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Development of Advanced Life Support Systems Control Software Integrating Operators' Empirical Knowledge

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ABSTRACT

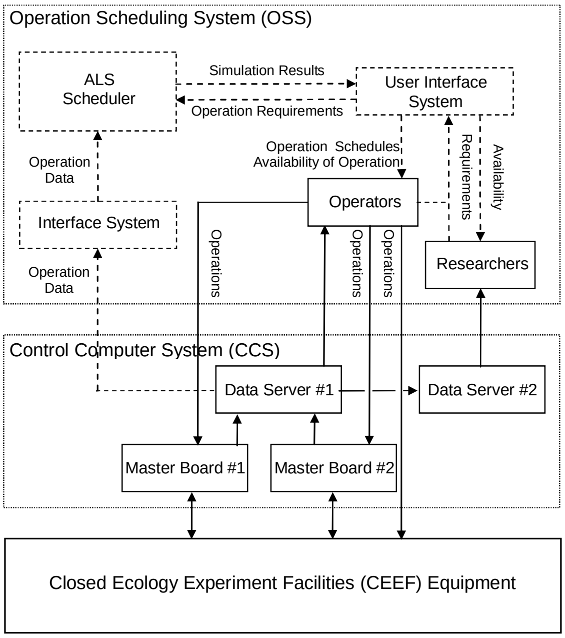
We developed an Advanced Life Support systems scheduler (ALS scheduler) to back up the habitation experiments of Closed Ecology Experiment Facilities (CEEF), and integrated the Lagrangian decomposition and coordination method for a scheduling algorithm of the scheduler. Later research revealed that when comparing solutions obtained by the Lagrangian decomposition and coordination method and by a skilled operator, respectively, a schedule sought by the skilled operator has different features from those of a schedule sought by the Lagrangian decomposition and coordination method. This paper describes how to generate a schedule such as one created by a skilled operator, while reducing complexity by integrating empirical knowledge to the Lagrangian decomposition and coordination method.

INTRODUCTION

The Closed Ecology Experiment Facilities (CEEF) was constructed to study propagation and accumulation of ^{14}C released from a reprocessing site of spent nuclear fuel. In the paper [1], as shown in Fig. 1, we described three layered control software for a Control Computer System (CCS) of the CEEF to back up the habitation experiments. In the paper [2], as shown in Fig. 2, we showed the development of an Advance Life Support systems scheduler (ALS scheduler), on one of three layers, the planning and scheduling level, and discussed the development of a scheduling algorithm which does not cause the complexity of the ALS scheduler to be exponentially increased. In that paper, we showed that the scheduling problem of ALS systems is decomposable into partial problems so that the Lagrangian decomposition and coordination method is applicable [2]. Later research revealed that when comparing solutions obtained by the Lagrangian decomposition and coordination method and by a skilled operator, respectively, a schedule sought by the skilled operator has different features from those of a schedule sought by the Lagrangian decomposition and coordination method. This agrees with what was cited in [3]. A solution is obtained by an individual deciding based not on optimization-orientation but on target achievement-orientation, which contrasts with a solution obtained by a mathematical solution method performing an optimization.

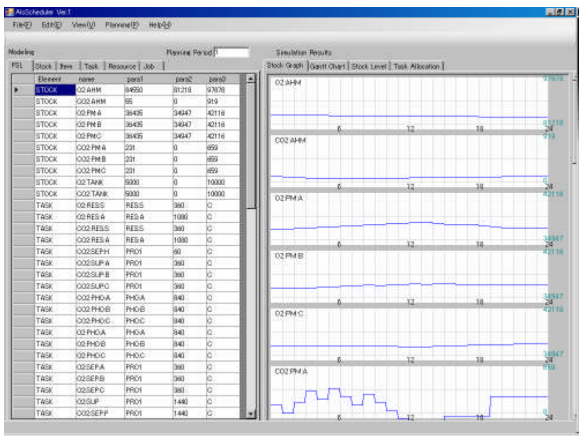
In practice, there are some cases where in an industrial system, a skilled operator can create a favorable schedule in a short time by applying the empirical knowledge that he/she has gained. Dispatching rules, which are each an empirical solving method in scheduling, have thus far been used the most. However, the dispatching rules have a disadvantage that when the rule changes, a rule prepared in advance cannot cope well with scheduling, and has difficulty in the extraction and maintenance of knowledge.

Meanwhile, because of advances in computer performance, solving methods came into use, by each of which a scheduling problem is solved as a large scale combination problem by an optimization method. In such case, a decomposition method is generally used in which a problem is decomposed into partial problems when the problem is decomposable, and the minimization of the partial problems leads to the minimization of the whole problem [4]. However, it is not ensured whether the partial problems are feasible before coordinating between the partial problems. Hence, a coordination method is desired in which complexity is not increased while maintaining the accuracy of a solution in the process of the coordination. This paper aimed at creating a schedule such as one created by a skilled operator, while reducing complexity by integrating empirical knowledge to indices and processes for decision-making in the Lagrangian decomposition and coordination method.



