Development of Advanced Life Support Systems Control Software Considering Computational Effort and Mathematical Validity

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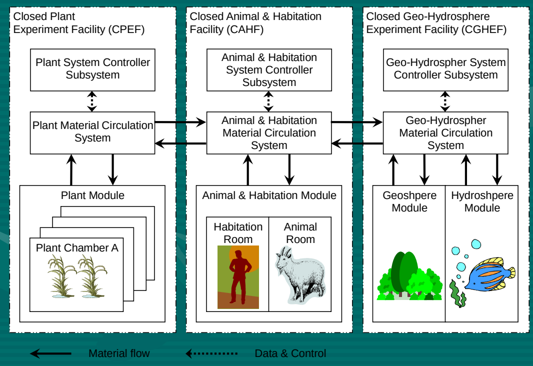
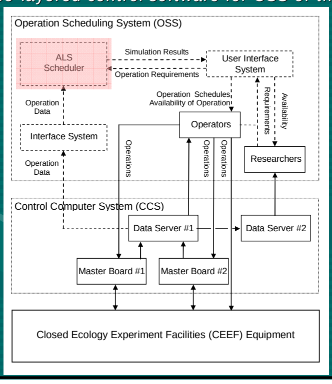
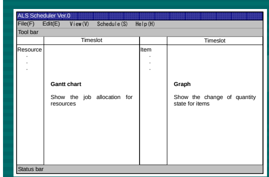
Closed Ecology Experiment Facilities (CEEF)



Development of an Advanced Life Support (ALS) scheduler

Three-layered control software for OSS of the CEEF





Scheduling methods

- A scheduling problem is a combinatorial problem of which the complexity is exponentially increased, depending on the scale of the problem (Bellman's curse of dimensionality).
- In conventional scheduling,
  - optimization techniques (Enumeration method, Dynamic Programming (DP), Branch and Bound method, etc.),
  - meta-heuristics (Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search (TS), etc.),
  - and dispatching rules.
- The development of an ALS scheduler aims to implement a dynamic scheduling algorithm that is capable of handling large-scale problems.
- In order to apply an optimization technique to dynamic scheduling, it is necessary to overcome exponentially-increasing complexity in solving a scheduling problem and thereby search for a solution within a practically acceptable time period.

Objective

- Objective
  - The object of this research is to develop a scheduling algorithm that prevents complexity from increasing exponentially, depending on the scale of the system, and takes mathematical validity into consideration.
- Discussions
  - the application of the Lagrange decomposition and configuration;
  - a method of determining Lagrange multipliers;
  - and comparison of this method with hand coded scheduling.

Complexity of algorithms for a single machine scheduling problem

Algorithms	Complexity
Enumeration method	T^J
Dynamic programming	$J^2(T-1)$
Branch and bound approach	$<T^J$
Meta-heuristics	$< T^J$
Lagrange decomposition and configuration	JTU

J: number of jobs, T: planning period, U: total number of iterations that must be iterated until a Lagrange multiplier is converged.

Formulation of Lagrange Decomposition and Configuration (LDC)

- Formulation

$$\min\{f(x) \mid g(x) \le 0\}$$ Optimization problem with constraints

- Lagrange function - Lagrange relaxation

$$l(x,\lambda) = f(x) + \lambda g(x)$$ Optimization problem without constraints

- Decomposition to partial problems

$$f(x) = f_1(x_1) + f_2(x_2) + \cdots$$
$$g(x) = g_1(x_1) + g_2(x_2) + \cdots$$

If $f(x)$ and $g(x)$ are separated in relation to jobs,

$$\min_x l(x,\lambda) = \sum_j \min_{x_j} l_j(x_j,\lambda)$$

Sum of minimizing Lagrange function related to jobs

Formulation of LDC of the ALS scheduler

$$\min \sum_{t=1}^{T}\sum_{j=1}^{J} c_j(1-\delta_{jt-1})\delta_{jt}$$ Switching cost of a device

