------------|----------------------|-------------------------|-----------------------|-------------------------------|
| Small               | 100                  | 20.38                   | 70.48                 | 2.01                          |
|                     | 200                  | 23.65                   | 142.25                | 5.25                          |
|                     | 300                  | 30.46                   | 233.45                | 12.52                         |
|                     | 400                  | 35.29                   | 307.28                | 20.34                         |
|                     | 500                  | 41.17                   | 380.65                | 30.54                         |
| Medium              | 600                  | 46.73                   | 472.25                | 35.95                         |
|                     | 700                  | 55.45                   | 521.25                | 42.65                         |
|                     | 800                  | 60.57                   | 622.54                | 50.62                         |
|                     | 900                  | 65.83                   | 720.26                | 65.24                         |
|                     | 1000                 | 102.52                  | 795.25                | 80.45                         |
| Large               | 1100                 | 110.52                  | 865.21                | 92.56                         |
|                     | 1200                 | 134.62                  | 964.21                | 99.67                         |
|                     | 1300                 | 158.35                  | 1011.25               | 110.32                        |
|                     | 1400                 | 177.23                  | 1001.24               | 131.21                        |
|                     | 1500                 | 220.24                  | 1266.14               | 146.95                        |
| Extra Large         | 1600                 | 255.38                  | 1358.36               | 172.21                        |
|                     | 1700                 | 260.25                  | 1465.87               | 181.25                        |
|                     | 1800                 | 263.24                  | 1425.32               | 189.21                        |
|                     | 1900                 | 264.58                  | 1673.43               | 190.58                        |
|                     | 2000                 | 274.67                  | 1699.37               | 197.21                        |
Figure 3: Improvements of PSBCSP

