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An Example of Radioactive Waste Treatment System Optimization Using Goal Programming

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Abstract

The ultimate object of our study is to minimize the release of radioactive material into the environment and to maximize the treatable amount of the generated wastes. In planning the practical operation of the system, however, the operating cost, process economics and technical flexibility must also be considered. For dealing with these multiple criteria decision making problems, we used a goal programming which is a kind of multi-objective linear programming. This method requires the decision maker to set goals for each objective that one wishes to attain.

I. Introduction

Optimal operation of radioactive waste treatment system has been an important problem during the last several decades. A wide variety of techniques have been applied to solve this problem. Most of the approaches are based on cost benefit concepts, and the problems are formulated as an optimal search problem that can be defined mathematically by a set of cost function and constraints.

Generally, in linear programming, the cost function and constraints must be expressed in single dimension. But the optimization problem for radioactive waste treatment system involves various types of requirements and constraints which are composed of various kinds of dimensions such as cost, radioactive waste volume, dose, radioactivity, time and etc. And also in planning the practical operation, technical flexibility, utility saving and process economics must be considered. But these multiple objectives are conflicting with each other.

In this study, to treat this complex problem, a mathematical procedure will be presented through the plan of the system operation in a goal programming which is a kind of multi-objective linear program.

Goal programming was proposed by Charnes and Cooper[5] (1961) for a linear programming. It has been further developed by Ijiri[6] and Lee[7] et al (1970's). The most striking characteristics of goal programming is that an optimal point which makes the best use of the restricted resources can be found.

The main purpose of this study is to demonstrate the potential of goal programming in the optimization for the operation of the radioactive waste treatment system which has multi-objectives and to present the guidelines for the application.

II. System modeling and optimization process

In order to carry out the optimization a feasible region must be determined, which is based on the system identification. In this study, system identification is based on the radioactive waste treatment system (Fig 1) of KUR (Kyoto University Research Reactor in Japan), and modeled according to the Goal Programming method.

The ultimate objective is to find a optimal operation point which is to minimize the released radioactivity of liquid waste and to maximize the total treatable radioactive waste amount within the restricted conditions such as cost, water consumption, temporary storage area of waste and so forth. Therefore, deviation variables are introduced as followings.

- ***Limit of storage area***

The floor area at the temporarily storage (TS) which is occupied for the temporary storage, is restricted by the following. ½ means that wastes are taken out to the outside every other six months for the long term storage.

$$\left\{\frac{1}{2}\sum_i\left(\frac{a_i}{v_i}\right)\times V_{TS,i}\right\}+d_1^- \le 90\left(m^2/_{yr}\right), i=(SLG, SLY, COM, IMC, WF)$$

- ***Cost restriction***

Treatment cost, C_t, the disposal cost as a consignment fee for the temporarily stored wastes cost, C_d, and the cost of water, C_w, are assumed to change proportionality with their respective amount.

$$\sum\left(C_{t,i}+C_d+C_w\right)+d_2^+ \le 10^7\left(Yen/_{yr}\right), i=(P-1, P-2, P-3, P-4)$$

- ***Water consumption***

Water is consumed for cooling P-3, and P-4 and back washing at the P-2, while the cooling water is recycled at the P-3, it is spent without reuse at the P-4. Water is also used for storage at the DT-1, DT-2, DT-3 so as to meet the release criteria (below 10^{-1} $\mu Ci/m^3$ or $20^{-1}\mu Ci/m^3$).

$$\sum_i V_{WATER,i}+d_3^+ \le 5000\left(m^3/_{yr}\right), i=(P-2, P-3, P-4, DT-1, DT-2, DT-3)$$

- ***Release limit of radioactive liquid waste***

In these processes (DT-1, DT-2, DT-3) if the radioactivity of liquid waste is higher than the release limit of liquid waste (10^{-1} $\mu Ci/m^3$ or $20^{-1}\mu Ci/m^3$), radioactive liquid waste is diluted to meet release criteria and released to the environment.

$$V_{WATER,DT-1} \ge 10\cdot A_{LLW,DT-1} - V_{LLW,DT-1} + d_4^-$$
$$V_{WATER,DT-2} \ge 10\cdot A_{LLW,DT-2} - V_{LLW,DT-2} + d_5^-$$
$$V_{WATER,DT-3} \ge 10\cdot A_{MLW,DT-3} - V_{MLW,DT-3} + d_6^-$$

From Equation 1-4, it is possible to construct the objective function as followings:

$$Minimize: P_1d_1^- + P_2d_2^- + P_3d_3^- + P_4\left(d_4^- + d_5^- + d_6^-\right)$$

III. Results and discussion

Through the goal programming, we were able to find an optimal operation point of the reference system, which makes the best use of the restricted resources.