Before starting an experiment, operators generate an operation schedule based on the design of the experiments using the scheduler, and confirm the results. When altering the schedule is required or when any abnormality occurs in the facilities after starting the experiment, operators regenerate the operation schedule based on the operation data, and then confirm the results. The operators manually implement the generated operation schedule.

Fig. 1 Expanded CCS of the CEEF



The ALS scheduler was developed using the MS Visual C++, and has the functions of describing a scheduling model using a Planning and Scheduling Language (PSL); allocating jobs using a scheduling algorithm; and displaying the result as a Gantt chart and a graph for a change of state quantity.

Fig. 2 ALS scheduler screen

SCHEDULING ALGORITHM

INTEGRATION OF EMPIRICAL KNOWLEDGE

For integration where empirical knowledge is integrated to scheduling, the following is given. A case where the generation process of a schedule is represented in a tree form, and a decision-making process in which a schedule creator makes a decision by trial and error is represented in a frame system [5]. Meanwhile, a case of a rule-based system where expert knowledge on the decision-making for schedule creation is represented in if-then form [6]; and a case of another rule-based system where procedures experts use for problem solving are put into a flowchart, and details are represented in if-then form [7]. In addition, there are cases which are of an individualization in which weights are changed for each job [4], a subjectivization in which an ideal position of a job is instructed to an objective function [4], and a list scheduling in which the priority of jobs is given [8].

Meanwhile, in the case where empirical knowledge is integrated to a railway operation system, a heuristic, in which an AI-based approach and an optimization method are combined, substitutes for experiences and divination which are difficult to be formulated. This heuristic is a mass of experience created by interviewing experts, and a railway operation system is formulated as a constrained minimization problem with this mass of experience as a constraint [9].

In light of the above, in this research, an integration method, in which empirical knowledge is integrated to the Lagrangian decomposition and coordination method, is considered as follows. In the formulation of a combination problem, decision-making indices, corresponding to an evaluation function and a constraint condition, and a decision-making process, corresponding to a search, are of importance. Thus, it is aimed at setting the schedule creator's intention to the evaluation function and the constraint condition, and integrating the schedule creator's intention to the process of decision making so that a solution is effectively searched. In the subsequent sections, the following are described: the formulation of a scheduling problem of the ALS systems using the Lagrangian decomposition and coordination method, and the integration of empirical knowledge to the decision-making indices and the decision-making process.

FORMULATION OF LAGRANGIAN DECOMPOSITION AND COORDINATION METHOD INTEGRATING EMPIRICAL KNOWLEDGE

<u>Formulation of Lagrangian decomposition and coordination method</u>

Symbols and subscripts are defined as follows:

i: state number (i=1, 2, …, I)

j: job number (j=1, 2, …, J)

m: device number (m=1, 2, …, M)

t: timeslot number (t=1, 2, …, T)

c_j: unit switching cost of job j

h_i: unit stock cost of state i on a timeslot

x_{it}: state quantity on timeslot t in state i

dx_{it}: deviation of state i from target value

X_{Li}: lower bound of state quantity in state i

X_{Ui}: upper bound of state quantity in state i

α_{ijt}: amount of change on timeslot t due to job j in state i

r_{it}: amount of output on timeslot t in state i

M_{jm}: index of describing whether to use a device m in job j (i.e., not use if =0; use if =1)

B_{ji}: index of describing whether state i is connected with job j (i.e., not connected if = 0; connected if = 1)

δ_{jt} : index of describing whether to execute job j on timeslot t (i.e., not execute if =0; execute if =1)

l: Lagrangian function

First, assuming that a cost to be optimized is a switching cost of a device and deviation from target value, then an objective function can be expressed using Eq. (1). The first term is a switching cost, and the second term is a deviation. A unit switching cost of job j, c_j multiplied by the switching index of job j on timeslot t, $(1-\delta_{jt-1})\delta_{jt}$. A unit stock cost of state i on a timeslot, h_i multiplied by the index of describing whether state i is connected with job j, B_{ji} and deviation of state i from target value on timeslot t, dx_{it}. Here, the added deviation term is improved from previous paper [2]. Schedule creators adjust their intent by c_j and h_i in this Eq.

$$min \quad \sum_{t=1}^{T}\sum_{j=1}^{J}\left[c_j\left(1-\delta_{jt-1}\right)\delta_{jt}+h_iB_{ji}dx_{it}\right] \tag{1}$$

As constraint conditions for the above equation, the change of state quantity, the constraint of lower bound of state quantity, the constraint of upper bound of state quantity, and the constraint of a competition on a device (not allowing simultaneous use of a device) are defined as Eqs. (2) to (5).

