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Multiagent-based Layout System for a Pressurized Logistics Carrier in H-IIA Transfer Vehicle

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Abstract

This paper applies the concept of a *multiagent approach* to a cargo layout system in an H-IIA Transfer Vehicle (HTV) pressurized logistic carrier, and investigates how its layout system addresses the following critical issues in space applications: (1) performance and (2) robustness. Through intensive simulations, we have revealed the following implications: (1) the multiagent-based cargo layout system has potential for finding good satisfied solutions within a few seconds, which results in a high system performance; and (2) the proposed system can maintain or improve its performance even if the quantity and weight of the cargo is changed, which indicates the robustness of the system.

Keywords: multiagent-based approach, cargo layout system, H-IIA transfer vehicle, pressurized logistic carrier

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1 Introduction

When designing systems for ground stations such as a crew task scheduling for a space shuttle [11, 12], it is important to address the following issues: (1) performance and (2) robustness. The same can be said for the cargo layout system for a pressurized logistics carrier in an H-IIA Transfer Vehicle (HTV), which determines the location of all cargos in the carrier. Such placement of cargo is critical for an orbiting HTV due to the influence on its center of gravity, and therefore several aspects such as the shape or structure of an HTV pressurized logistics carrier [10] are investigated and its verification programs [5] are explored.

Considering the above two issues from the viewpoints of the cargo layout system for an HTV pressurized logistics carrier, the first issue, *performance*, should be improved by finding good satisfied solutions as quickly as possible (*i.e.*, the center of gravity of an HTV pressurized logistics carrier should be found as close as possible to the center of its carriers quickly). The second issue, *robustness*, should be also addressed to cope with changes in the quantity and weight of cargo.

To explore a cargo layout system that considers all of the two critical issues in an HTV pressurized logistics carrier, this paper focuses on *multiagent systems* [13] studied in computer science and aims to determine how a multiagent-based cargo layout system contributes to satisfy the above issues.

This paper is organized as follows. The next section starts by briefly introducing an HTV pressurized logistics carrier including its racks and cargos. Section 3 explains how the multiagent-based approach determines the location of all cargos in an HTV pressurized logistics carrier to satisfy strict conditions. Section 4 presents our simulation results and Section 5 discusses an effectiveness of a multiagent-based layout system in space applications. Finally, our conclusions are presented in Section 6.

2 HTV Pressurized Logistics Carrier

As shown in Figure 1, an HTV pressurized logistics carrier consists of two rack bays, *i.e.*, the No.1 and No.2 rack bays, and each of rack bay consists of four HTV Resupply Racks (HRRs) [8].

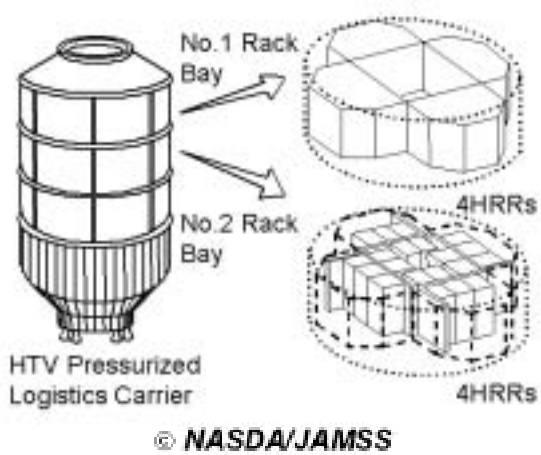

Figure 1: **HTV resupply rack (HRR)**

Focusing on one HRR, it is clear that HRRs consist of several Cargo Transfer Bags (CTBs) as shown in Figure 2. This figure, in particular, shows that an HRR consists of two types of CTBs, *i.e.*, the single-size CTB[1] represented by "A," and the half-size CTB represented by "B." In addition to these CTBs, the double- and triple-size CTBs must be considered as other types of CTBs.[2]

