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

International Conference on Environmental Systems (ICES)
San Francisco, California, USA, June 29 - July 3, 2008

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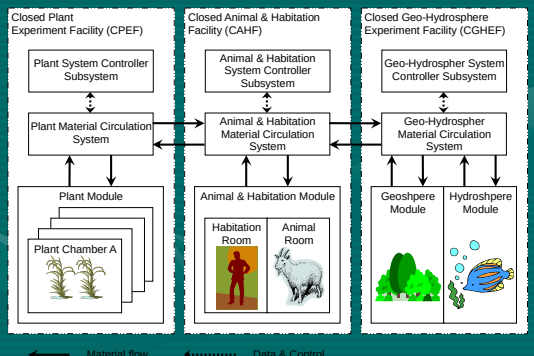
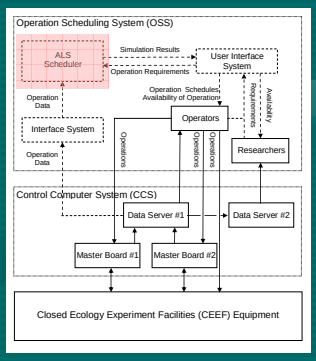
CEEF Control Room

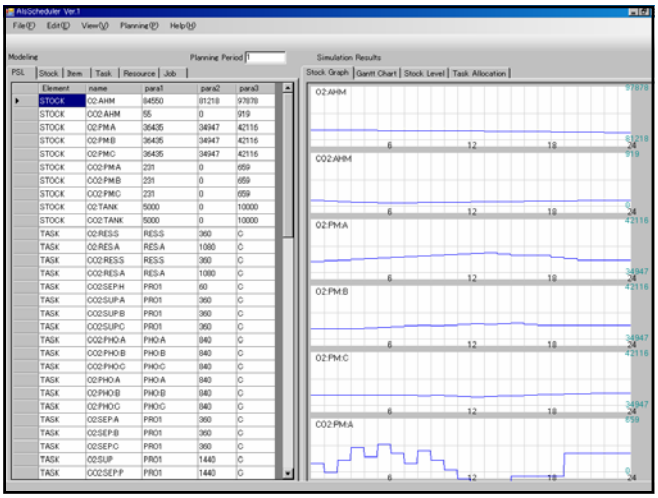
Closed Ecology Experiment Facilities (CEEF)



Background (1/3)

- In the ICES2006 paper, we described three layered control software for a Control Computer System (CCS) of the CEEF to back up the habitation experiments.
- In the ICES2007 paper, we showed the development of an Advanced Life Support systems scheduler (ALS scheduler) on one of three layers, and discussed the development of a scheduling algorithm that does not exponentially increase the complexity of the ALS scheduler.





Background (2/3)

- In the ICES2007 paper, we showed that the scheduling problem of the ALS system is decomposable into partial problems so that the Lagrangian decomposition and coordination (LDC) method is applicable.
- Later research revealed that when comparing solutions obtained by the LDC method and by a skilled operator, the schedule desired by the skilled operator has different features from those of a schedule determined by the LDC method. This agrees with what was cited in Kuroda M., Production Scheduling, 2002.
- A solution is obtained by an individual deciding based on target achievement-orientation, not optimization-orientation, which contrasts with a solution obtained by a mathematical solution method performing an optimization.

Background (3/3)

- In practice, an industrial system has some cases in which a skilled operator can create a favorable schedule in a short time by applying the empirical knowledge.
- Dispatching rules, each of which is 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 manage the scheduling well, and the rule has difficulty with extracting and maintaining knowledge.
- Given advances in computer performance, solution methods came into use, each solving a scheduling problem as a large scale combination problem using an optimization method.

Objective

This research 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 (LDC) method.

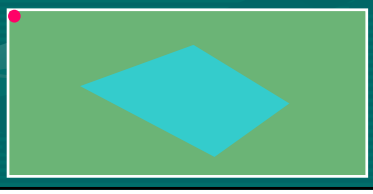
Integrating empirical knowledge to scheduling (1/2)

- Here are some examples of integrating empirical knowledge to scheduling.
  - 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 decides by trial and error is represented in a frame system.
  - The case of a rule-based system where expert knowledge of the decision-making for schedule creation is represented in if-then form; and a case of another rule-based system where procedures experts use for problem solving are put into a flowchart, and the information is represented in if-then form.
  - In addition, there is a list scheduling in which the priority of jobs is given.
- Where empirical knowledge is integrated into a railway operation system, a heuristic, in which an AI-based approach and an optimization method are combined, substitutes for experiences and divination that are difficult to formulate.
  - This heuristic is a mass of experience created by interviewing experts.