$$subject \quad to \quad x_{it+1}=x_{it}+\sum_{j=1}^{J}\delta_{jt}\alpha_{ijt}-r_{it} \quad \forall i,t \tag{2}$$

$$x_{it}\geq X_{Li} \quad \forall i,t \tag{3}$$

$$x_{it}\leq X_{Ui} \quad \forall i,t \tag{4}$$

$$\sum_{j}^{J}\delta_{jt}M_{jm}\leq 1 \quad \forall t,m \tag{5}$$

<u>Lagrangian relaxation</u>

Next, an optimization problem with constraints is replaced by one without constraints by using Lagrangian multipliers. This is referred to as a Lagrangian relaxation. That is, the formulation of an optimization problem is changed from a strict formulation in which constraints must be satisfied to a relaxed formulation in which constraint violations must be reduced. In Eqs. (1) to (5), introducing Lagrangian multipliers denoted by λ, where λ is for the constraining of a competition on a device, then Eq. (5) is relaxed as follows:

$$min \quad l=\sum_{t=1}^{T}\sum_{j=1}^{J}\left[c_j\left(1-\delta_{jt-1}\right)\delta_{jt}+h_iB_{ji}dx_{it}\right] +\sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\left(\sum_{j=1}^{J}\delta_{jt}M_{jm}-1\right) \tag{6}$$

$subject \quad to$ Eqs. (2)-(4)

where λ also represents the use fee of a device.

<u>Decomposition to partial problems</u>

A decision variable vector δ and a state variable vector x related to Eqs. (6), (2) to (4), (second term in Eq. (6), δ is not explicitly expressed) are decomposed for individual jobs. Hence, minimizing the problem expressed using Eqs. (6), (2) to (4) is equivalent to independently minimizing partial problems which are expressed using Eqs. (7), (8), (3) and (4) related to jobs j. This formulation can minimize complexity using Dynamic Programming (DP) for solving partial problems.

$$min \quad l_j=\sum_{t=1}^{T}\left[c_j\left(1-\delta_{jt-1}\right)\delta_{jt}+h_iB_{ji}dx_{it}\right] +\sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\delta_{jt}M_{jm} \tag{7}$$

$$subject \quad to \quad x_{it+1}=x_{it}+\delta_{jt}\alpha_{ijt}-r_{it} \quad \forall i,t \tag{8}$$

Although Eqs. (7), (8), (3) and (4) represent scheduling problems corresponding to individual jobs, these problems are related to each other so that the result of one scheduling influences another scheduling since there are terms related to interference of states (a substance in a tank, or the like) and a competition on a device.

A devised point in the present formulation is to introduce the term B_{ji} in Eq. (7) and to decompose terms not explicitly expressed for individual jobs. This is because, in decision-making of the individual jobs after decomposition, a good result is obtained by considering only a state that is directly influenced due to the execution of a job. Before introducing the term B_{ji}, good results were not obtained due to excessive interference.

COOPERATION BY LAGRANGIAN DECOMPOSITION AND COORDINATION METHOD INTEGRATING EMPIRICAL KNOWLEDGE

Computation is performed so that individual scheduling as a whole gradually comes into cooperation while iteratively solving the partial problems. At this time, if the Lagrangian multipliers are suitably determined, more effective searching can be expected than random searching. Here, the Lagrangian multipliers are determined using the concept of auction [4]. When a competition occurs on a device on a timeslot, the setting of an appropriate price allows one job that has happened to be on the device to escape to another timeslot, so that only a job necessary to use the device remains even paying a high use fee. That is, even if individual jobs behave egoistically, adjusting the price of the device brings the competition into a resolution, thus enabling a good schedule to be created. What is meant by egoistically is that the Lagrangian multipliers in individual jobs (partial problems) are minimized. For the adjustment of the price, the direction of a price increase is determined using the subgradient method. As the subgradients of this problem, λ represents the number of shortages of devices.

Subsequently, using the duality gap expressed in Eq. (11), a created schedule is evaluated. A duality gap is the difference between Lagrangian multipliers of a main problem expressed by Eq. (9) and a dual problem expressed by Eq. (10), and also implicates a discrepancy (poor price setting) between a set price and a price in real life. In this computation, when the duality gap becomes not greater than a threshold or when the subgradient becomes 0, the iteration is terminated. A procedure for this computation is shown in Fig. 3. Following the procedure, the interference of states and competition on devices will be eliminated.

Here, solving process of partial problems in Step 2 and correcting the process of solutions of partial problems to feasible ones in Step 5 were integrated in empirical knowledge. We thought problems have solving processes derived from empirical knowledge, adhering partial problems optimization. The processes are represented by a tree described in if-then form.

