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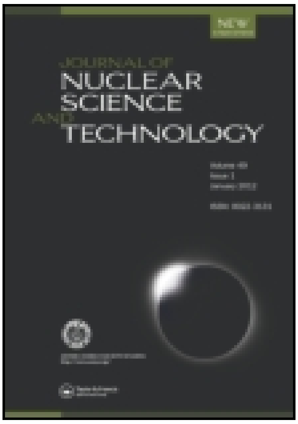

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SHORT NOTE

Multiobjective Optimization for Expansion Planning of Rad-Waste Management System

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In regard to rad-waste management, it is becoming more and more important to achieve assigned tasks reliably, safely and even more economically. Due to various changes, however, management plan adopted as a compromise policy may become unsatisfactory. It is much of significance, therefore, to apply and examine effectiveness of systematic procedure which enables us to persist rationality even subject to such changes. Following the step-wise procedure(4), expansion planning of the rad-waste management system will be studied, in this note, within the general framework of the previous study(1).

1. Statement of Problem

The rad-waste management model in the Research Reactor Institute of Kyoto University was described(1) by a set of linear inequalities after certain transformations. Recalling that some of their upper bounded values corresponded to the limits on capacity or activity level of the processing units, we can relax these limits by expanding their capacities. Introducing additional variables u_i ($i=1, \ldots, 8$) which denotes the expanded amount of each capacity, we can express the relaxed and modified forms of the model as shown in **Table 1**.

Table 1 Relaxed and modified forms of constraints associated with expansion planning

(1) Manageable capacity for each plant $V(\cdot|\cdot)^{\dagger 1}$
 (a) For treatment plant
 $0.5(f_i+u_i)T(i) \leqq V(\mathrm{m}|i) \leqq (f_i+u_i)T(i)$;
 $(m, i) = \{$(LLW, TR-2), (LLW, TR-3), (MLW, TR-4), (SLG, TR-5)$\}$
 (b) For inlet tank
 $V(m|i) \leqq (f_i'+u_i)N(i)$;
 $(m, i) = \{$(LLW, T-1), (MLW, T-2)$\}$
(2) Inventory of stored wastes$^{\dagger 2}$
 (Floor area manageable for stored wastes) $\leqq$ (Existing area) $+u_7$
 (γ-radiation dose from stored wastes; D) $\times$ (Attenuation factor; $e^{-\mu u_8}$) $\leqq$ (Permissible level; 5 mR/yr)$^{\dagger 3}$
(3) Decontamination factor of treatment $D_f^{\dagger 4}$
 $(1/D_f)_i = d_{0i}+d_{1i}V(m_1|i)/V(m_2|i) + d_{2i}(1+u_i/U_i)T(i)/V(m_2|i)$;
 $(m_1, m_2, i) = \{$(SLG, LLW, TR-2), (SLG, LLW, TR-3), (SLY, MLW, TR-4)$\}$
(4) Water consumption $V(\mathrm{WATR}|\cdot)^{\dagger 5}$
 $\sum_i V(\mathrm{WATR}|i) \leqq 2{,}500(V_t/532)$ (m^3/yr) ;
 $i = \{$TR-1, -3, -4, -5, T-5, -6$\}$
(5) Capital cost for expansion $C_n^{\dagger 6}$
 $C_{ni} = C_{pi}(1+r)^N \sum_i (u_i/U_i)$;
 $i = \{$T-1, -2, TR-2, -3, -4, -5, E-2, (Area, Shield)$\}$

Notes:
†1 The expanded units will be operated paralell with existing ones.
†2 The average energy level of stored wastes is assumed 1 MeV.
†3 This was approximated as $D \leqq 5(1+\mu u_8)$.
†4 Available in region, $0 \leqq u_i \leqq U_i$
 U: Upper per day capacity of existing unit.
†5 Imposed from previous result(1).
 V_t: Total sum of generated wastes (nominal value = 532 m^3/yr)
†6 Estimated from existing units by neglecting scale merit.
 C_p: Capital cost in N years ago
 r: Average discount rate over periods.

$\mu=0.1465$, $N=15$ and $r=0.12$ were used in computation. Referred to previous literature(1) in regard to detail notation.

Generally speaking, much capital cost is necessary to account enough margin, and proper proportion is desirable between capital and annual management costs. In another aspect, protection of the environment is very important which requires much capital and management costs. Thus these (1) capital cost for expansion (ENL¥), (2) annual man-

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agement cost (MAN¥), (3) released amount of radioactivity (CURY), and (4) margin with manageable amount of wastes (AMNT) are known to be major and closely related objectives whose attaining levels must be articulated by considering tradeoffs among them.

In a summary, the problem to be considered here is such that: *When no feasible policy can be provided only by the existing capacity of the management system against estimated increase in waste generation*, make a best-compromise expansion plan under the multiple objectives mentioned above.*

2. Step-wise Procedure for Problem-solving[(4)]

Being impossible to determine the adequate extent of expansion a priori, it is usual[(2)] to account possibility of expansion for every unit. From practical aspects, however, such overall approach, as it were, will suffer defects such that: (1) It is very likely that small amounts of expansion are distributed over unduly many units. (2) Number of variables which enter the resulting optimization problem becomes large.