Integrating empirical knowledge to scheduling (2/2)

- This research considers an integration method, in which empirical knowledge is integrated to the LDC method, 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.
  - This formulation aims at setting the schedule creator's intention to the evaluation function and the constraint condition, and integrating the schedule creator's intention into the process of decision making so that a solution is effectively discovered reducing extra search.

Solution Space



Formulation of the LDC for the ALS scheduler

Unit switching cost

Unit stock cost

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

Decision variable

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

State variable

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

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

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

Relaxation

Formulation of the LDC, Decomposition

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

Decomposition

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

Dynamic Programming (DP) for solving partial problems.

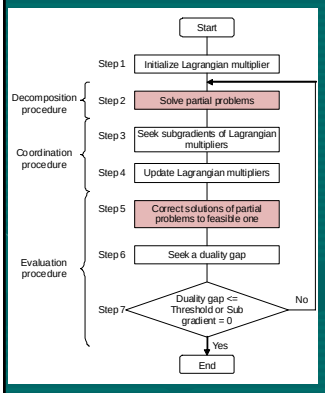
$$\min \quad l_j = \sum_{t=1}^{T}\left[c_j\left(1-\delta_{jt-1}\right)\delta_{jt}+h_i B_{ji} dx_{it}\right] + \sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\delta_{jt}M_{jm}$$

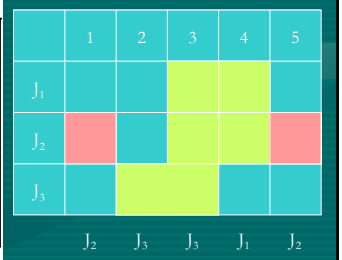
$$\text{subject to} \quad x_{it+1} = x_{it} + \sum_{j=1}^{J}\delta_{jt}\alpha_{ijt} - r_{it} \quad \forall i,t$$

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

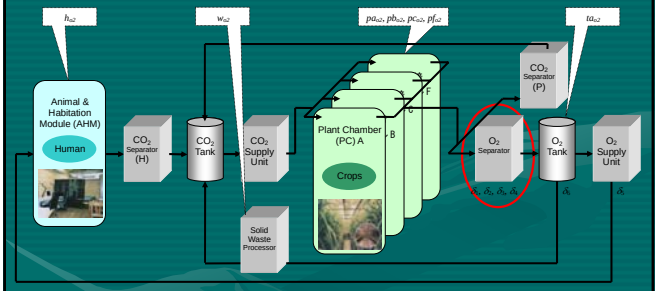
$$x_{it} \leq X_{Ui} \quad \forall i,t$$

Procedure for LDC





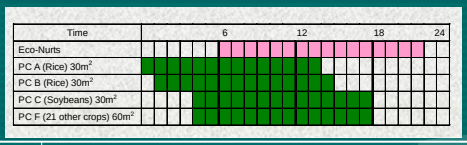
CEEF gas circulation system



O_2 Concentration:	Target :20.3%, High: 23.5% Low: 19.5%
CO_2 Concentration:	less than 5000 μLL^{-1}

O_2 Concentration:	Target :20.3%, High: 23.5% Low: 19.5%
CO_2 Concentration:	700 ±70μLL^{-1} for light periods less than 1500 μLL^{-1} for dark periods

Setup values for the simulation



Eco-Nauts	Two people live in the simulation, cultivating rice, soybeans and 21 other crops to produce their own food. They sleep from 10:00 p.m. to 6:00 a.m., and their metabolism is two-thirds that of normal activity during this time.
Crops	Rice in PCs A and B The light periods are 12 midnight to 2:00 p.m. for PC A, and 1:00 a.m. to 3:00 p.m. for PC B Soybeans in PC C and 21 other crops in PC F The light period is 5:00 a.m. to 7:00 p.m.
Tanks	CO_2 Tank : Initial 5000 g, Max 10000 g, Min 0 g O_2 Tank : Initial 5000 g , Max 10000 g, Min 0 g