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

$$x_{it} \ge X_{Li} \quad \forall i,t$$ Lower bound of state quantity

$$x_{it} \le X_{Ui} \quad \forall i,t$$ Upper bound of state quantity

$$\sum_{j}^{J}\delta_{jt}M_{jm} \le 1 \quad \forall t,m$$ Competition for a device

Relaxation

$$\min \quad l = \sum_{t=1}^{T}\sum_{j=1}^{J} c_j(1-\delta_{jt-1})\delta_{jt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\theta_{it}(X_{Li}-x_{it}) + \sum_{t=1}^{T}\sum_{i=1}^{I}\mu_{it}(x_{it}-X_{Ui}) + \sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\left(\sum_{j=1}^{J}\delta_{jt}M_{jm}-1\right)$$

Decomposition into partial problems

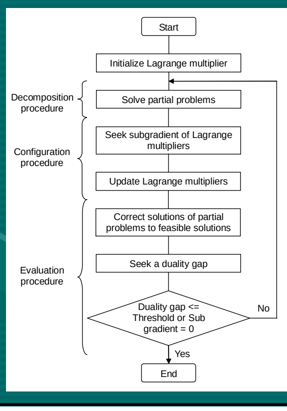
Can the Eq. separate for individual jobs ?

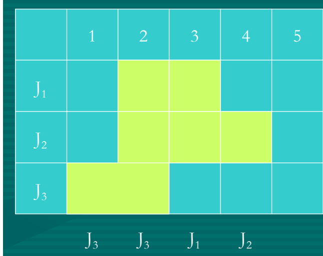
$$\min \quad l = \sum_{t=1}^{T}\sum_{j=1}^{J} c_j(1-\delta_{jt-1})\delta_{jt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\theta_{it}(X_{Li}-x_{it}) + \sum_{t=1}^{T}\sum_{i=1}^{I}\mu_{it}(x_{it}-X_{Ui}) + \sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\left(\sum_{j=1}^{J}\delta_{jt}M_{jm}-1\right)$$

Can decompose this Eq. into partial problems

$$\min \quad l_j = \sum_{t=1}^{T} c_j(1-\delta_{jt-1})\delta_{jt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\theta_{it}(X_{Li}-x_{it})B_{ji} + \sum_{t=1}^{T}\sum_{i=1}^{I}\mu_{it}(x_{it}-X_{Ui})B_{ji} + \sum_{t=1}^{T}\sum_{m}^{M}\lambda_{mt}\delta_{jt}M_{jm}$$

Procedure for LDC





Configuration procedure, Steps 3 and 4

Usage fee for device (Number of shortages of devices)

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

Direction of a price adjustment is determined by using the subgradients method

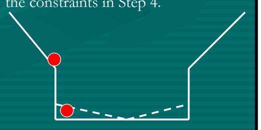
Amount of constraint violation of a lower bound

$$\theta_{it} = \begin{cases} \theta_{it} + \max(X_{Li}-x_{it},0) & x_{it} < X_{Li} \\ (X_0 - x_{it})/(X_0 - X_L) & X_{Li} < x_{it} < X_0 \\ 0 & other \end{cases}$$

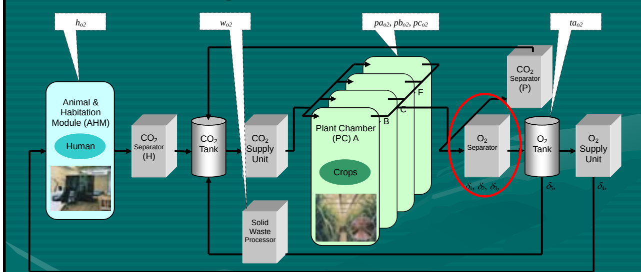
Constraint violation is warned of in advanced by providing the gradients to the Lagrange multipliers, even when the multipliers do not violate the constraints in Step 4.

