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New classification of medical staff clinical services for optimal reconstruction of job workflow in a surgical ward: Application of spectrum analysis and sequence relational analysis

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Abstract

In order to optimize the job workflow of medical staff, clinical job workflow was investigated from the viewpoint of its periodicity and the strength of causal association among jobs. Time-motion study for the staff at a surgical ward was carried out. To detect the periodicity of the occurrence of each job element, its frequency histogram was determined, and the discrete Fourier transformation was applied. For the analysis on the strength of the relationship among the job-sequence, the sequence relational analysis was developed, which was the expansion of the relation analysis to the sequence process. The job elements were classified into five incident patterns based on the periodicity of each element and into three patterns based on the association with other job elements. Based on time-motion study data, job workflow patterns of medical staff' were clarified based on the incident pattern of the job elements and the association with other job elements.

Keywords: Workflow; Time-motion study; Discrete Fourier transformation (DFT); Spectrum analysis; Root-mean-square (RMS); Relational analysis

1. Introduction

How to plan an efficient, effective, and safe hospital job workflow is a question of worldwide significance in hospital administration (Murray, 2002; Robert, 1998). Despite the number of reports discussing time-motion study in the medical field, as well as mathematical approaches, workflow continues to remain a major concern for hospital managers and medical staff (Harauchi et al., 1999; Hollingsworth et al., 1993; Ishii et al., 2002; Misener et al., 1987).

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In order to discuss the medical job workflow rationally, it is necessary to understand the actual job workflow quantitatively, modify the obtained information using computational analysis, measure each job element of the medical staff, and clarify the frequencies of actual medical job elements.

In this study, we propose a new classification of medical staff responsibilities, for optimal reconstruction of job workflow, using spectrum analysis and sequence relational analysis based on a series of time-motion data in a surgical ward in Japan. The classification has two viewpoints, the periodicity of job elements and the strength of interdependency among the job elements.

2. Materials

A time-motion study of the job workflow of medical staff (physicians, nurses, and nurse aides) was carried out from 1998 to 2001 in a surgical ward of a university hospital in Osaka, Japan. The time-motion study was performed for 24 consecutive hours. In order to maintain the accuracy of job element records, graduate students who were certified as nurses, radiological, and clinical laboratory technicians were assigned to record the medical staff job elements and their durations based on units per second (Finkler et al., 1993; Melissa and Betty, 1998; Thomas et al., 2000; Wirth et al., 1977). In the case of nurses, the ward used a primary nursing care system composed of three groups and three shifts per day (eight working hours per shift). All the members of the same group were observed for better understanding of the total number of job elements in the group.

Each observer recorded the job elements conducted by the nurse or physician in terms of "where," "since when," "until when," "by whom," "for whom," and "what job element," in a free format. No classified codes or templates were prepared before implementation of this study, in order to prevent prejudice and preconceptions of the observer. The recorded job workflow was checked in parallel with this study, in order to maintain accurate recordings.

During the total 23 study days of a four year study, all the job elements from a total of 188 staff members were recorded, and over 110,000 precise job element records were entered into the computer.

3. Methods

3.1. Classification of actual job elements by coding

The coding format for the observed data was defined by the Osaka Time-Motion Study Group, which consisted of academic researchers and experienced clinical staff members. Each category consisted of up to 175 items for nurses and 115 items for physicians. All the records of the job elements were uploaded on the time-motion database by trained specialists using a particular format.

3.2. Extraction of job element frequency using frequency analysis

Initially, each ward job element was investigated and categorized. Using all the data, identical job elements were grouped, and respective cumulative frequency histograms were plotted every 30 min, along with the time in days. Discrete Fourier transformation (DFT) was applied to the job element frequency data and a frequency analysis was performed. These steps were reiterated for each observed day and for each job element item.

3.3. Relational analysis of the job elements

The relationship between the job element sequences includes other aspects such as interdependency of some job elements. To measure this factor, we proposed a simple and effective procedure, referred to as root-mean-square (RMS), to determine the frequency difference between two different job elements at 10 min intervals throughout the day.

From the time-motion study database, the number of cases observed for every job element at 10 min intervals throughout the day was extracted. The RMS value of any two different job elements was calculated using the following expression:

$$RMS(\tau) = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} (f(t) - g(t+\tau))^2 \, dt}, \tag{1}$$

where, $f(t)$ is the function of the signal waveform for a certain job element, $g(t)$ the function of the signal waveform of another job element, and τ the phase difference (time difference) between the signal waveforms of $f(t)$ and $g(t)$. The correlations among the job elements were further investigated using these results.

4. Results

4.1. Classification of job elements by coding

Initially, the following two flags were prepared to discriminate simultaneously or ambiguously recorded job elements. (1) Serial job elements: this flag was used when an observer could not record the end of a job element because a medical staff member accomplishes many job elements quickly, in a short time. (2) Parallel job elements: these were applied when a medical staff member performed two or more job elements at the same unit time. For example, carrying out vital sign measurements such as thermometry along with observation of patient status and explaining the status to the patient.