Main problem: $$l_l = \min_x l(x,\lambda) \tag{9}$$

Dual problem: $$l_u = \max_\lambda \min_x l(x,\lambda) \tag{10}$$

Duality gap: $$l_u - l_l \tag{11}$$

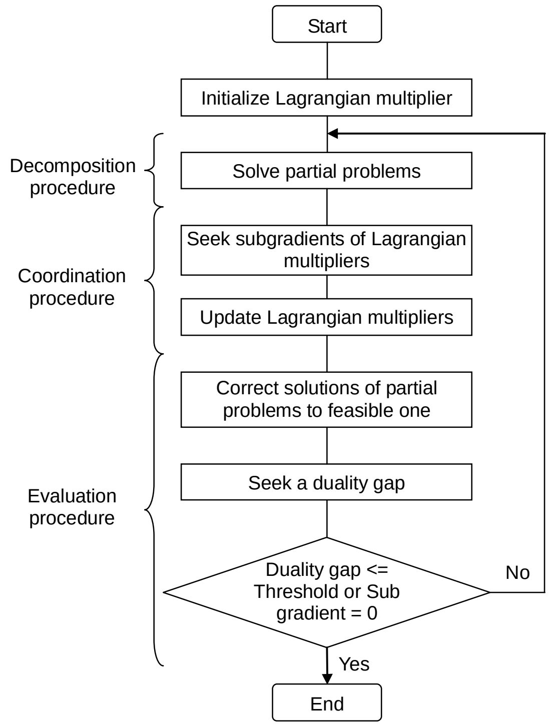


Fig. 3 Lagrangian decomposition and coordination

Step 1: Initialize Lagrangian multipliers

Set the Lagrangian multipliers λ =0.

Step 2: Solve partial problems

Solve partial problems consisting of Eqs. (7), (8), (3) and (4) related to jobs j; and seek schedules δ_{jt} for the individual jobs. Computational order of j depends on knowledge integrated in if-then form.

Step 3: Seek subgradients of the Lagrangian multipliers.

Seek subgradients of λ.

$$subgrad(\boldsymbol{\lambda}) = \{\cdots, \partial l/\partial\lambda, \cdots\};.$$

Step 4: Update Lagrangian multipliers

$$\boldsymbol{\lambda} = \boldsymbol{\lambda} + s_i \cdot subgrad(\boldsymbol{\lambda})$$ s_i: step width

Step 5: Correct solutions of partial problems to feasible ones

When there is a constraint violation in the schedule obtained in Step 2, the schedule is corrected to a feasible one. In the present computation, when a competition occurs, the job is moved forward or back to the nearest unoccupied timeslot by a timeslot. Computational order of *j* depends on knowledge integrated in if-then form.

Step 6: Seek a duality gap

Compute the Lagrangian functions l_l and l_u with respect to the schedules obtained in Steps 2 and 5, and to obtain the duality gap l_u - l_l.

Step 7: Conditions of termination

The computation is terminated when one of the following conditions is established. The duality gap becomes less than or equal to a threshold. Subgradients become 0, and this means that the Lagrangian multipliers converge.

CALCULATION EXAMPLES

CEEF GAS CIRCULATION SYSTEM MODEL

The forgoing scheduling algorithm is implemented to the ALS scheduler. Here, before starting full scale development, we executed a simulation where the present method is applied to a scheduling problem of an O_2 separator of a gas circulation system, and discussed the performance. We carried out the simulation using the spreadsheet and the VBA program of MS-Excel.

Figure 4 shows the CEEF gas circulation system used in this simulation [2]. This system consists of an Animal and Habitation Module (AHM); 4 Plant Chambers (PCs) A, B, C, and F; O_2 and CO_2 tanks; O_2 separator; CO_2 separator (H); CO_2 separator (P); O_2 supply unit; CO_2 supply unit; and a solid waste processor. Although the O_2 and CO_2 tanks are expressed as one unit in Fig. 4, there are multiple tanks. The specifications and environmental conditions of module and chambers are shown in Table 1 [10]. The volume of the AHM is 177m^3. O_2 concentration is set as 20.3% (target), 23.5% (high) and 19.5% (low). CO_2 concentration is set as less than 5000 μLL^{-1}. For the PCs, volumes of A, B, C are each 146.3 m^3, and the volume of F is 239 m^3. The O_2 concentration is the same as the AHM. CO_2 concentration is set as 700±70μLL^{-1} for light periods and less than 1500□μLL^{-1} for dark periods.

When formulating a scheduling problem on the O_2 separator using Eqs. (7), (8), (3) and (4), given that a planning period is one day (timeslot is set as one hour), it is formulated with the values given such that T=24, the number of states I=6 (States of PCs A, B, C, F, AHM, and O_2 Tank), the number of jobs J=4 (O_2 Separator of PCs A, B, C and F), the number of devices M=1 (O_2 Separator), the number of variables=96 (4 variables δ_1, δ_2, δ_3, and δ_4 x 24 timeslot), and the number of constraint conditions=432 (7 constraints of Eqs (12) - (17) x 24 timeslot x 3 kinds of constraints of Eqs (12)-(17), (3), (4)). Equations of constraint conditions, which are related to a change of state quantity corresponding to Eq. (8), are expressed by Eqs. (12) to (18).