On the other hand, a step-wise procedure begins to derive basic expansion units which mean the minimum required only to recover feasibility against the imposed changes, and views the rest as candidates. Then by evaluating the ideal goal** for such basically expanded system, some additional units will be chosen so that the objectives having insufficient ideal values can be improved most efficiently. As a measure to do this, the sensitivity—a variation rate of objective value to a unit capacity expansion of each candidate was utilized conveniently[(3)]. This is repeated until a decision maker (DM) will judge that the ideal goal has been established sufficiently.

Thus through the step-wise procedure, we can build an adequate framework of the expansion problem under multiobjectives while checking up on the evolution of the system along prescription of the expansion; that is to say, we can know that those expansions are bottlenecks for the feasibility, those for this objective, those for that objective and so on. Such understanding is very helpful for practical decision makers. In addition, we can avoid the computational troubles mentioned already.

3. Numerical Results and Discussion

First every unit is chosen as the candidate for expansion. They are the inlet tanks (T-1 and -2), treatment plants (TR-2~-5) and the floor area and shield at the storage (E-2). Fixing the operating days of each treatment plants, $T(i)$; $i=\{$TR-2~-5$\}$ and evacuation frequency for each inlet tank, $N(i)$; $i=\{$T-1, -2$\}$ at round numbers of the previously obtained solution[(1)], the problem under consideration is known to be formulated as the multiobjective linear programming.

Then solving the auxiliary linear programming, four units (TR-2, -4, -5, E-2 (Shield)) were chosen as the basic units to be installed against the increase in wastes. In thus basically expanded system, the ideal value was calculated for each objective. To improve the attained levels which were judged insufficient as the ideal value by the DM*** (AMNT, CURY), two additional units (T-2 and TR-3) were chosen through the sensitivity analysis. The same procedure was repeated until all the rest of the unsatisfied ideal values become none. (*ref.* **Table 2**)

In thus finally expanded system (*i.e.* Basic, T-2, TR-3 and E-2 (Area)), a set of ideal values, (ENL¥, MAN¥, CURY, AMNT) = (6,059.5, 1,131.4, 236.6, 3.02) was obtained. Then through the man-computer communication, the conflicting objectives were articulated progressively. After all, the best-compromise solution was derived as (30,000, 1,500, 299.6, 2.50), and the corresponding result as shown in **Table 3**.

This was the same result as obtained by the overall approach[(2)]. This implies that we can expect a desired effect—even better with practical point of view, by the proposed

* Two times as much as the nominal value was presumed.

** The optimal value that will be gained with no concern to the attained levels of other objectives.

*** The author acted as the decision maker.

Table 2 Decision process to choose expansion units

No. of repetition	1	2
Expanded extent	Basic units	Basic, T-2, TR-3
Ideal value & Judgement	ENL¥[†1]=6,059.5 ; sat. MAN¥[†2]=1,131.4 ; sat. CURY[†3]=255.02 ; unsat. AMNT[†4]=2.35 ; unsat.	6,059.5 ; sat. 1,131.4 ; sat. 236.56 ; sat. 2.43 ; unsat.

Sensitivity matrix (repetition 1)

I_{NE} \ I_{UG}	AMNT ($\times 10^2$)	CURY
T-1	0.0	0.0
[T-2]	5.36	0.0
[TR-3]	1.32	−2.20
Area	0.005	0.0

Sensitivity matrix (repetition 2)

I_{NE} \ I_{UG}	AMNT ($\times 10^2$)
T-1	0.0
[Area]	2.80

[ ]: Suggested units for expansion
I_{UG}: Index set representing unsatisfied ideal goal
I_{NE}: Index set representing not-expanded candidate unit
†1 ¥10,000, †2 ¥10,000/yr, †3 μCi/yr, †4 Times to nominal value; †1~†3: Minimize, †4: Maximize

Table 3 Resulting expansion plan

i	Unit (u_i)	Required amount	Existing amount
1	T-1	—	40×2 (m³)
2	T-2	1.38 (m³)	20×2 (m³)
3	TR-2†	26.94 (m³/d)	40 (m³/d)
4	TR-3	26.94 (m³/d)	40 (m³/d)
5	TR-4†	2.73 (m³/d)	4 (m³/d)
6	TR-5†	0.31 (m³/d)	0.4 (m³/d)
7	E-2 (Area)	10.02 (m²)	90 (m²)
8	(Shield)†	2.35 (cm)	—

† Basic expansion unit

method compared with the overall approach, a utopian scheme in the case of no computational difficulties and no labor accompanied in realization of the plan. Furthermore, by relying on the statement in Sec. 2, we can make sure that rather small expansions in T-2 and E-2 (Area, Shield) are essential to get the best-compromise management obtained here.

4. Concluding Remarks

The expansion problem of the rad-waste management system was studied assuming the total amount of waste generation is expected to increase. The step-wise procedure was shown to be useful to build a framework of the problem and to understand the structure of the expanded system.

The advantages in computation over the overall approach were not made so clear since the seven units out of eight candidates were chosen as the expansion units in this study. It was verified, however, that a meaningful and also desired planning was derived through the proposed procedure. In fact, comparing with the empirically inspected plan[5] prior to construction of the Kyoto University High Flux Reactor, it can be said that essence of the both plans is very similar with each other. It is left for further studies to concern with this kind of problem in more complicated and large-scale systems where the advantages of the proposed procedure will be presented more obviously.

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