Design of Intelligent Control Software for Mini-Earth

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Background (1/2)

- A habitation experiment using the Closed Ecology Experiment Facilities (CEEF) that we call Mini-Earth was started in 2005, and three experiments were conducted in which two persons stayed in the CEEF for one week. In the future, stays will be gradually extended. In 2009, a habitation experiment with two persons staying for four months will be carried out.
- Although the CEEF has a challenging target of developing advanced life support system technologies, its system has been developed based on existing conventional plant system technologies.
- For monitoring and control systems, almost no automation has been introduced. This system has many manually operated parts that require operators to determine whether to start and stop operations.

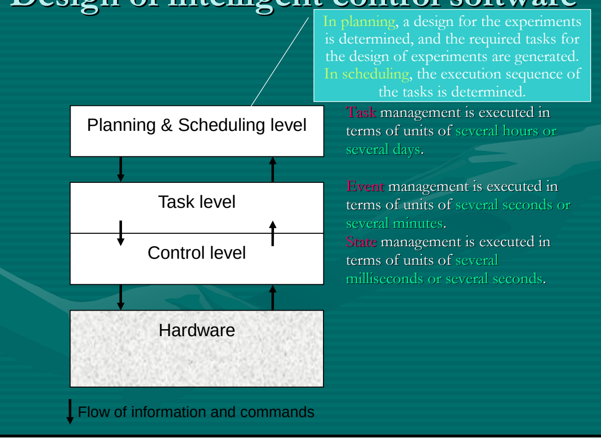
Background (2/2)

- At present, as the first step for managing such a system, a CEEF behavioral prediction system (CPS) is under development. In the CPS, an operator creates an operation schedule for the CEEF.
- It is not easy to create a complex operation schedule. Creating an operation schedule exceeds the operator's ability to consider all the possible variations of conditions during a long-term habitation experiment.
- Therefore, we will develop an Operation Schedule Interactive Generation system (OSIG) to be installed in the CPS by 2009 when long-term habitation experiment will start.

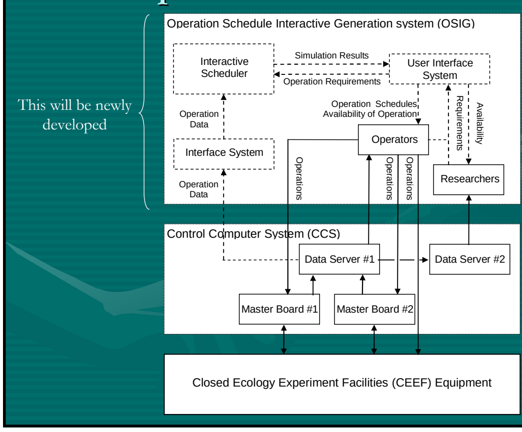
Objective

- In this research, we will develop intelligent control software consisting of three layers of planning & scheduling, task, and control levels for a Controlling Computer System (CCS) of the CEEF.
- In this presentation, we will talk about the development of the Operation Schedule Interactive Generation system (OSIG) , especially focusing on the planning & scheduling level.