To find the optimal operation point, we assumed and varied three values: (1) total treatable radioactive waste volume, (2) release limit of radioactive liquid waste and (3) priority order. A nominal value of total treatable radioactive waste volume was assumed to be 532 m^3/yr and varied from nominal value to 2 times as much as nominal value in this study. The release limit of radioactive liquid waste was also assumed to be varied from $10^{-1}\mu Ci/m^3$ to $20^{-1}\mu Ci/m^3$. 24 (4!) objective functions varied with the priority order were considered for each case.

As a result of calculation for all cases, the optimal operation point was as illustrated in Table 1. In this case the total treatable radioactive waste is 2 times as much as nominal value and the release limit of radioactive liquid waste is $20^{-1}\mu Ci/m^3$. The LLW routed to P-1 as well as P-2. Both the P-1 and P-2 are operated at the lowest rate ($20m^3/yr$) and the highest production rate of sludge (5%). P-3 is operated at the lowest rate ($2m^3/yr$) with the lowest production rate of slurry (2%). Although the release limit of liquid waste is lower than any other cases, the operation days, total cost, and storage area are reduced. All objective functions have the same results regardless of the priority order only at the optimal operation point.

IV. Conclusions

The Goal Programming method has capabilities to predict the optimal point at any given constraints as aforementioned. Although there are many constraints involved to solve the complex problem, the decision maker has a freedom to calculate the optimal operation point to satisfy its needs.

At the optimal operation point of the reference system, which makes the best use of the restricted resources, following conclusions are obtained:

- Both the P-1 and P-2 are operated at the lowest rate (20 m^3/day) with the highest production sludge (5%),
- P-3 is operated at the lowest rate (2 m^3/day) and lowest production rate of slurry (2%) while the operating days is longer than any other units,

- Total treatable radioactive waste volume is 2 times as much as nominal value, and
- Release limit of radioactive liquid waste is $20^{-1}\mu Ci/m^3$.

