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Sensitivity Analysis on the Priority Order of the Radiological Worker Allocation Model using Goal Programming

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Abstract

In nuclear power plant, it has been the important object to reduce the occupational radiation exposure (ORE). Recently, the optimization concept of management science has been studied to reduce the ORE in nuclear power plant. In optimization of the worker allocation, the collective dose, working time, individual dose, and total number of worker must be considered and their priority orders must be thought because the main constraint is necessary for determining the constraints variable of the radiological worker allocation problem. The ultimate object of this study is to look into the change of the optimal allocation of the radiological worker as priority order changes. In this study, the priority order is the characteristic of goal programming that is a kind of multi-objective linear programming. From a result of study using goal programming, the total number of worker and collective dose of worker have changed as the priority order has changed and the collective dose limit have played an important role in reducing the ORE.

I. Introduction

The occupational radiation exposures in nuclear power plant are not only the factor of plant safety management but also the basic element of the plant safety evaluation.[1] Therefore, radiological protection problems have been serious social concerns during the last several decades. Recently, many countries have concentrated an attention upon ALARA principles more than ever. Recently, the optimization concept of management science has been studied to reduce the ORE in nuclear power plant. In management science the worker allocation problem or work assignment problem have been studied for a long time. The worker allocation is the methodology of management science to assign many work (or job) to the worker more effectively with a satisfaction of constraints. The constraints are such as the total worker number, collective dose, working time and individual dose that are in conflict with each other. To solve this multi criteria problem, we must have a method which is able to deal with the multi dimension problem.[2] To solve this complex problem, a mathematical procedure will be presented through a goal programming which is a kind of multi-objective linear program. But the priority order of the system constraints is very important in goal programming because it is able to change the result of optimization. Therefore, the ultimate objective of this study is to examine which system constraint is the main factor of the radiological worker allocation model. Priority order has changed and its effects have studied to accomplish this study. It was the collective dose limit that is the most important factor of this model to reduce the ORE.

II. System Modeling[5]

The target system of this study is the allocation of radiological worker in overhaul period (or refueling period) of nuclear power plant. The worker allocation is to allocate many workers to various works. After considering many kinds of constraints, we have the optimal solution of the worker allocation to each works. The ultimate object is to find the effect as the change of priority order. We assumed the followings to find the optimal allocation of worker: (1) all of workers have the same labor skill, (2) all of works (or job) have carried out, only if total work time is satisfied. System contraints and deviation variables are as followings.[4,5]

• ***Collective Dose Limit***

In the overhaul period of nuclear power plant, radiological workers are exposed to radiations. Therefore, in planning of work schedules, the goal which is attained is set. The collective dose that workers are exposed to is estimated by multiplying the area dose rate (ADR) with the working time (WT) and the number of worker (X).

$$\sum_{i=1}^{n}(ADR_i \times WT_i \times X_i) - d_1^+ = goal \qquad (1)$$

(i = 1, 2 , 3 ,...., n , n = the number of job)

where ADR_i : the area dose rate for the i^{th} job (mR/hr)

WT_i : the worker's working time for the i^{th} job (hr)

X_i : the number of worker for the i^{th} job (man)

goal : the objective to be attained (man-rem)

• ***Individual Dose Limit***

Individual dose can be calculated by dividing the collective dose (CD) with the number of worker (X). The results of this calculation should not exceed the individual dose limit. Here, the individual dose limit is the goal which must be satisfied to obey the regulation. Therefore, this goal can be varied with other things.

$$\sum_{i=1}^{n} CD_i / \sum_{i}^{n} X_i - d_2^+ = goal \qquad (2)$$

where CD_i : collective dose for the i^{th} job (man-rem)

• ***Total Worker Limit***

The total worker which can join the radiological work during of overhaul period is limited. But if the total worker is not restricted, the optimal solution can be obtained within other constraints.

$$\sum_{i=1}^{n} X_i - d_3^+ = goal \qquad (3)$$

• *Minimum Work Time Limit*

There are many works (or jobs) which should be carried out in overhaul period. And they are various in view of their properties. Each of them has minimum work time required to carry out a job. MWTL is the minimum working time required to carry out a job.

$$WT_i \times X_i + d_4^- = goal(MWTL_i) \qquad (4)$$

• *Objective Function*

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

$$Minimize\ : P_1 d_1^+ + P_2 d_2^+ + P_3 d_3^+ + P_4 d_4^-$$

where $d_i\pm$: over or under achievement for the i^{th} goal

P_i : the priority for the i^{th} goal

III. Results

We applied the goal programming to optimize the radiological worker allocation for three cases. They are the 11^{th} refueling outage of the Beaver Valley Power Station Unit 1 in USA [3], the 9^{th} overhaul period of the Kori unit 3 and the 9^{th} overhaul period of the Kori unit 4 in Korea. In USA case, we chose the 10 works of steam generator maintenance. And in other cases, we used the total work of overhaul period. The total work of overhaul period was grouped to 20 main works. The data for this study was omitted because of limited space. Four system constraints have the high priority order in turn and other constraints have same order except one that has the high order.

Table 1, 2, and 3 show the results of each case as a different priority order. In Table 1,2 and 3, X_1, X_2, X_3,..., X_{10},... means the number of worker to be allocated to each work. In tables the reference data is the actual number of worker data during overhaul period in each nuclear power plant and the right side of 'reference data' (section of 'high priority order') is the result that is obtained using goal programming as the priority order changes. CD Limit is the result when the collective dose limit has the high priority order. ID Limit is the result when the individual dose limit has the high priority order. TW Limit means that the total worker limit is the highest priority order. MWTL has the same meaning.