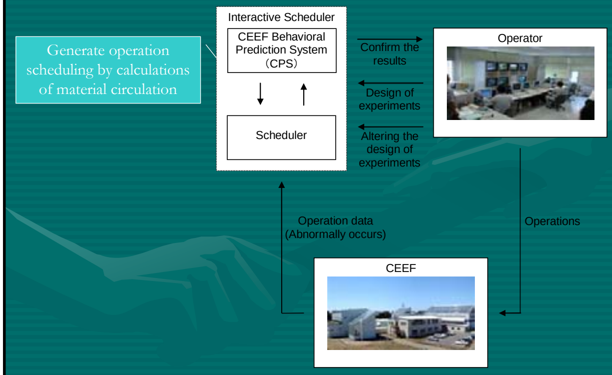
Design of intelligent control software



Expanded CCS of the CEEF

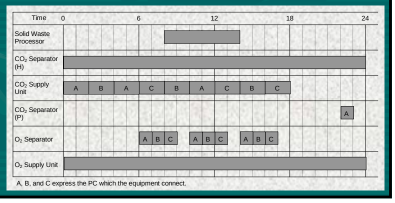


Flow of information and decision-making in the OSIG



Scheduling for initial schedule

- SIMULATION SCHEDULING
  - Simulation scheduling evaluates tasks stored in the queue of each machine using a priority rule, allocating the task having the highest priority to the relevant machine. By repeating this process, it creates the operation schedule. A priority rule used in this process is called a dispatching rule.
  - For simulation, a forward simulation technique in task allocation in the forward direction of time axis is used.
- DISPATCHING RULE
  - As the dispatching rule, we adopted a Shortest Processing Time (SPT) in which a task having the shortest processing time is selected among tasks to be allocated.



Scheduling for changing circumstances

Penalty propagation network : Making the size of the penalty for the constraint violation propagate over the neighboring constraints in turn, this gradually reduces the total size of the penalties as a whole.

$$min \sum_{\forall i, \forall j \in M} \left(\alpha_{i,j} + \lambda_{i,j}\beta_{i,j}\right) \qquad \lambda_{i,j} = d_{i,j} + t_j - t_i > 0$$

Objective function : Sum of constraint violation penalties

$$subject \quad to \quad t_i - t_j \geq d_{i,j} \quad \forall i, \forall j \in M$$

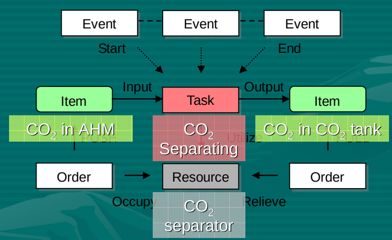
Constraint conditions : Processing times and precedence relationships.

$$t_i = c_i \quad \forall i \in E^{fix}$$

i, j :	Event numbers
t :	Event times (Decision valuables)
c, d :	Constant numbers
M :	Aggregation of constraints relations
E^{fix} :	Aggregation of fixed events
α :	Penalty quantity generated by constraint violation
β :	Penalty quantity corresponding to the degree of constraint violation

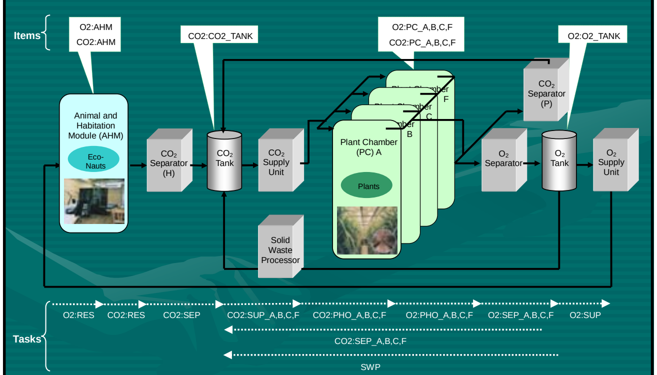
Description of scheduling problem

Planning and Scheduling Language (PSL) is a general purpose language for scheduling manufacturing processes that can express large scale and complex problems by using only declarative descriptions.



Attribute of elements	Constraints
Item (Stock Level)	Task (Precedence constraints)
Resource (Load)	Item (Stock level constraints)
	Resource (Switching, Load, and State constrains)

CEEF gas circulation system



Specification and environmental conditions

Animal and Habitation Module (AHM)	Volume	340m[3] (Habitation Room, Animal Room, Access Aisle)
	O_2 Concentration	Target :20.3%, High: 23.5% Low: 19.5%
	CO_2 Concentration	less than 5000 μLL^{-1}
Plant Chambers (PCs)	Volume	146.3 m^3 (A,B,C), 239 m^3 (F) 332.2 m^3 (Preparation Room)
	O_2 Concentration	Target: 20.3% High: 23.5% Low: 19.5%
	CO_2 Concentration	700 ± 70 μLL^{-1} for light periods. less than 1500 μLL^{-1} for dark periods.

