An Algorithm for management of the shift schedule in nuclear power plants with a consideration for human factors

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Introduction

- Shiftwork

Different groups of workers work at the different period of time on the same day or a timework system being operated in a part-time type.

- An object of Shiftwork

- To achieve workers' physical safety and mental stability

- The enhancement of company productivity,

- The reduction of labor cost under a 24 hours continuous working environment

- It is important to establish an effective shift assignment schedule for several work groups to work repetitively or periodically for a period of time.

Introduction

- For example

when changes in the work schedule such as substitution and overtime happen, work assignment to shift workers has often been uneven.

In this case, workers' fatigue may increase or workers' health may break down due to overtime and inadequate work assignment made by no consideration of human factors.

- In this study, we developed a systematic shift scheduling method for maintaining a balance of shift workers' workload for the application to the shiftwork management system in nuclear power plants.

Factors for the management of shiftwork

- The characteristics and limitations in human factors

- designing working time, the number and length of overtime, others

- The domestic and international legal requirements (nuclear power plants in Korea)

- the requirements in the Labor Standard Act
- the international labor law (ILO convention No. 171, 178)
- the requirements in the Atomic Energy Act
- ANSI/ANS 3.2

The characteristics and limitations in human factors

- The basic items

- which are proposed by

1) Retenfranz et al., (1976)
2) Shift Work Committee, Japan Association of Industrial Health (1979)
3) basic constraints

- Musliu et al.,(2004),
- Aykin(1996 ; 2000)

Number of shifts	Which means 2 shifts, 3 shifts, or 4shifts, etc. For 3 shifts, there are a morning shift, an afternoon shift, and a night shift
Length of shifts	Which is coupled to 4 Shift types and has 6 hours, 8 hours, 12 hours, and more than 12 hours.
Changeable start time in each shift	Which means starting time and ending time of work
Shift types	Which can classify short-term shifts, medium-term shifts, and long-term shifts.
Lengths and numbers of various breaks e.g. rest break, lunch break, dinner brake, relief break, etc	For example, rest break, lunch break, dinner brake, relief break, etc., which are related to break time and rest days. Break time occurs in the middle of work, and rest days are dependent on shift types.

The characteristics and limitations in human factors 1

Number of shifts	Which means 2 shifts, 3 shifts, or 4shifts, etc. For 3 shifts, there are a morning shift, an afternoon shift, and a night shift

- 3 Shifts

- 3 shift system is best shift type and number of shifts (Matsumoto, 1979),

- 5 days a week and 40 hours a week has been a social system (Kogi, 1991; Kroemer 1994; ILO, 1994).

- In nuclear power plants, after the accidents of TMI and Chernovyl, a three shift system has been recommended in order to reduce shift workers' workload (NUREG-0737), and almost nuclear power plants execute three shifts at present.

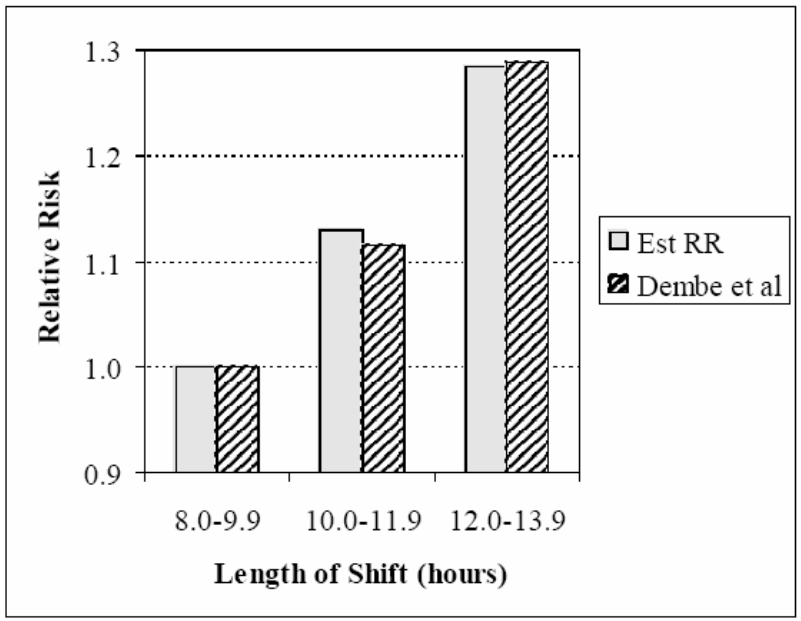
The characteristics and limitations in human factors 2

Length of shifts	Which is coupled to 4 Shift types and has 6 hours, 8 hours, 12 hours, and more than 12 hours.