$$h_{O2}(t+1) = h_{O2}(t) + dO_2(t)\cdot\delta_{5t} - Ch_{O2} \tag{12}$$

$$pa_{O2}(t+1) = pa_{O2}(t) + Cpa_{O2} - SeO_2\cdot\delta_{1t} \tag{13}$$

$$pb_{O2}(t+1) = pb_{O2}(t) + Cpb_{O2} - SeO_2\cdot\delta_{2t} \tag{14}$$

$$pc_{O2}(t+1) = pc_{O2}(t) + Cpc_{O2} - SeO_2\cdot\delta_{3t} \tag{15}$$

$$pf_{O2}(t+1) = pf_{O2}(t) + Cpf_{O2} - SeO_2\cdot\delta_{4t} \tag{16}$$

$$\begin{aligned} ta_{O2}(t+1) = ta_{O2}(t) &+ SeO_2\cdot\delta_{1t} + SeO_2\cdot\delta_{2t} + SeO_2\cdot\delta_{3t} \\ &+ SeO_2\cdot\delta_{4t} - dO_2(t)\cdot\delta_{5t} - Cw_{O2}\cdot\delta_{6t} \end{aligned} \tag{17}$$

$$w_{O2}(t) = \begin{cases} Cw_{O2}\cdot\delta_{6t} & (t = T_w) \\ 0 & (other) \end{cases} \tag{18}$$

where the symbols used are defined as,

dO_2: amount of supplied O_2;

Ch_{O2}: amount of CO_2 generated by human breathing;

Cpa_{O2}, Cpb_{O2}, Cpc_{O2}, and Cpf_{O2}: amount of O_2 generated due to the photosynthesis of plants in PCs A, B, C, and F;

SeO_2: amount of O_2 separated from O_2 separator;

Cw_{O2}: amount of O_2 supplied to solid waste processor;

h(t), *pa(t)*, *pb(t)*, *pc(t)*, *pf(t)*, *ta(t)*, and *w(t)*: respective amounts of O_2 in AHM, PCs A, B, C, F, and solid waste processor;

T_w: start timeslot of a solid waste process job; a solid waste processor was assumed to start at 8 o'clock; and

$\delta_{jt} \in \{0,1\}$.

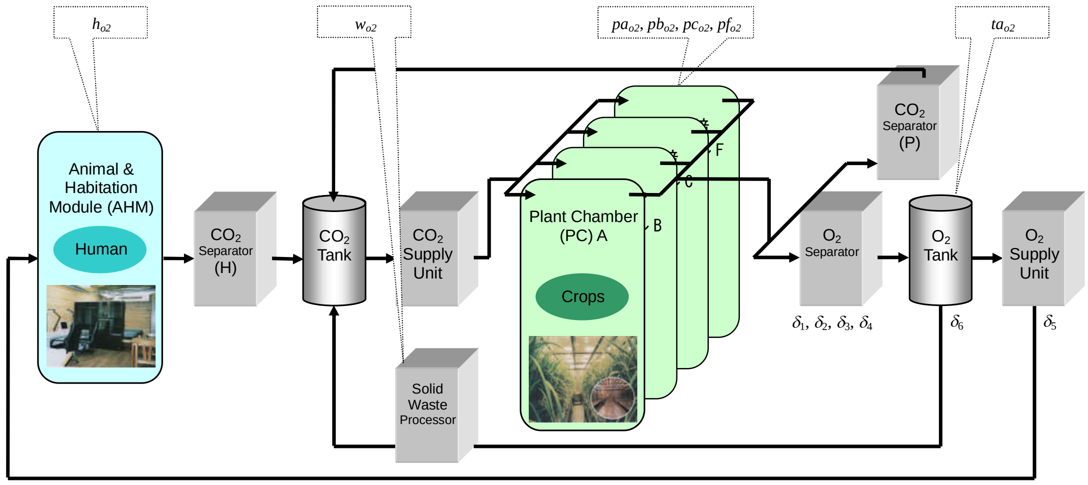


Fig. 4 CEEF gas circulation system

Table 1 Specifications and environmental conditions of module and chambers

AHM	Volume	177m^3 (Habitation Area and Animal Area)
	O_2 Concentration	Target: 20.3%, High: 23.5% Low: 19.5%
	CO_2 Concentration	High: less than 5000 μLL^{-1}
PCs	Volume	146.3 m^3 (A,B,C) 239 m^3 (F)
	O_2 Concentration	Target 20.3% High 23.5% Low 19.5%
	CO_2 Concentration	Light Period: 700±70μLL^{-1} Dark Period: less than 1500 μLL^{-1}

Table 2 shows the setup values for the simulation. Two people (Eco-Nauts) live, cultivating rice, soybeans, and other 21 crops, to produce food for themselves. The scheduling of human activity was given before the scheduling by the ALS scheduler. The individuals sleep from 22 to 6 o'clock. They cultivate rice in PC A (the light period is 0 to 14 o'clock) and PC B (the light period is 1 to 15 o'clock), and soybeans in PC C (the light period is 5 to 19 o'clock), and the other 21 crops in PC F (the light period is 5 to 19 o'clock). The values of stocks (Stocks), stock constraints (Stock Levels), and load constraints (Load Levels) of the items are shown in Table 2.