Setup values for the simulation

Eco-Nauts	Two persons live in the simulation, cultivating rice and soybeans to produce their own food for themselves. They sleep from 12 midnight to 6:00 a.m., and their metabolism then is two thirds that of normal activity.
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, 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 in PC F
Stocks	CO_2 Tank : Initial 5000 g, Max 10000 g, Min 0 g O_2 Tank : Initial 5000 g , Max 10000 g, Min 0 g

Schedule description using PSL

```
PROBLEM   CEEF        210

TIMEUNIT  60
CELLTIME  60

TIMEMIN   2006        7           1
TIMEBASE  2006        7           1
TIMEMAX   2006        7           2

%         Item                  Quantity   %
STOCK     O2:ABHM               84550
STOCK     CO2:ABHM              125
STOCK     O2:PCM_A              36435
STOCK     O2:PCM_B              36435
STOCK     O2:PCM_C              36435
STOCK     CO2:PCM_A             125
STOCK     CO2:PCM_B             125
STOCK     CO2:PCM_C             125
STOCK     O2:O2_TANK            5000
STOCK     CO2:CO2_TANK          5000

%            Item           Lower    Upper    %
STOCKLEVEL   O2:ABHM        81218    97878
STOCKLEVEL   CO2:ABHM0      2083
STOCKLEVEL   O2:PCM_A       34947    42116
STOCKLEVEL   O2:PCM_B       34947    42116
STOCKLEVEL   O2:PCM_C       34947    42116
STOCKLEVEL   CO2:PCM_A      0        896
STOCKLEVEL   CO2:PCM_B      0        896
STOCKLEVEL   CO2:PCM_C      0        896
STOCKLEVEL   O2:O2_TANK     0        10000
STOCKLEVEL   CO2:CO2_TANK   0        10000

%            Task           Process   Time (h)   Type   %
OPERATION    CO2:RES_S      RES       6          CONS
OPERATION    CO2:RES_A      RES       18         CONS
OPERATION    CO2:SEP        PROC 1    1          CONS
OPERATION    CO2:SUP_A      PROC 3    2          CONS
OPERATION    CO2:SUP_B      PROC 3    2          CONS
OPERATION    CO2:SUP_C      PROC 3    2          CONS
OPERATION    CO2:SEP_A      PHO_A     1          CONS
OPERATION    CO2:PHO_C      PHO_C     14         CONS
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                .
%            Precedence task   Successive task   Type   Time
PRECEDENCE   CO2:PHO_A         CO2:SEP_A         ESR    6
PRECEDENCE   CO2:PHO_B         CO2:SEP_B         ESR    6
PRECEDENCE   CO2:PHO_C         CO2:SEP_C         ESR    6
PRECEDENCE   O2:SEP_A          CO2:SEP_A         SSS
PRECEDENCE   O2:SEP_B          CO2:SEP_B         SSS
PRECEDENCE   O2:SEP_C          CO2:SEP_C         SSS
PRECEDENCE   CO2:SUP_A         CO2:SUP_B         SS
PRECEDENCE   CO2:SUP_B         CO2:SUP_C         SS
PRECEDENCE   CO2:RES_S         CO2:RES_A         SS
PRECEDENCE   O2:RES_S          O2:RES_A          SS

%      Item           Task        Qty (g/h)   Type   %
ITEM   CO2:ABHM       CO2:RES_S   255         C
ITEM   CO2:ABHM       CO2:RES_A   1147.6      C
ITEM   CO2:ABHM       CO2:SEP     -58.4       D