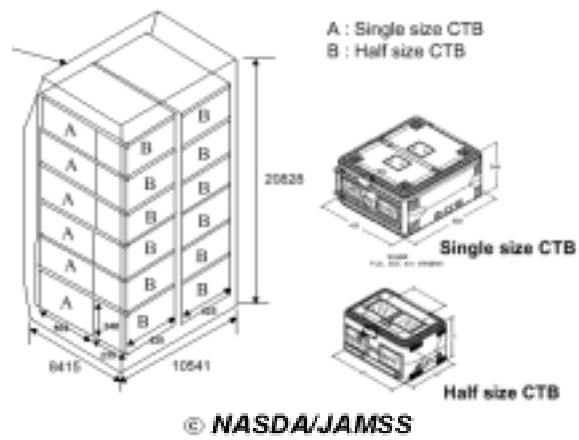

Figure 2: **Cargo transfer bag (CTB)**

Using these different types of CTBs, the goal of the cargo layout system for an HTV pressurized logistics carrier is to place all CTBs to make its center of gravity as close as possible to its actual center quickly. Because of the need for high precision, the center of gravity of an HTV pressurized logistics carrier must not exceed 25 *mm* from its center.

[1] This CTB is also called the full-size CTB.

[2] In an actual mission, the following materials also have to be included in addition to CTBs: (1) M01 and M02 bags, whose capacities are equal to six and four single CTBs, respectively; (2) ISPR (International Standard Payload Rack); (3) fuel; (4) water; (5) the exposed pallet [7]; and (6) the HRR frames (type I and II). We are currently implementing an extended cargo layout system that copes with all of the above materials.

3 Multiagent-based Layout System

3.1 Why a multiagent approach?

What is important here is that the quantity and weight of each CTB is different according to the space mission on its HTV. Since the placement of such CTBs directly affects the orbit of an HTV due to a change in the center of gravity of an HTV pressurized logistics carrier, the ground-based human operators should pay careful attention to determining the location of the CTBs. However, it is difficult to guarantee that human operators will perform perfect and correct operations.

To cope with this problem, this paper employs a *multiagent approach*, in which a CTB is implemented as an agent and each CTB independently moves and determines its own location to make the center of gravity of an HTV pressurized logistics carrier as close as possible to its actual center quickly. The reasons for employing a multiagent approach are related to the two critical issues, *performance* and *robustness*, described in Section 1. Detailed reasons are summarized as follows.

- **Performance**
  Focusing on scheduling problems as an aspect of the *constraint satisfaction problem* (CSP) [9] in the cargo layout system, many researches have investigated *scheduling theory* [2] based on *operations research* or *metaheuristics methods* such as genetic algorithms (GA) [4] or simulated annealing (SA) [1]. However, the former methods require a lot of time or huge computational costs to find optimal solutions, while the latter methods generally have to search solutions from the beginning again when some schedules are modified. In contrast to these methods, Fujita and Iima showed that a multiagent approach could find good schedules in a reasonable time for rescheduling problems [3, 6]. Our previous research also found that the multiagent approach is capable of finding good feasible solutions quickly, even though the solutions may not be optimal [11].

- **Robustness**
  In constraint satisfaction problems, even small modifications generally affect whole systems. For example, solutions change when some objects that should satisfy constraints are added/removed or their attributes are changed. To explore approaches that are robust to small modifications, our previous research investigated the robustness of the multiagent approach and found that it is highly capable at dealing with anomalies occurring in a scheduling domain [12].

3.2 Algorithm of cargo layout system

To apply the above advantages of the multiagent approach into the cargo layout system for an HTV pressurized logistics carrier, we propose the following algorithms.

1. **CTB type determination**
   First, the system chooses the CTB type from the largest size (the triple-size) to the smallest size (the half-size). This is simply because the largest size of the CTBs has a greater chance of affecting the center of gravity of an HTV pressurized logistics carrier.

2. **CTB selection**
   Next, the system selects one CTB whose type is determined in 1.

3. **CTB search**
   The selected CTB temporarily moves from the current location to one unit[3] upper, lower, right, and left of its original location, then the CTB returns to its original position and

[3] The *unit* is determined by a human designer. In our system, one unit is determined by the smallest-sized CTB (*i.e.*, the half-size CTB).

is also temporarily exchanged with a randomly selected CTB. During these movements and exchanges, each center of gravity of a HTV pressurized logistics carrier is stored in the system.

4. **CTB move or exchange**
   If one of the stored of center of gravity is lower than that of the original location, the selected CTB is moved or exchanged to lower the center of gravity.