The classification has three hierarchies for both physicians and nurses (Table 1). The hierarchies, from top to bottom, were "the purpose of the job element", "the category of the job element", and "the specified category of the job element."

Table 1 shows the number of classifications by year. While the first hierarchy shows the same number of categories, for the second and the third hierarchies, the numbers were different for each of the years. For physicians, the numbers of the third hierarchy varied from 105 to 115. In the case of nurses, the numbers were dispersed from 91 to 175. In Table 2, some examples of coding classifications for job elements are shown for the nurses in 1999.

Table 1
The number of classifications of each stage by code classification

Job description	Year	First hierarchy (Purpose)	Second hierarchy (Job classification)	Third hierarchy (Specified category)
Doctor	1998	4	33	115
	1999	4	29	105
	2000–2001	4	29	105
Nurse or nurse's aide	1998	4	30	175
	1999	4	33	169
	2000–2001	4	33	91

Table 2
Example of the code classification result of the job elements (Extract from the job elements of nurses in 1999.)

Purpose	Job classification	Specified category	Code No.
Nursing for recuperation	Comfort of a patient	Turning of own body	010901
		Applying a poultice	010902
		Massage	010903
		Preparation or cleaning up	0109J1
		Others	0109T1
Nursing for support medical practice	Exchanging information	Handing over	020701
		With a doctor	020702
		With other medical staff	020703
		Conference	020704
		Preparation or cleaning up	0207J1
		Others	0207T1
Other nursing	Moving or waiting	Moving	030701
		Waiting	030702
		Preparation or cleaning up	0307J1
		Others	0307T1

4.2. The occurrence periodicity of job elements

Based on DFT analysis, all the job elements were classified into five incident patterns by their occurrence periodicity.

(1) Occurring accidentally (emergent type): job elements that occur on an unscheduled or unpredictable timing basis, e.g., "call system."
(2) Occurring at all times (routine type): job elements that occur on a daily routine basis, e.g., "moving."
(3) Occurring regularly (time-dependent type): job elements that occur periodically at a scheduled time in a day, e.g., "conference."
(4) Occurring during spare time (arbitrary-provided type): job elements that are provided without time constraints, e.g., "self-learning."
(5) Exhibiting various occurrence patterns (mixed type): job elements that have mixed characteristics or show rather different occurrence tendencies among the observed days, e.g., "intravenous management."

Fig. 1 shows the occurrence frequency histogram of a routine type of job element for a nurse classified as "moving," while Fig. 2 shows the DFT results for the cited histogram. This job element occurred throughout the day (Fig. 1) and did not show periodicity (Fig. 2).

Fig. 3 shows the occurrence frequency histogram of a mixed type of job element for a nurse classified as "handing over," while Fig. 4 shows the DFT results for the cited histogram. This job element showed several periodicities (Fig. 4) and presented deviation in its incidence time (Fig. 3).

Fig. 5 shows the occurrence frequency histogram of a time-dependent job element for a nurse classified as "conference," while Fig. 6 shows the DFT results for the cited histogram. This job element occurred only at a scheduled time of day (Fig. 5) and did not show periodicity (Fig. 6).

4.3. Job element classification by the correlation

For the job elements classified as emergent type, routine type and time-dependent type, the RMS value was calculated, and the strength between the job elements was investigated. For example, the calculation result of the RMS value of