Table 2 Setup values for the simulation

Eco-Nauts	2 people, CO_2 : 1578.0 g/day, O_2 : 1205.7 g/day They sleep from 22 to 6 o'clock, and their metabolism is two thirds that of normal activity while sleeping.
Crops	PCs A and B: Rice (442.0 g/day x 2) The light period is 0 to 14 o'clock in PC A. The light period is 1 to 15 o'clock in PC B. PC C: Soybeans (194.0 g/day) The light period is 5 to 19 o'clock in PC C. PC F: The other 21 crops The light period is 5 to 19 o'clock in PC F.
Stocks	CO_2 Tank: 5000 g, O_2 Tank: 5000 g AHM; O_2: 48559 g, CO_2: 96 g PCs A, B, and C; O_2: 40060 g, CO_2: 184 g PC F; O_2: 65443 g, CO_2: 301 g
Stock Levels	CO_2 Tank: Min 0 g, Max 10000 g O_2 Tank: Min 0 g, Max 10000 g AHM; O_2: Min 45155 g, Max 54418 g, CO_2: Min 0 g, Max 1592 g PCs A, B, and C; O_2: Min 37323 g, Max 44979 g, CO_2: Min 0 g, Max 395 g PC F; O_2: Min 60972 g, Max 73479 g, CO_2: Min 0 g, Max 645 g
Load Levels	CO_2 Separator: 58.4 g/h O_2 Separator: 1289.9 g/8h CO_2 Supply Unit: 942.1 g/12h O_2 Supply Unit: 50.5 g/h

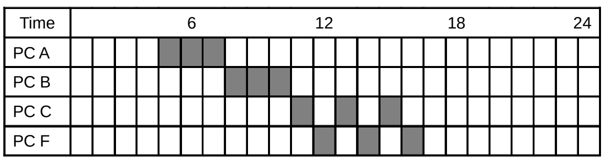
O_2 and CO_2 are expressed in grams in normal atmosphere.

RESULTS AND DISCUSSION

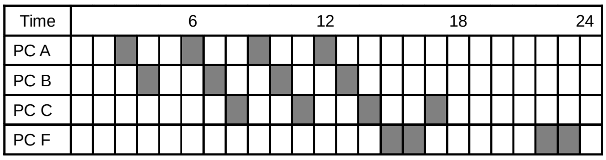
Figures 5 to 9 show results obtained by performing one-day scheduling on an O_2 separator based on the above setting, using the spreadsheets and the VBA program of MS-Excel. Figure 5 shows Gantt charts of O_2 Separator; Fig. 6 shows the change in Lagrangian functions; Fig. 7 shows the changes in the amount of change of

Lagrangian functions; Fig. 8 shows the change in the quantity in an O_2 tank; and Fig. 9 shows the change in the O_2 concentration of PCs. In Figs. 5 to 9, and Table 3, subscripts *(s)*, *(sd)*, *(sd)**, and *(h)* of *l* represent the differences in the method of derivation of schedules; these subscripts respectively represent the schedules created, using the evaluation function by using switching cost and deviation in the following manners: use (c_j=0.1, h_i=0) of the switching cost; use (c_j=0.1, h_i=0.1) of the switching cost and deviation and use (c_j=0.1, h_i=0.1) of the switching cost and deviation by integrating empirical knowledge to the process of coordination, and for the schedule created by a skilled operator. These notations are used below for the sake of discrimination. Here, comparison of *(s)* with *(sd)* examines the integration of empirical knowledge to decision-making indices, and comparison of *(sd)* with *(sd)** examines the integration of empirical knowledge to decision-making process. In addition, in Fig. 7, *la*, *lb*, *lc*, and *lf* each show the amount of change in the change of values of the Lagrangian functions of jobs in which the PCs A, B, C, and F are respectively treated.

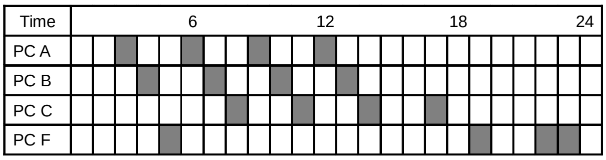
First, in Fig. 5, it has been observed that *(s)* differs from *(sd)*, *(sd)**, and *(h)*. In the case of *(sd)* and *(sd)**, the schedules created are similar to that of *(h)* created by the skilled operator. The results were little influenced by the adjustment of parameters of c_j and h_i unless these are 0. Next, in Fig. 6, it has been observed that as far as the indices represented by the Lagrangian function are concerned, schedules created by *(sd)* and *(sd)** are more favorable than those by the skilled operator. Figure 7 shows the comparison between changes in the amount of change of Lagrangian functions for the schedules. For *(s)*, the amount of change of Lagrangian functions is not stabilized at 0 within one-day cycle. For *(sd)* and *(sd)**, the amount of change of Lagrangian functions alternately takes high and low values with time, and is eventually stabilized at approximately 0 within one-day cycle. The same is true for *(h)*. Especially, it can be more clearly seen from the distributions in which more smooth curves can be drawn by plots of *(sd)* and *(sd)**, that coordination is performed between respective jobs. In each graph, *l* takes a maximum value at 8 a.m. since a large quantity of O_2 is supplied (Fig. 8) at 8 a.m. from an O_2 tank to a solid waste processor. Next, jobs are assigned to an O_2 separator according to the procedure of Fig. 3, and *l* again approaches 0 at around 15 o'clock. The O_2 concentration of *(sd)** alone at that time is shown in Fig. 9. The O_2 concentrations of the respective chambers have been controlled within the allowable range (19.5% to 23.5%). Table 3 shows the amplitudes of change of O_2 concentration and O_2 Tank of *(sd)* and *(sd)** are the smallest.