Table 2: Total cost of GHG model

| Size of the problem | Number of S/R orders | Total Cost ($) | Improvement |
|---------------------|-----------------------|----------------|-------------|
|                     |                       | ACO | GA | PSBCSP |               |
| Small               | 100                    | 38.63 | 30.48 | 20.38 | 33.1364829 |
|                     | 200                    | 44.39 | 33.27 | 23.65 | 28.9149384 |
|                     | 300                    | 53.11 | 39.21 | 30.46 | 22.3157358 |
|                     | 400                    | 61.43 | 46.46 | 35.29 | 24.0421868 |
|                     | 500                    | 68.35 | 53.69 | 41.17 | 23.3190538 |
| Medium              | 600                    | 75.08 | 59.8 | 46.73 | 21.8561873 |
|                     | 700                    | 83.33 | 67.4 | 55.45 | 17.7299703 |
|                     | 800                    | 93.13 | 75.57 | 60.57 | 19.8491465 |
|                     | 900                    | 108.8 | 81.73 | 65.83 | 19.4543007 |
|                     | 1000                   | 144.19 | 115.61 | 102.52 | 11.32255 |
| Large               | 1100                   | 144.41 | 121.37 | 110.52 | 8.93960616 |
|                     | 1200                   | 177.13 | 144.5 | 134.62 | 6.83737024 |
|                     | 1300                   | 212.07 | 173.63 | 158.35 | 8.80032252 |
|                     | 1400                   | 226.55 | 188.34 | 177.23 | 5.89890623 |
|                     | 1500                   | 264.33 | 227.34 | 220.24 | 3.12307557 |
| Extra Large         | 1600                   | 310.75 | 257.89 | 255.38 | 0.97328318 |
|                     | 1700                   | 307.02 | 262.2 | 260.25 | 0.36231884 |
|                     | 1800                   | 307.75 | 265.78 | 263.24 | 0.95677628 |
|                     | 1900                   | 315.14 | 267.14 | 264.58 | 0.95829901 |
|                     | 2000                   | 324.96 | 276.18 | 274.67 | 0.54674487 |
Figure 4: Total cost comparison of PSBCSP 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          | PSBCSP      |             |
| Small               | 100                   | 92.48        | 81.87       | 70.48       | 13.9123     |
|                     | 200                   | 185.49       | 160.14      | 142.25      | 11.171475   |
|                     | 300                   | 253.37       | 242.98      | 233.45      | 3.92213351  |
|                     | 400                   | 339.72       | 322.75      | 307.28      | 4.79318358  |
|                     | 500                   | 412.27       | 401.84      | 380.65      | 5.27324308  |
| Medium              | 600                   | 525.89       | 492.95      | 472.25      | 4.19920884  |
|                     | 700                   | 606.97       | 568.06      | 521.25      | 4.24032673  |
|                     | 800                   | 678.58       | 646.14      | 622.54      | 3.65245922  |
|                     | 900                   | 749.84       | 734.27      | 720.26      | 1.90801749  |
|                     | 1000                  | 802.25       | 810.36      | 795.25      | 1.86460339  |
| Large               | 1100                  | 891.05       | 913.53      | 865.21      | 5.289372    |
|                     | 1200                  | 978.88       | 991.12      | 964.21      | 2.71511018  |
|                     | 1300                  | 1111.92      | 1058.06     | 1011.25     | 4.42413474  |
|                     | 1400                  | 1048.96      | 1185.43     | 1001.24     | 15.5378217  |
|                     | 1500                  | 1276.62      | 1266.77     | 1266.14     | 0.04973278  |
| Extra Large         | 1600                  | 1269.03      | 1326.66     | 1358.36     | -2.38945924 |
|                     | 1700                  | 1458.74      | 1430.43     | 1465.87     | -2.47757667 |
|                     | 1800                  | 1356.87      | 1411.65     | 1425.32     | -0.96837035 |
|                     | 1900                  | 1548.66      | 1629.72     | 1673.43     | -2.68205581 |
|                     | 2000                  | 1649.24      | 1673.48     | 1699.37     | -1.54707556 |
Figure 5: CPU time comparison of PSBCSP 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 emission | Improvement |
|---------------------|-----------------------|-------------------------------|-------------|
|                     |                       | ACO  | GA  | PSBCSP |
| Small               | 100                   | 11.84| 4.08| 2.01   | 50.7352941 |
|                     | 200                   | 20.1 | 9.47| 5.25   | 44.561774  |
|                     | 300                   | 33.67| 20.52|12.52  | 38.9863548 |
|                     | 400                   | 46.09| 30.77|20.34  | 33.8966526 |
|                     | 500                   | 56.2 | 41.59|30.54  | 26.5688868 |
| Medium              | 600                   | 66.7 | 50.55|35.95  | 28.8822948 |
|                     | 700                   | 77.52| 62.02|42.65  | 31.2318607 |
|                     | 800                   | 92.85| 74.45|50.62  | 32.0080591 |
|                     | 900                   | 103.82|81.5 |65.24  | 19.9509202 |
|                     | 1000                  | 125.29|102.05|80.45  | 21.1660951 |
| Large               | 1100                  | 125.44|105.56|92.56  | 12.3152709 |
|                     | 1200                  | 145.29|119.59|99.67  | 16.6569111 |
|                     | 1300                  | 166.49|137.26|110.32 | 19.6269853 |
|                     | 1400                  | 175.28|146.19|131.21 | 10.2469389 |
|                     | 1500                  | 198.19|169.85|146.95 | 13.4824845 |
| Extra Large         | 1600                  | 226.35|188.38|172.21 | 8.58371377 |
|                     | 1700                  | 224.1 | 191.01|181.25 | 5.10968012 |
|                     | 1800                  | 224.56|193.18|189.21 | 2.05507817 |
|                     | 1900                  | 229.06|194.03|190.58 | 1.77807555 |
|                     | 2000                  | 235.03|199.52|197.21 | 1.15777866 |
5. Result and Discussion
In this paper we have mainly concentrated on GHG emission produced by automated storage and retrieval systems. Our main intention to reduce the cost of GHG emission. We developed a mathematical model 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, a two stage positive selection based clonal selection principle is used. The results were simulated using Mat lab and compared with other two algorithms namely Ant Colony and Genetic Algorithm. It is 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 we can solve the same model using other hybrid algorithm to get a best result.

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