Amount of constraint violation of an upper bound

$$\mu_{it} = \begin{cases} \mu_{it} + \max(x_{it}-X_{Ui},0) & X_{Ui} < x_{it} \\ (x_{it} - X_0)/(X_U - X_0) & X_0 < x_{it} < X_{Ui} \\ 0 & other \end{cases}$$



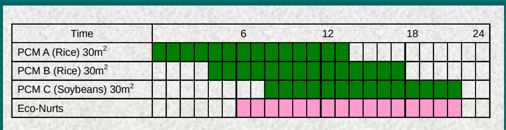
CEEF gas circulation system



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

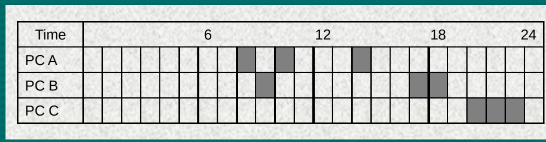
Setup values for the simulation

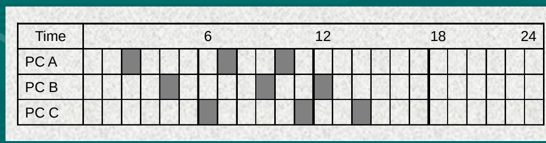


Eco-Nauts	Two people live in the simulation, cultivating rice and soybeans to produce their own food. They sleep from 10 p.m. to 6:00 a.m., and their metabolism is two-thirds that of normal activity during this time.
Crops	Rice (442.0 g/day) in PCs A and B The light periods are 12 midnight to 2:00 p.m. for PC A, and 4:00 a.m. to 6:00 p.m. for PC B Soybeans (194.0 g/day) in PC C The light period is 8:00 a.m. to 10:00 p.m. They do not cultivate crops in PC F
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

Results (1/3), one-day scheduling of the O_2 Separator

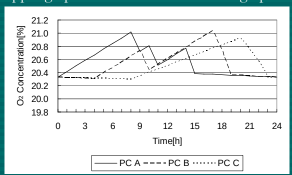
Upper chart: This method,　Lower chart: Hand-coding

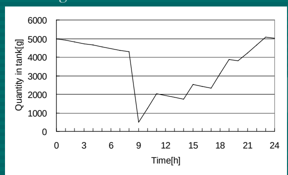


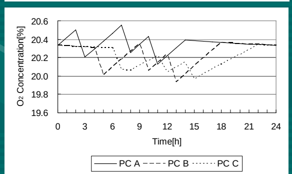


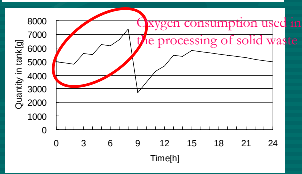
Results (2/3), changes of states

Upper graph: This method,　Lower graph: Hand-coding







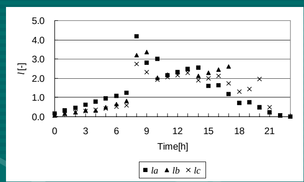


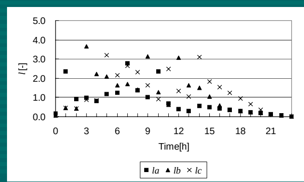
Changes of PCs O_2 concentration　Min 19.5%~Max 23.5%

Changes of O_2 Tank　Min 0g~Max 10000g

Results (3/3), changes of Lagrange functions of the jobs

On the left: This method,　On the right: Hand-coding





Lagrange function's index

Switching cost of a device

Upper and lower bounds of state quantity

Competition on a device

Summary

- Application of Lagrange decomposition and configuration
  - An ALS scheduling problem can be decomposed into partial problems -> scheduling can be performed without exponentially increasing complexity.
- Method of determining Lagrange multipliers
  - Cooperation for the scheduling of partial problems can be achieved by adjusting the price, based on the concept of an auction
- Comparison of this method with hand-coded scheduling
  - Lagrange function values' distribution of hand-coded scheduling shows variations. I think that proficient operators create a schedule with a different index to this method.
  - The problem of how to create schedules in the same manner as a professional operator with this method is the subject of future research.
- In the future, we will validate the performance of the present algorithm while increasing the number of jobs and applying the algorithm to dynamic scheduling. We will also add the emulation of a proficient operator's skills to this method.

Acknowledgement

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