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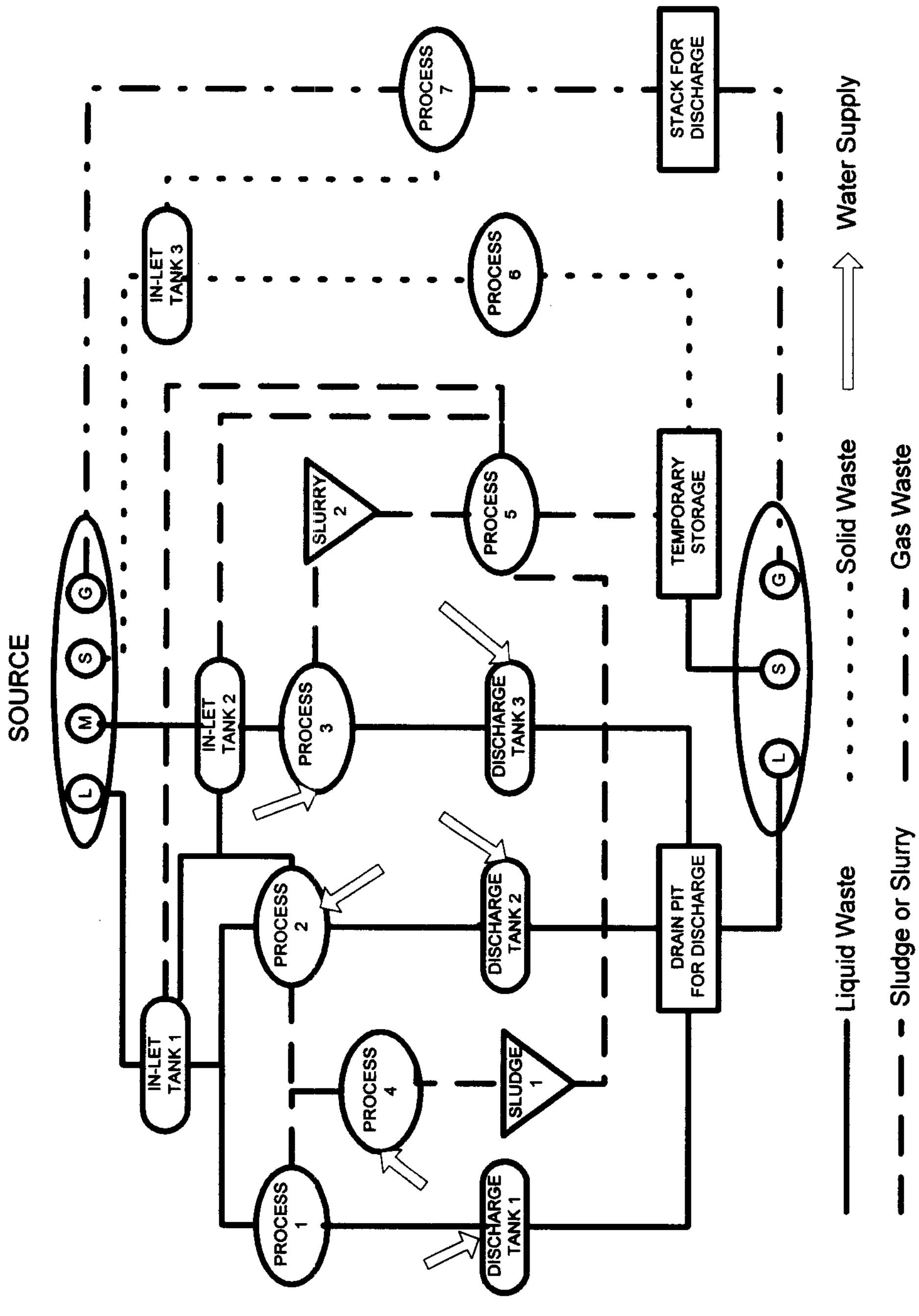

Fig.1 Reference System

Table 1 Total treatable radioactive waste volume : $2 \times 532 m^3 / yr$
Release limit of radioactive liquid waste : $20^{-1} \mu Ci/m^3$

Waste Volume (m^3/yr)		**Operation Days (d/yr)**		**Evacuation Frequency**		**Water Volume (m^3/yr)**	
P-1, LLW	259.1	P-1	12.9	IT-1	26.5	DT-1	1045.9
P-2, LLW	236.4	P-2	11.8	IT-2	3.2	DT-2	131.2
P-3, MLW	16.1	P-3	8.1			DT-3	7.6
P-1, SLG	12.9	P-4	61.9			COOLING	3815.3
P-2, SLG	11.8	MON	59.4				
S-2, SLY	0.3	REG	6.2				
Treatable Volume per Day of Sludge or Slurry (m^3/day)				P-1			20
				P-2			20
				P-3			2
				P-4			0.4
Generated Sludge or Slurry of Liquid Wastes (%)				P-1			5
				P-2			5
				P-3			2
Treatment Cost		1.552E6		**Total Operation Days (d)**			160.3
Storage Cost		8.179E6		**Storage Area (m^2)**			22.33
Water Cost		2.494E5		**Surface Dose (mR)**			4.42
Total Cost (Yen/yr)		9.980E6		**Water Consumption (m^3/yr)**			5,000

NOMENCLATURE

P_i : the i-the priority

d_i^- : under-achievement for the i-th goal

d_i^+ : over-achievement for the i-th goal

$V_{i,j}$: volume of the j-th unit for the item i (m^3)

$C_{t,j}$: total cost for the j-th unit (Yen/yr)

C_d : disposal cost (Yen/yr)

C_w : water cost (Yen/yr)

a_i : base area of each waste drum (m^2)

v_i : volume of each waste drum (m^3)