- 8 Hours

- 12 hours for 2 shifts, 8 hours for 3 shifts, and 6 hours for 4 shifts.
- Heart rates, blood pressure, body temperature, oxygen consumption, and others (Volle et al., 1979)
- ILO(8 hours a day, 5 days 40 hours a week)

Comparison of the estimated relative risk with that reported by Dembe et al (2004)



The characteristics and limitations in human factors 3

Changeable start time in each shift	Which means starting time and ending time of work

- Work time

For Example

start time : 7 o'clock in the morning in 3 shifts
morning shift(7:00 ~ 15:00), afternoon shift(15:00 ~ 23:00), and night shift(23:00 ~ 7:00).

It is desirable to decide work start time and end time by consideration of business properties, transportation facilities, and existence of a supporting program (Knauth, et al., 1983).

The characteristics and limitations in human factors 4

Shift types	Which can classify short-term shifts, medium-term shifts, and long-term shifts.

- Shift type

- short-term shifts : shifts change after two to three days of work.
- long-term shifts : shifts change after working for a period of time more than 7 days.

- There have been different opinions regarding to the shift term.

The characteristics and limitations in human factors 5

Lengths and numbers of various breaks e.g. rest break, lunch break, dinner brake, relief break, etc	For example, rest break, lunch break, dinner brake, relief break, etc., which are related to break time and rest days. Break time occurs in the middle of work, and rest days are dependent on shift types.

- Breaks, etc

- Rest days, Break time (include mealtime, breaks, and naps)

1) At least 11 hours of rest must be guaranteed between the end of shift work and the start of next shift work.

2) After the completion of a night shift, there should be at least 24 hours of rest.

- Consideration of circadian rhythm (clockwise)

Counterclockwise shift changes should be avoided since they are retrogressive to physiological functions (Knauth, 1996).

The Basic Mathematical model

- Integer Programming (IP) - Dantzig(1954)

Minimize $$\sum_{j=1}^{n} c_j \cdot x_j \qquad (1)$$

Subject to $$\sum_{j=1}^{n} a_{ij} \cdot x_j \geq r_j, \quad \text{for } i = 1, 2, ..., m \qquad (2)$$

$$x_j \geq 0; \quad \text{all integer}, \quad \text{for } j = 1, 2, ..., n \qquad (3)$$

n: Index for shifts

m: Number of time period to be scheduled over a single day.

xj: Number of employees assigned to shift j.

rj: Number of employees required to work in the ith time period.

cj: Cost of having an employee work in shift j.

aij : 1 or 0(1: if the time period i is a work period of shift j, 0: others).

Previous studies of Shiftwork

1) Dantzig(1954), Bachtold & Jacobs(1990), Thompson(1995), Aykin(1996, 2000)

➡ these models considered insufficient the ergonomic constraints of actual practices.

2) Schwarzenau et al(1986), Nachreiner et al(1993)

➡ lack flexibility even in the consideration of legal criteria for work time, and do not consider human factors having been raised recently such as restriction of back-shift which is reverse to worker's physiological rhythm.

They also do not consider human factors criteria about education and training , and workers' return to work after a few days off for rest.

The results of previous studies are not sufficiently usable in practical business.

An objective function in the model being proposed in this study

Objective	Advantage
minimize $z = d_1 + d_2$ **Where,** ***d1*: differences in the sum of work time of each shift** ***d2*: differences in the sum of break time of each shift**	It is necessary to have an objective to minimize differences in workload and working time among shift groups Hence, balancing the work time and break time of workers in shift groups is necessary

1) In case of **overstaffing**, it may bring in disadvantages by increasing labor cost due to decrement of worker utilization and increment of excessive workers.

2) In case of **understaffing**, it may have risky factors in aspect of safety since it can finally reduce service quality and give workers excessive workload.

3) In case that **just cost is considered for the objects** of shiftwork scheduling, optimal number of workers can not be obtained as expected and understaffing may be resulted with a high possibility. This may act a cause of human errors in safety-related jobs.

