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)

<table>
<thead>
<tr>
<th>Number of shifts</th>
<th>Which means 2 shifts, 3 shifts, or 4 shifts, etc. For 3 shifts, there are a morning shift, an afternoon shift, and a night shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of shifts</td>
<td>Which is coupled to 4 Shift types and has 6 hours, 8 hours, 12 hours, and more than 12 hours.</td>
</tr>
<tr>
<td>Changeable start time in each shift</td>
<td>Which means starting time and ending time of work</td>
</tr>
<tr>
<td>Shift types</td>
<td>Which can classify short-term shifts, medium-term shifts, and long-term shifts</td>
</tr>
<tr>
<td>Lengths and numbers of various breaks e.g. rest break, lunch break, dinner brake, relief break, etc</td>
<td>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.</td>
</tr>
</tbody>
</table>
The characteristics and limitations in human factors

| Number of shifts | Which means 2 shifts, 3 shifts, or 4 shifts, 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.
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The characteristics and limitations in human factors

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

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

Shift types

<table>
<thead>
<tr>
<th>Shift type</th>
<th>Which can classify short-term shifts, medium-term shifts, and long-term shifts</th>
</tr>
</thead>
</table>

- 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

- 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
\[
\sum_{j=1}^{n} c_j \cdot x_j
\]  
(1)

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

\[
x_j \geq 0; \quad \text{all integer, for } j = 1, 2, ..., n
\]  
(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

   these models considered insufficient the ergonomic constraints of actual practices.

   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

<table>
<thead>
<tr>
<th>Objective</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimize ( z = d_1 + d_2 )</td>
<td>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.</td>
</tr>
</tbody>
</table>

Where,
- \( d_1 \): differences in the sum of work time of each shift
- \( d_2 \): differences in the sum of break time of each shift

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 AM and NA are not considered.
7) Among each workgroup, a duplicated work or break should not appear.
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: MMMBBBBABNNNBBS (5)
Workgroup II: BBBBBBBNBBBBBSMM (6)
Workgroup I: MMMBBBBABNNNBBSMMMBB (7)
Workgroup II: BBBBBBBNBBBBBSBBAAA (8)
# Result

<table>
<thead>
<tr>
<th>work groups</th>
<th>Days</th>
<th></th>
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<tbody>
<tr>
<td></td>
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<td>3</td>
<td>4</td>
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<td>6</td>
<td>7</td>
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<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>I</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>B</td>
<td>B</td>
<td>S</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>B</td>
</tr>
<tr>
<td>II</td>
<td>B</td>
<td>S</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>B</td>
</tr>
<tr>
<td>III</td>
<td>A</td>
<td>B</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>B</td>
<td>B</td>
<td>S</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>IV</td>
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<tr>
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<td>N</td>
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<td>M</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>N</td>
</tr>
</tbody>
</table>

- 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)
2) A management of the shift work schedule factors

<table>
<thead>
<tr>
<th>Operation stage</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation</strong></td>
<td><strong>content</strong></td>
</tr>
<tr>
<td>Plan/design</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>A review and examine working time</td>
</tr>
<tr>
<td>1.2</td>
<td>A decision of shift work type</td>
</tr>
<tr>
<td>1.3</td>
<td>A comparison of working time</td>
</tr>
<tr>
<td>1.4</td>
<td>Resting time, duty-off</td>
</tr>
<tr>
<td>1.5</td>
<td>The introduction of work type</td>
</tr>
<tr>
<td>1.6</td>
<td>The application of a law</td>
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<tr>
<td>1.7</td>
<td>A supplement of the personnel</td>
</tr>
<tr>
<td>1.8</td>
<td>A management of qualification and training</td>
</tr>
<tr>
<td>1.9</td>
<td>Overhaul work support</td>
</tr>
<tr>
<td>Operation stage</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>A taking over the shifts</td>
</tr>
<tr>
<td>2.2</td>
<td>Overtime</td>
</tr>
<tr>
<td>2.3</td>
<td>The modification of work type and schedule</td>
</tr>
<tr>
<td>2.4</td>
<td>Duty of fitness</td>
</tr>
<tr>
<td>2.5</td>
<td>Mental health, Drugs abuse</td>
</tr>
<tr>
<td>2.6</td>
<td>Assign for a task</td>
</tr>
<tr>
<td>2.7</td>
<td>Supervise</td>
</tr>
<tr>
<td>2.8</td>
<td>A operational records of a critical facilities</td>
</tr>
<tr>
<td>2.9</td>
<td>A management of operation and maintenance using a critical of facilities</td>
</tr>
<tr>
<td>Modification</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>A decision of shift modification</td>
</tr>
<tr>
<td>3.2</td>
<td>A review and examine working time</td>
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</tr>
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</table>
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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