5. **CTB loop check**
   If one of CTBs changes its location according to the movement or exchange in 4., then return to 2.; otherwise go to 6.

6. **CTB type check**
   Finally, the system checks whether all CTB types (from the half-size CTB to the triple-size CTB) cannot change their locations further to minimize the difference between the center of gravity of a HTV pressurized logistics carrier and its center. If they cannot change anymore, then finish; otherwise return to 1.

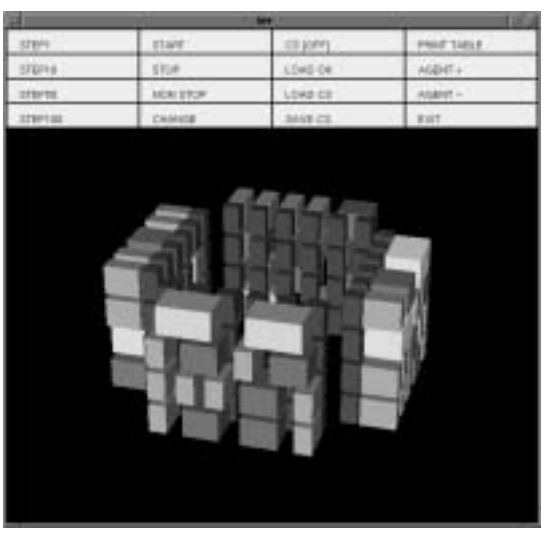

Figure 3: **Cargo layout system**

These algorithm are executed by the system's Graphical User Interface (GUI) as shown in Figure 3.

4 Simulation

4.1 Simulation design

In the following, we present a simulation that investigates the effectiveness of a multiagent approach in the cargo layout system for an HTV pressurized logistics carrier. Specifically, we investigated the four cases as shown in Figure 4. In case 1, both the quantity and weight of CTBs are fixed in advance; in case 2, the quantity of CTBs is fixed in advance, while the weight of CTBs is determined at random; in case 3, both the quantity and weight of CTBs are determined at random; and, in case 4 both the quantity and weight of CTBs are changed after the placement of all CTBs in case 3.

	Case 1	Case 2	Case 3	Case 4
Quantity of CTBs	Fix		Random	Change
Weight of CTBs	Fix	Random		Change

Figure 4: **Simulation cases**

The capacity of an HTV pressurized logistics carrier in this simulation is 144 calculated from its structure. To understand the meaning of this capacity, supposing that the quantities of each type of CTB are prepared as shown in the fix column of Table 1, its capacity is calculated as $144 = (96 \times 0.5(half) + 40 \times 1(single) + 16 \times 2(double) + 8 \times 3(trible))$. Note that the quantity of CTBs in cases 1 and 2 shown in Table 1 makes it easy to bring the center of gravity of an HTV pressurized logistics carrier close to its actual center. This is because, an average, the multiples of four CTBs contribute to balancing the four sides (*i.e.*, upper, lower, right, and left sides) of an HTV pres-

surized logistics carrier. In cases 3 and 4, on the other hand, the quantity of each CTB type is determined at random under the condition that the total capacity is 144 shown in the same table.

Table 1: **Number of CTBs**

CTB type	Fix	Random
Half-size	96	?
Single-size	40	?
Double-size	16	?
Triple-size	8	?
Total capacity	144	144

The average weight of each CTB is determined as shown in Table 2. Based on this setting, the weight of CTBs in case 1 is set as the same values shown in the table. In cases 2, 3 and 4, however, the weight of CTBs is determined at random around the average weight as shown in Table 2.

Table 2: **Weight of CTBs**

CTB type	Average weight (kg)
Half-size	6.0
Single-size	12.0
Double-size	24.0
Triple-size	36.0

Specifically, in case 4, the following were tested after case 3 was completed: (a) one half-size CTB is removed; (b) one single-size CTB is removed; (c) the weight of one double-size CTB is changed, *decreasing* from 21.0 (kg) to 12.0 (kg); and (d) the weight of one triple-size CTB is changed, *increasing* from 18.0 (kg) to 25.0 (kg).