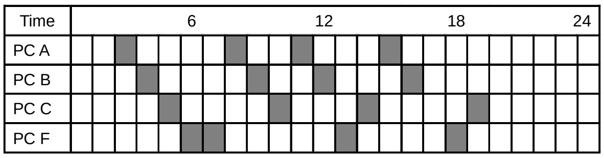
(s) Schedule is generated by evaluation function *l(s)* consists of switching



(sd) Schedule is generated by evaluation function *l(sd)* consists of switching and deviation



(sd)* Schedule is generated by evaluation function *l(sd)** consists of switching and deviation



(h) Hand coding schedule

PC A, PC B, PC C, and PC F show plant chamber in which O_2 separator is connected.

Fig. 5 Gantt charts of O_2 separator

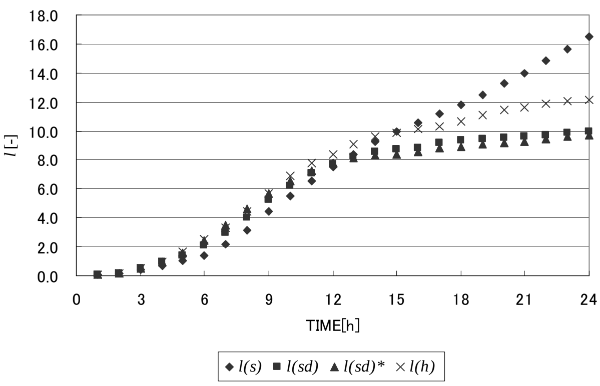
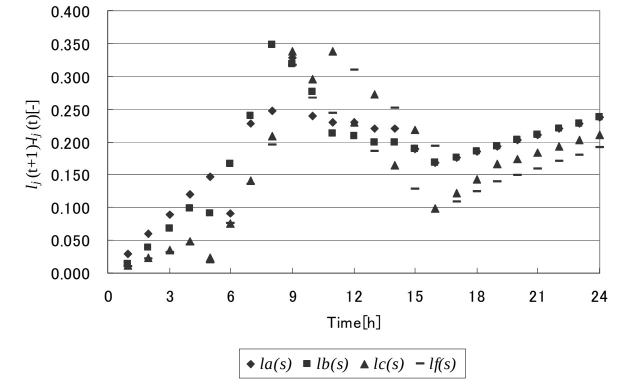
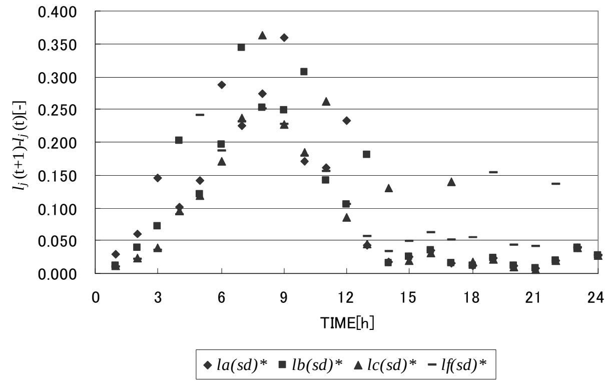