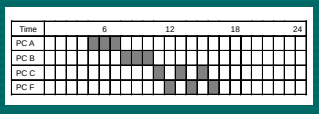
Parameters of evaluation function

1. (s) c_j=0.1 and h_i=0 of the switching cost
2. (sd) c_j=0.1 and h_i=0.1 of the switching cost and deviation
3. (sd)* c_j=0.1 and h_i=0.1 of the switching cost and deviation by integrating empirical knowledge into the process of coordination
4. (h) the schedule created by a skilled operator

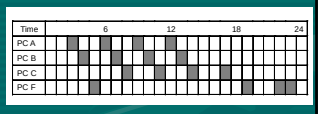
Here, comparison of (s) with (sd) examines the integration of empirical knowledge into decision-making indices,
and comparison of (sd) with (sd)* examines the integration of empirical knowledge in the decision-making process.

Results, Gantt charts of O_2 separator

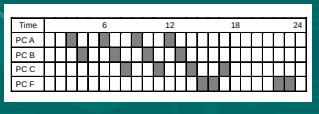
(s) Switching cost



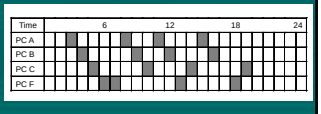
(sd)* Switching cost and deviation by integrating empirical knowledge into the coordination process



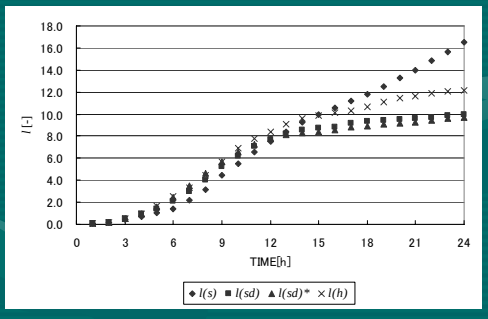
(sd) Switching cost and deviation



(h) Skilled operator

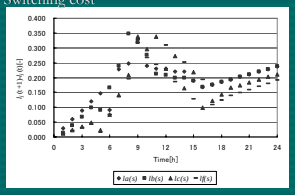


Results, Change in Lagrangian functions

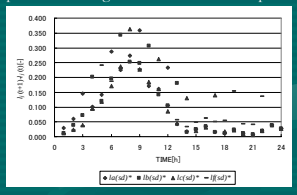


Results, Comparison between changes in the amount of change of Lagrangian functions

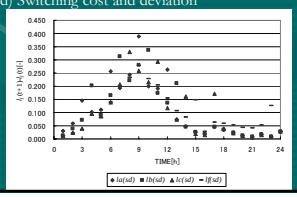
(s) Switching cost



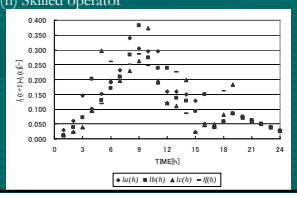
(sd)* Switching cost and deviation by integrating empirical knowledge into the coordination process



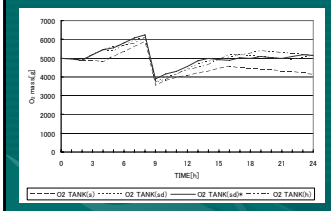
(sd) Switching cost and deviation



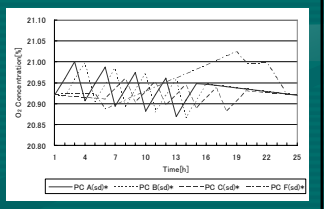
(h) Skilled operator



Results, Change in the quantity of O_2 tanks and in the O_2 concentration of PCs



Change in the quantity of O_2 tanks



Change in the O_2 concentration of PCs

Results, 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

Conclusions

- In this presentation, we discussed the integration of empirical knowledge into the Lagrangian decomposition and coordination (LDC) method, and reached the following conclusions.
- Integration of Empirical Knowledge into Decision-making Indices
  - Setting the evaluation function influences schedule generation to a great extent.
  - 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 into Decision-making Process
  - For the values of the Lagrangian function, performance in the case where empirical knowledge is integrated 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.

Acknowledgement

- This report includes a part of the results from research conducted under contract with Aomori Prefectural Government, Japan.