4.2 Evaluation criteria

The following two indexes are employed as evaluation criteria in this simulation and in this paper the *performance* is defined as a criterion that considers the two indexes.

$$\begin{aligned} Solution = \quad & |HTVgx - 0.0| + |HTVgy - 0.0| + \\ & |HTVgz - 0.0| \\ Cost = \quad & Search\_by\_MoveExchange(triple) + \\ & Search\_by\_MoveExchange(double) + \\ & Search\_by\_MoveExchange(single) + \\ & Search\_by\_MoveExchange(half) \end{aligned}$$

The first index (*solution*) evaluates the difference between the center of gravity of an HTV pressurized logistics carrier and its center. In this case, the center is set as the datum point (0.0, 0.0, 0.0). Note that (1) $HTVgx$, $HTVgy$, and $HTVgz$ indicate the x, y, and z center of gravity of an HTV pressurized logistics carrier, respectively; and (2) a unit of this criterion is "*mm*."

The second index (*cost*), on the other hand, adds the number of temporal movements and exchanges of each CTB type to determine their placements in order to minimize the above difference. For example, $Search\_by\_MoveExchange$ (*triple*) means the numbers count how many times all *triple* -size CTBs temporarily move to other locations or exchange places with other CTBs to determine the placements that makes the center of gravity of an HTV pressurized logistics carrier as close as possible to its actual center. Note that this index does not represent the number of actual moved or exchanged CTBs, but the number of CTBs temporarily moved or exchanged while searching for good placements.

4.3 Simulation results

Figure 5 shows both solutions and costs in cases 1, 2, and 3, represented by black and white boxes, respectively. The left axis indicates solutions; the right axis indicates costs; and the horizontal axis indicates the three cases. Figure 6 shows both solutions and costs in case 4. Both black and white boxes and both left and right axes have the same meanings of those in Figure 5. The horizontal axes indicate four sub-cases from (a) to (d). Note that

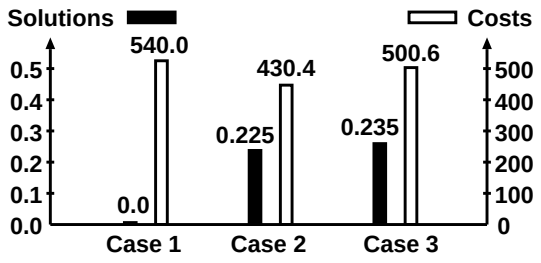

Figure 5: **Simulation (Cases 1 to 3)**

(1) both results in Figures 5 and 6 are averaged from five different random seeds; and (2) all results are calculated within a few seconds.

From these results, we find the following implications: From cases from 1 to 3, (1-a) the multiagent approach derives good solutions that are close to the datum point. In particular, the perfect solution is found in case 1; (1-b) the costs are small and reasonable because only three or four temporal movements or exchanges are required for each CTB to find good solutions. For example, case 1 only requires $3.375 = 540.0 - (96 + 40 + 16 + 8)$ temporal movements or exchanges for each CTB. From case 4, (2-a) the solutions do not deteriorate but rather improve against those in case 3, in spite of the small search area (because CTBs in case 4 do not start from the beginning but restart from the final placements in case 3); (2-b) the costs in case 4 are lower than those of case 3. In particular, the case of removing CTBs contributes to reducing the costs in comparison with the case of changing the weights of CTBs.

5 Discussion

5.1 Performance and robustness

From the simulation results, we found that the proposed multiagent-based layout system for an HTV pressurized logistics carrier shows its effectiveness in terms of *performance* and *robustness* as follows.

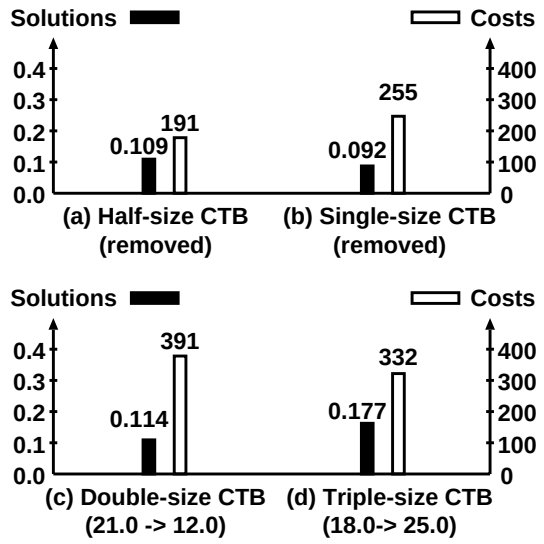

Figure 6: **Simulation (Case 4)**

- **Performance**
  First, cases 1 to 3 show that the proposed system derives good solutions within a few seconds, satisfying a strict condition that the center of gravity of an HTV pressurized logistics carrier does not exceed 25 *mm*. Worthy of note here is that such a high performance can always be maintained, even with different quantities and weights of the CTBs.