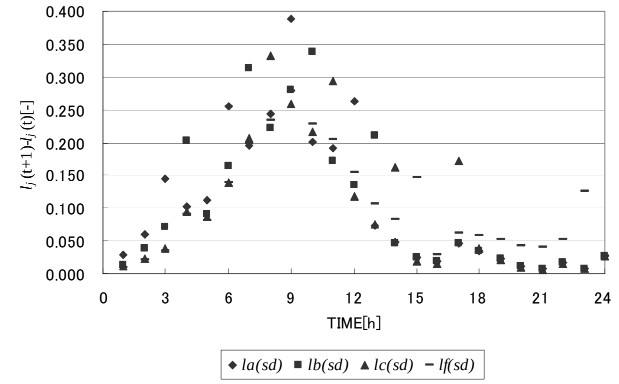
Fig. 6 Change in Lagrangian functions



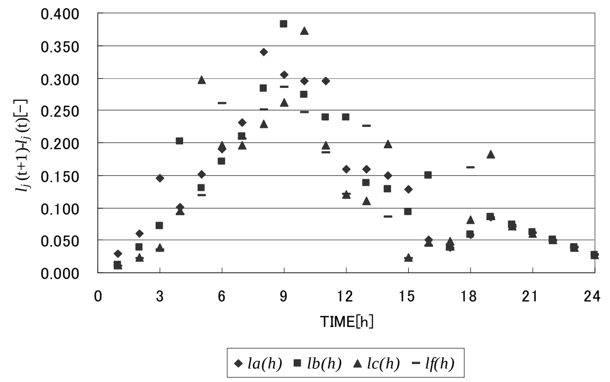
(s) Schedule is generated by evaluation function *l(s)* consists of switching



(sd)* Schedule is generated by evaluation function *l(sd)** consists of switching and deviation integrating empirical knowledge



(sd) Schedule is generated by evaluation function *l(sd)* consists of switching and deviation



(h) Hand coding schedule

la, *lb*, *lc*, and *lf* each show the amount of change in the change of values of Lagrangian functions of jobs in which the PCs A, B, C, and F are respectively treated.

Fig.7 Changes in the amount of change of Lagrangian functions

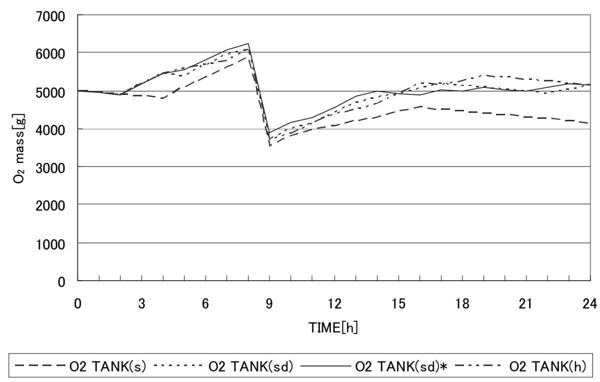


Fig. 8 Change in the quantity of O_2 tanks

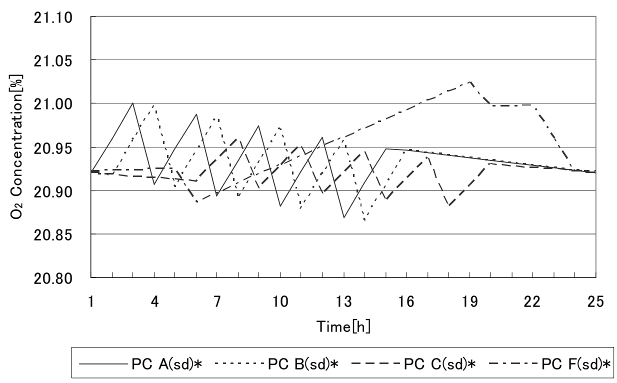


Fig. 9 Change in the O_2 concentration of PCs

Table 3 Amplitude of change of O_2 concentration and O_2 Tank

	PC A [%]	PC B [%]	PC C [%]	PC F [%]	O_2 TANK [g]
(s)	0.280	0.279	0.122	0.067	2355
(sd)	0.132	0.132	0.078	0.099	2355
*(sd)**	0.132	0.132	0.078	0.138	2355
(h)	0.174	0.174	0.157	0.067	2355

CONCLUSION

In this paper, we discussed the integration of empirical knowledge to the Lagrangian decomposition and coordination method, and reached the following conclusions.

Integration of Empirical Knowledge to Decision-making Indices

It has been observed that setting the evaluation function influences on the generation of schedule to a great extent. However, because the problem under consideration is a combination problem, it is likely that the coordination of the parameters is not as sensitive as that of a continuous function. It is inferred that terms to be used for the generation of a schedule similar to one by a skilled operator are switching cost and deviation.

Integration of Empirical Knowledge to Decision-making Process

For the values of the Lagrangian decomposition function, performance in the case where empirical knowledge is integrated, which is described in Steps 2 and 5 in Fig.3, was slightly increased compared with the case where it is not. However, pronounced superiority was not confirmed. This is probably because the present examples are those of competition for only four jobs. Difference in the performance most likely becomes noticeable when the problem becomes large-scale. For such a problem, further study is necessary.

Through the simulation in which empirical knowledge is integrated to the indices and process of the decision-making, the effect of the integration was studied. By integrating the schedule creator's intension to the indices of the decision-making, it becomes possible to create schedules, using the Lagrangian decomposition and coordination method, which are similar to those created by the skilled operator. However, in the present simulation, an effect to be produced by the integration to the decision-making was not sufficiently confirmed.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AHM: Animal and Habitation Module

ALS: Advanced Life Support

CCS: Control Computer System

CEEF: Closed Ecology Experiment Facilities

PC: Plant Chamber

PSL: Planning and Scheduling Language