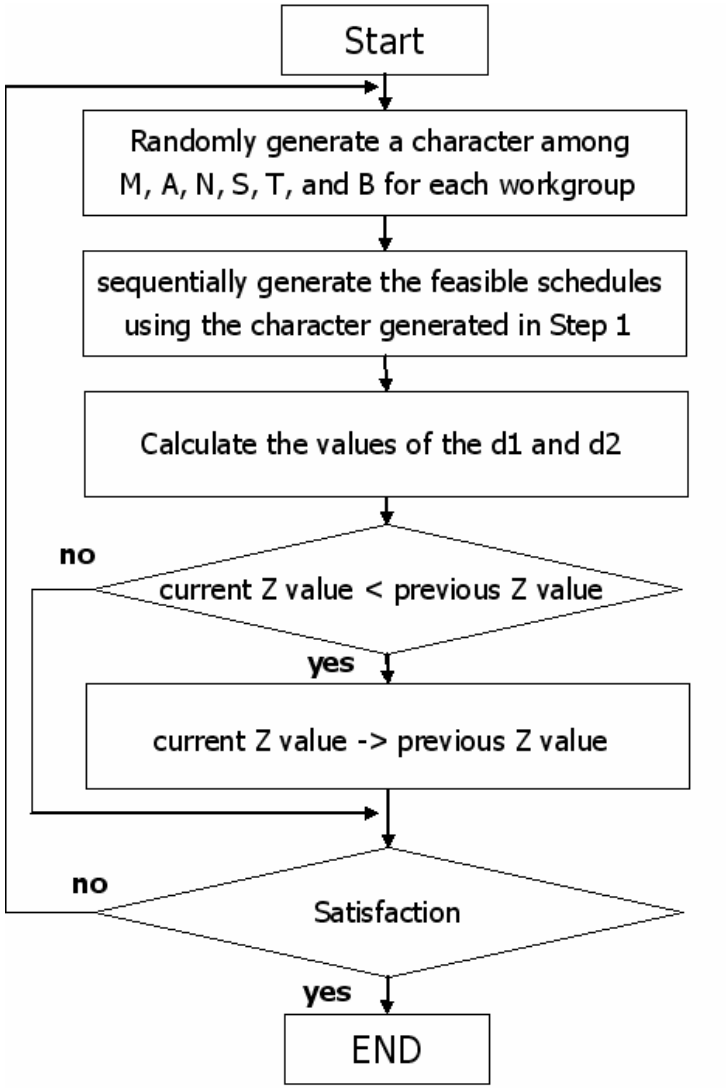
Constraints of this model (for example)

- The common constraints (Musliu et al(2004), and Aykin(1996, 2000))

1) Six workgroups and three shifts are considered.
2) Each shift consists of M(Morning work), A (Afternoon work), N (Night work), S (Supporting work), T (Training work), and B (Break time).
3) Continuous works for three days for M, A, and N should be performed in each workgroup.
4) Continuous works for three weeks for T should be performed in each workgroup.
5) Shift design is scheduled during 180 days (=6 months * 30 days).

- The specific constraints (Nuclear Power Plants in KOREA)

1) The work times (including M, A, N, S, and T) of five days and the break times of two days should be assigned in each week.
2) The break times of two days should be assigned after each N shift.
3) The break time of a day should be assigned when the shifts (MA and AN) is changed.
4) The shift S should be assigned one time after the night work of two continuous days, that is, NN.
5) The breaks of continuous four days should not appear, that is, the NNNN is not considered.
6) The back shifts such as A M and N A are not considered.
7) Among each workgroup, a duplicated work or break should not appear.



The procedure for the heuristic approach

Step 1: Randomly generate a character among M, A, N, S, T, and B for each workgroup.
Step 2: As shown in expressions (7) and (8), sequentially generate the feasible schedules by using the character generated in Step 1 for each workgroup
Step 3: Calculate the values of the d1 and d2 in each workgroup, and then store the value of Z shown in expression (5).
Step 4: If the current Z value obtained in Step 3 is better than the previously stored Z value, then the former replaces the latter as current value.
Step 5: Stop condition.

Workgroup I: MMMBBAAABNNNBBS (5)

Workgroup II: BBAAABNNNBBSMMM (6)

Workgroup I: MMMBBAAABNNNBBSMMMBB (7)

Workgroup II: BBAAABNNNBBSMMMBBAAA (8)