- **Robustness**
  Next, case 4 indicates that the proposed system performs better, even though the quantity and weights of the CTBs are changed after they are all placed. What should be noted here is that such a high robustness is found in spite of the small search area in case 4 in comparison with case 3. In particular, this robustness contributes to reducing in astronauts' workloads when replacing the CTBs in HRRs in preparation of re-entry, retiring the HTV, or for some mission changes.

These are the great potentials of the multiagent-based layout system. Therefore, why can the system derive such good performance and show such a

high robustness? Some reasons are summarized as follows: (1) the phased reduction of search space from the triple-size CTBs to the half-size CTBs contributes to finding good solutions in the same way as the mechanism of simulated annealing; and (2) the combination of *local search* and *global information* contributes to reducing costs, where the local search is operated by the movement or exchange of each CTB, while all CTBs can utilize the current center of gravity of an HTV pressurized logistics carrier as the global information.

5.2 Other potential advantages

In addition to the good performance and high robustness of the multiagent-based layout system, other potential advantages are summarized as follows.

- **Support for human ground-based operators**
  The proposed system enables human operators at ground stations to easily check and modify the placement of CTBs by employing the GUI shown in Figure 3. The system also can calculate the placements of all CTBs within a few seconds. These features and capabilities of the system contribute to (1) reducing the load of ground-based operations and (2) preventing mistakes by human operators.
- **Reduction of mission cost**
  Since the proposed system is implemented by ordinal personal computer (PC), a Pentium 700 MHz processor with a Linux OS, the mission cost can be drastically reduced by employing the proposed multiagent-based system.
- **Adjustment of the center of gravity**
  In this simulation, the proposed system calculates the placement of all CTBs to make the center of gravity of an HTV pressurized logistics carrier as close as possible to its actual center. Using the same mechanism, the system can adjust the center of gravity of a whole loaded HTV instead of a HTV pressurized logistics carrier. Since the center of gravity of a whole loaded HTV is slightly displaced from its actual center, it must be adjusted back to its actual center. This can be easily done by our system.[4] Furthermore, the system can be used for adjusting a gap between the center of gravity of an HTV *pressurized* section and its *un-pressurized* section.
- **Analysis of other aspects**
  In addition to calculating the CTB placement, the proposed system can be used to analyze both appropriate and inappropriate CTBs quantity ratio for shifting the center of gravity of an HTV pressurized logistics carrier close to its actual center. Such analysis concretely provides us with appropriate quantities of half-, single-, double-, and triple-size CTBs according to the mission. Using the same features of the system, we can analyze what type of HRRs (type I or II) should be used and where they should be located in the HTV. Furthermore, the system is also useful for determining the amount of fuel required, which is affected by the loaded CTBs.

6 Conclusion

This paper applied the concept of a *multiagent approach* to a cargo layout system in an HTV pressurized logistic carrier, and investigated its effectiveness from the several aspects. Focusing on the critical issues of performance and robustness in space applications, intensive simulations have revealed the following implications: (1) the multiagent-based cargo layout system has potential for finding good satisfied solutions within a few sec-

[4] We are currently implementing an extended cargo layout system that can adjust the center of gravity of a whole loaded HTV.

onds, which results in a high system performance; and (2) the proposed system can maintain or improve its performance even if the quantity and weight of the cargo is changed, which indicates the robustness of the system.

Furthermore, the proposed system holds great potential in the following aspects: (1) a support for human ground-based operators, (2) a reduction in mission cost, (3) adjustment of the center of gravity of a whole loaded HTV, and (4) analyses of the appropriate CTB quantity, the appropriate type and location of HRRs, and the amount of fuel required. These potentials will be examined further in the near future.

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