As shown in table, the number of worker to be allocated changes if the priority order of system like the characteristic of goal programming. But no one can say which is more correct except one that is the decision maker. In other words, it depends on the decision maker's choice that which result is correct. Fig. 1 and Fig. 2 show that the difference between result and actual data changes as the priority order changes. First of all, when the collective dose limit is the high priority order, the reduction of the collective dose is relatively large. But the reduction of total worker is not very large. Secondly the result that the individual dose limit is high priority order is as follows. The individual dose limit is also the constraints about the radiation exposure dose same as the collective dose. Therefore, the result that the individual dose is a high priority is similar to the result of the former. The next is the result that the total worker is a high priority order. In a view of the reduction of total worker, this is the most effective case but in view of the collective dose, this is the most ineffective case. It is thought that the collective dose increase because of the excessive reduction of total worker. Finally, MWT limit cannot be beneficial with two aspects, the collective dose and total worker. But in the respect of the accomplishment of work it may be effective. Many worker and much working time are the key point of the accomplishment of work. That is to say, the collective dose and total worker may increase respectively to accomplish the work.

IV. Conclusion

As shown in Fig 1, the total number of worker decreased using this study. When the total worker limit is the highest priority order, the reduction of worker is most large. It means that the decision maker must give a high priority order to the total worker limit to reduce the total worker participated in each work. But the decision maker must consider the reduction of the collective dose. If the decision maker wants to reduce the collective dose, he must concentrate the collective dose limit as the high priority order.

In Table 1~3, total worker and total CD (collective dose) have a tendency to be reduced. That is to say, the occupational dose or the total worker in NPP has a possibility to be reduced by the systematic management with goal programming.

Using the goal programming, the decision maker has to consider the priority of each constraint because the result can be varied as the priority order. The decision maker must give a high priority to the object regarded as an ultimate goal. In nuclear power plant, the CD limit must be given the high priority order because the limit related the radiation dose is most important thing. Also the ultimate objective of this study is the reduction of collective dose of radiological workers.

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Table 1. The number of worker of each work in Beaver Valley unit 1

Number of Workers		Reference Data	High Priority Order			
			CD Limit	ID Limit	TW Limit	MWT Limit
X1		200	198	198	196	200
X2		204	201	203	201	202
X3		140	140	140	139	140
X4		131	130	131	130	130
X5		128	125	127	125	128
X6		43	40	41	40	42
X7		40	39	39	38	40
X8		40	33	35	32	39
X9		42	40	40	39	41
X10		29	27	28	25	27
Tot	Worker	997	973	982	965	990
	CD	64.1	61	62.1	63.9	63.6

Table 2. The number of worker of each work in Kori unit 3

Number of Workers		Reference Data	High Priority Order			
			CD Limit	ID Limit	TW Limit	MWT Limit
X1		60	60	60	59	60
X2		23	21	22	20	23
X3		21	21	21	21	21
X4		34	35	36	34	34
X5		16	14	15	11	15
X6		22	21	21	21	21
X7		253	251	252	250	253
X8		31	31	31	30	31
X9		50	50	50	48	50
X10		22	21	22	21	21
X11		21	20	20	20	20
X12		10	10	11	10	10
X13		83	82	82	81	83
X14		45	41	41	41	44
X15		24	24	25	23	24
X16		49	47	47	47	49
X17		19	20	19	19	19
X18		79	74	74	73	78
X19		106	103	105	101	106
X20		388	385	386	385	388
To	worker	1356	1331	1340	1315	1350
	CD	300.7	281.1	289.2	298.7	297.6

Table 3. The number of worker of each work in Kori unit 4

Number of Workers		Reference Data	High Priority Order			
			CD Limit	ID Limit	TW Limit	MWT Limit
X1		68	66	66	66	68
X2		12	10	11	8	11
X3		15	13	15	13	14
X4		17	17	17	17	17
X5		20	18	19	15	20
X6		39	36	36	36	38
X7		38	38	38	38	38
X8		31	31	31	30	31
X9		23	21	21	19	22
X10		7	7	7	7	7
X11		27	24	25	21	25
X12		29	26	27	26	28
X13		61	58	60	57	61
X14		30	30	30	28	30
X15		14	14	14	14	14
X16		44	44	44	43	44
X17		18	18	18	18	18
X18		58	52	54	52	57
X19		78	77	78	75	78
X20		244	238	242	237	244
Tot	worker	873	838	853	820	865
	CD	73.8	53.0	55.8	71.2	67.5

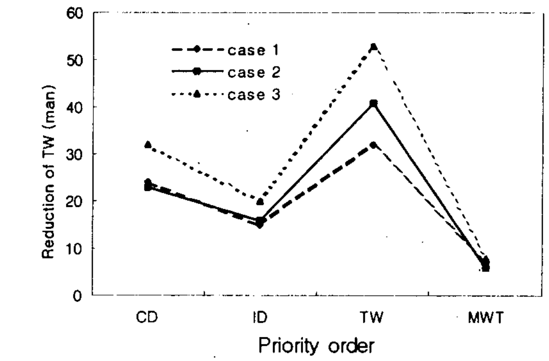

Figure 1. Reduction of total worker according to the priority order

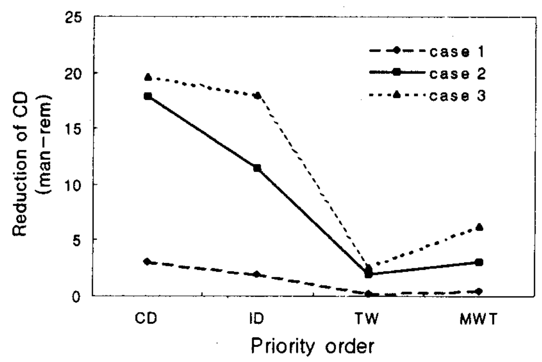

Figure 2. Reduction of the CD according to the priority order