Result

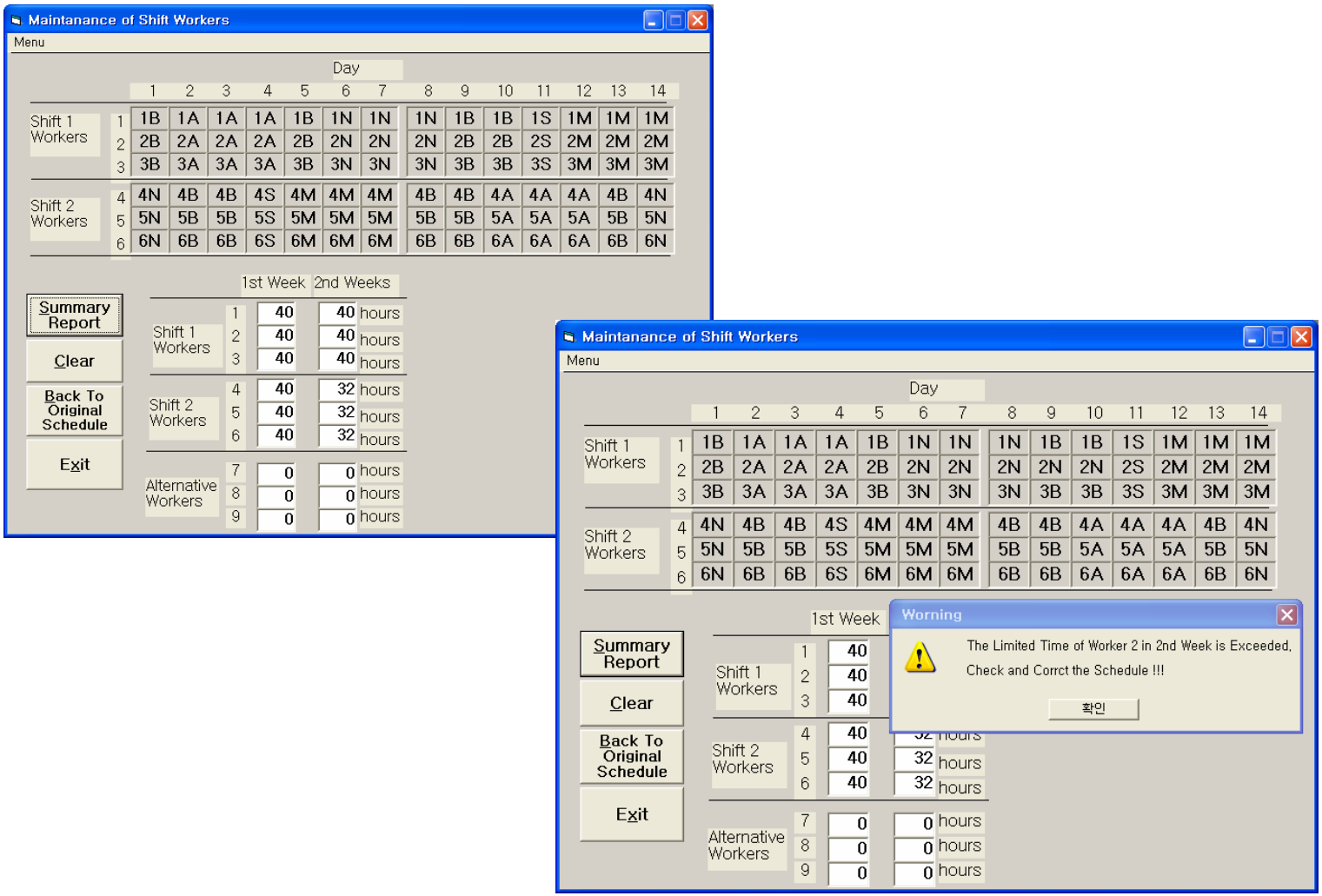
		Days																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
work groups	I	B	A	A	A	B	N	N	N	B	B	S	M	M	M	B	B	A	A	A	B
	II	B	S	M	M	M	B	B	A	A	A	B	N	N	N	B	B	S	M	M	M
	III	A	B	N	N	N	B	B	S	M	M	M	B	B	A	A	A	B	N	N	N
	IV	T	T	T	T	T	B	B	T	T	T	T	T	B	B	M	M	M	B	B	A
	V	M	M	B	B	A	A	A	B	N	N	N	B	B	S	T	T	T	T	T	B
	VI	N	N	B	B	S	M	M	M	B	B	A	A	A	B	N	N	N	B	B	S

- Working time, rest days, rotation and others are almost the same for each work group.