ITEM   CO2:CO2_TANK   CO2:SEP     -58.4       D
ITEM   CO2:CO2_TANK   CO2:SUP_A   -628        C
ITEM   CO2:CO2_TANK   CO2:SUP_B   -628        C
ITEM   CO2:CO2_TANK   CO2:SUP_C   -330.9      C
ITEM   CO2:CO2_TANK   CO2:SEP_A   198.7       D
ITEM   CO2:CO2_TANK   CO2:SEP_B   198.7       D
ITEM   CO2:CO2_TANK   CO2:SEP_C   118         D
                .
                .
                .
                .
%          Resource            Task        %
RESOURCE   CO2_SEPARATOR       CO2:SEP
RESOURCE   CO2_SUPPLY          CO2:SUP_A
RESOURCE   CO2_SUPPLY          CO2:SUP_B
RESOURCE   CO2_SUPPLY          CO2:SUP_C
RESOURCE   CO2_SEPARATOR_P     CO2:SEP_A
RESOURCE   CO2_SEPARATOR_P     CO2:SEP_B
RESOURCE   CO2_SEPARATOR_P     CO2:SEP_C
                .
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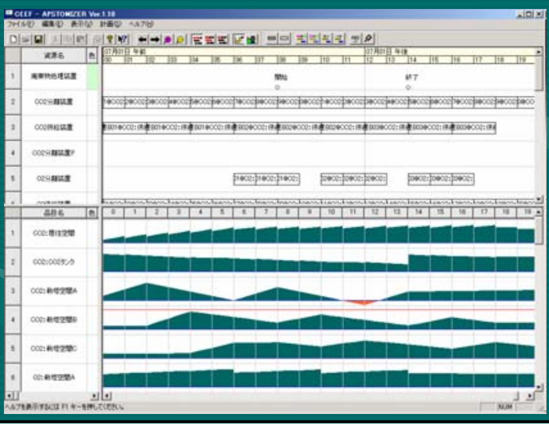
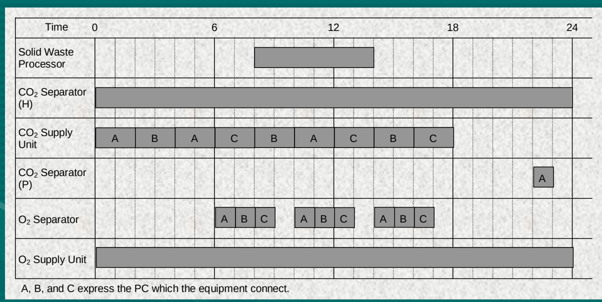
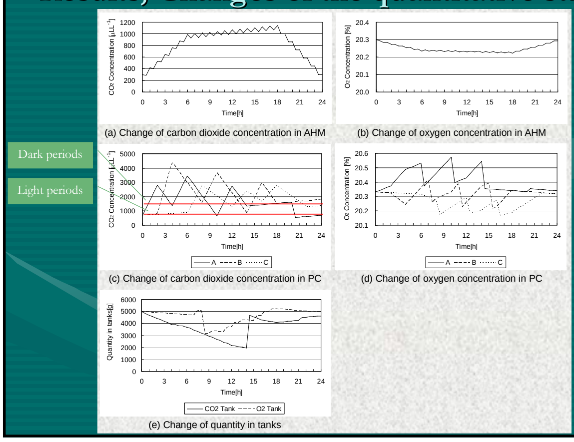
Display of APSTOMIZER



Results, Operation schedule



Results, Changes of the quantitative states



Summary (1/2)

- As the result, we have addressed the following issues in areas such as constraint conditions, dispatching rules, and algorithm development.
- CONSTRAINT CONDITIONS
  - In order to describe the scheduling problem using a PSL, it is necessary to understand the operational characteristics of individual CEEF equipment and to define the constraint conditions relating to operation.
    - In constraint condition, there are constraints such as the processing time of each process, precedence relationship between processes, simultaneous starting or finishing between processes, and continuous usage of the same equipment.
  - Each piece of equipment in the CEEF has been modified many times and their specifications have been updated each time. We are currently surveying the accuracy of the specifications of each piece of equipment. This survey will make it possible to describe the constraint conditions for operating the entire CEEF.

Summary (2/2)

- DISPATCHING RULES
  - In our simulation, we used an SPT for the dispatching rule. However, when we think about the true purpose for operating the CEEF, which is to realize a material circulation that can support human life, the dispatching rule should not be determined by SPT.
  - In actual development, we will adopt a dispatching rule that generates a schedule able to equalize the fluctuation of material circulation. I described the details in my paper.
- ALGORITHM DEVELOPMENT
  - At present, we are developing a new scheduling algorithm utilizing multi-agent reinforcement learning. Using this algorithm will enable generating a schedule that can equalize the fluctuation of material circulation. This new algorithm will be able to automatically study new schedules corresponding to changing situations. We will publish another paper in the future about this new algorithm.

Acknowledgement

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