Discussion & conclusion

- We have proposed a heuristic approach for effectively balancing shift schedules.
- The algorithm proposed in this study can be applied to public facilities and industries where the system safety issues is a matter of highest priority such as NPPs.
- A software program can solve these problems.
(SWSS)
- For a good management of shift work scheduling should be managed by the life cycle management(LCM) which includes plan, design, operation, and modification

1) S/W(Example)


Maintanance of Shift Workers
Menu
Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Shift 1 Workers
1 1B 1A 1A 1A 1B 1N 1N 1N 1B 1B 1S 1M 1M 1M
2 2B 2A 2A 2A 2B 2N 2N 2N 2B 2B 2S 2M 2M 2M
3 3B 3A 3A 3A 3B 3N 3N 3N 3B 3B 3S 3M 3M 3M
Shift 2 Workers
4 4N 4B 4B 4S 4M 4M 4M 4B 4B 4A 4A 4A 4B 4N
5 5N 5B 5B 5S 5M 5M 5M 5B 5B 5A 5A 5A 5B 5N
6 6N 6B 6B 6S 6M 6M 6M 6B 6B 6A 6A 6A 6B 6N
Summary Report
Clear
Back To Original Schedule
Exit
1st Week 2nd Weeks
Shift 1 Workers
1 40 40 hours
2 40 40 hours
3 40 40 hours
Shift 2 Workers
4 40 32 hours
5 40 32 hours
6 40 32 hours
Alternative Workers
7 0 0 hours
8 0 0 hours
9 0 0 hours
Maintanance of Shift Workers
Menu
Day
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Shift 1 Workers
1 1B 1A 1A 1A 1B 1N 1N 1N 1B 1B 1S 1M 1M 1M
2 2B 2A 2A 2A 2B 2N 2N 2N 2N 2N 2S 2M 2M 2M
3 3B 3A 3A 3A 3B 3N 3N 3N 3B 3B 3S 3M 3M 3M
Shift 2 Workers
4 4N 4B 4B 4S 4M 4M 4M 4B 4B 4A 4A 4A 4B 4N
5 5N 5B 5B 5S 5M 5M 5M 5B 5B 5A 5A 5A 5B 5N
6 6N 6B 6B 6S 6M 6M 6M 6B 6B 6A 6A 6A 6B 6N
1st Week
Worning
The Limited Time of Worker 2 in 2nd Week is Exceeded,
Check and Corrct the Schedule !!!
확인
Summary Report
Clear
Back To Original Schedule
Exit
Shift 1 Workers
1 40
2 40
3 40
Shift 2 Workers
4 40
5 40 32 hours
6 40 32 hours
Alternative Workers
7 0 0 hours
8 0 0 hours
9 0 0 hours

2) A management of the shift work schedule factors

Operation stage		Information		
		Operation contents	*Input*	*Output*
Plan/ design	1.1	A review and examine working time	The regulation, ergonomic criteria	Guideline of working time
	1.2	A decision of shift work type	2, 3, 4 shifts	The result of shift type's strength and weakness
	1.3	A comparison of working time		
	1.4	Resting time, duty-off		
	1.5	The introduction of work type	AN assignment to a position, Reorganization, Support works, Workloads	The solution of operational aspects
	1.6	The application of a law	Modification of works, The division of works and workers, The requirement of training time	
	1.7	A supplement of the personnel		
	1.8	A management of qualification and training		
	1.9	Overhaul work support		

Plan/Design

Operation stage		Information		
		Operation contents	*Input*	*Output*
Opera -tion	2.1	A taking over the shifts		A leave application, Approval of taking over the shifts, Changes of work schedules
	2.2	Overtime	The present condition of overtime for shift workers	Overtime schedule, A guideline of overtime and take over the shifts
	2.3	The monitoring of continuous working time at work in schedule	Schedule	The condition of overtime , The condition of continuous working time
	2.4	Duty of fitness		A diary of hand over
	2.5	Mental health, Drugs abuse	Doping test	A diary of hand over
	2.6	Assign for a task		A diary of hand over
	2.7	Supervise		A diary of hand over
	2.8	A operational records of a critical facilities		A diary of operating, A record of an automation values, out of orders, accidents
	2.9	A management of operation and maintenance using a critical of facilities		A diary of hand over

Operation

Operation stage		Information		
		Operation contents	*Input*	*Output*
Modifi -cation	3.1	A decision of shift modification		
	3.2	A review and examine working time	The regulation, ergonomic criteria	A guideline of working time
	3.3	The modification of work type and schedule	Assignment to a position, Reorganization, Support works, Workloads	The solution of operational aspects
	3.4	Modification	Planning of modification, modification of works, Division of works and workers, The requirement of training time	A plan of modification
	3.5	A supplement of the personnel		
	3.6	A management of qualification and training		
	3.7	Overhaul work support		

Modification

Discussion & conclusion

- Our heuristic algorithm can consider easily, the flexibility of real shift work situation.

- Our algorithm can handle a multi goal programming. For example there can be many goals, such as Qualification, Training, Overtime, Take over, Illness, Duty off, and others

- Thank you for your attention!

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