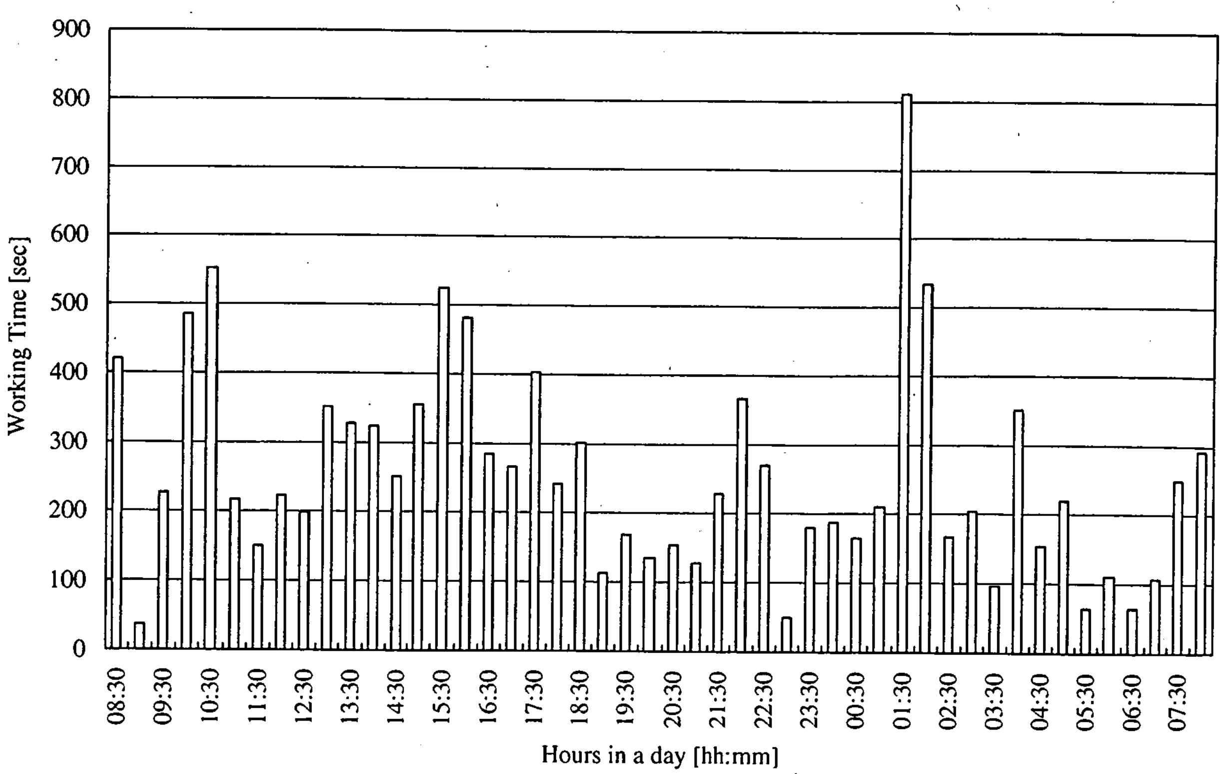

Fig. 1. Example of a histogram (Routine type job element of nurse: "moving".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

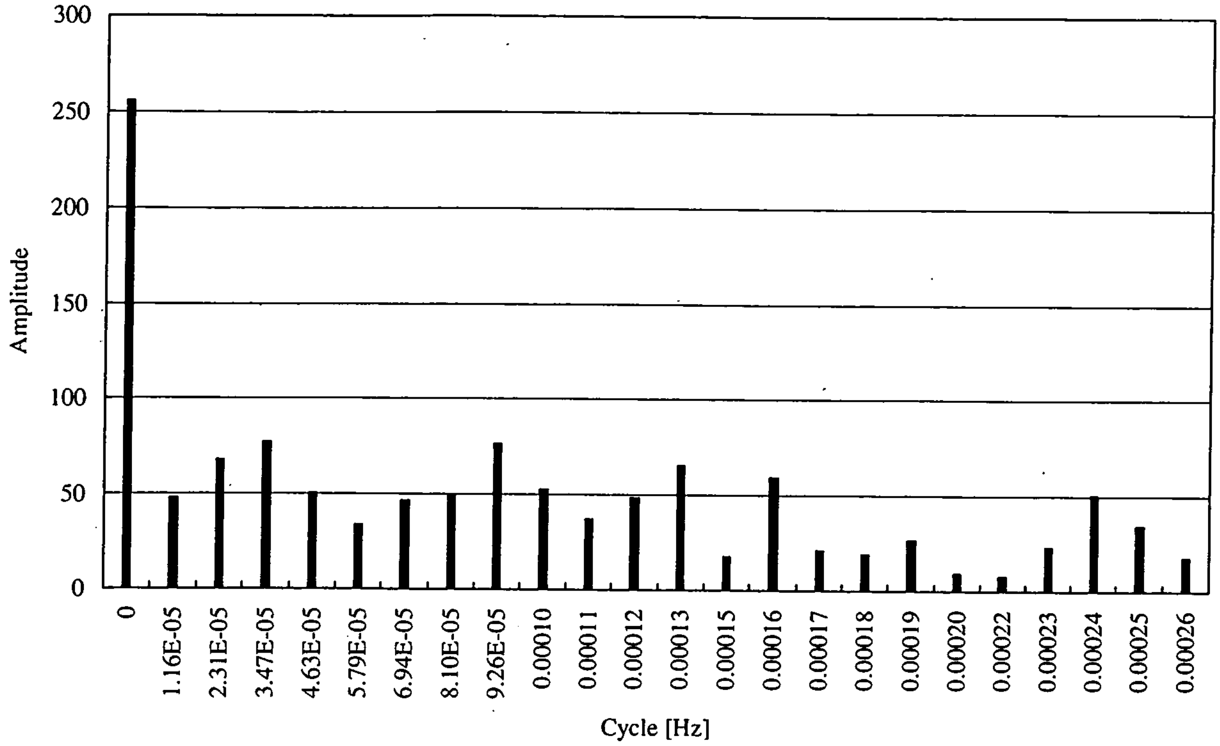

Fig. 2. Example of the result of DFT (Routine type job element of nurse: "moving".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

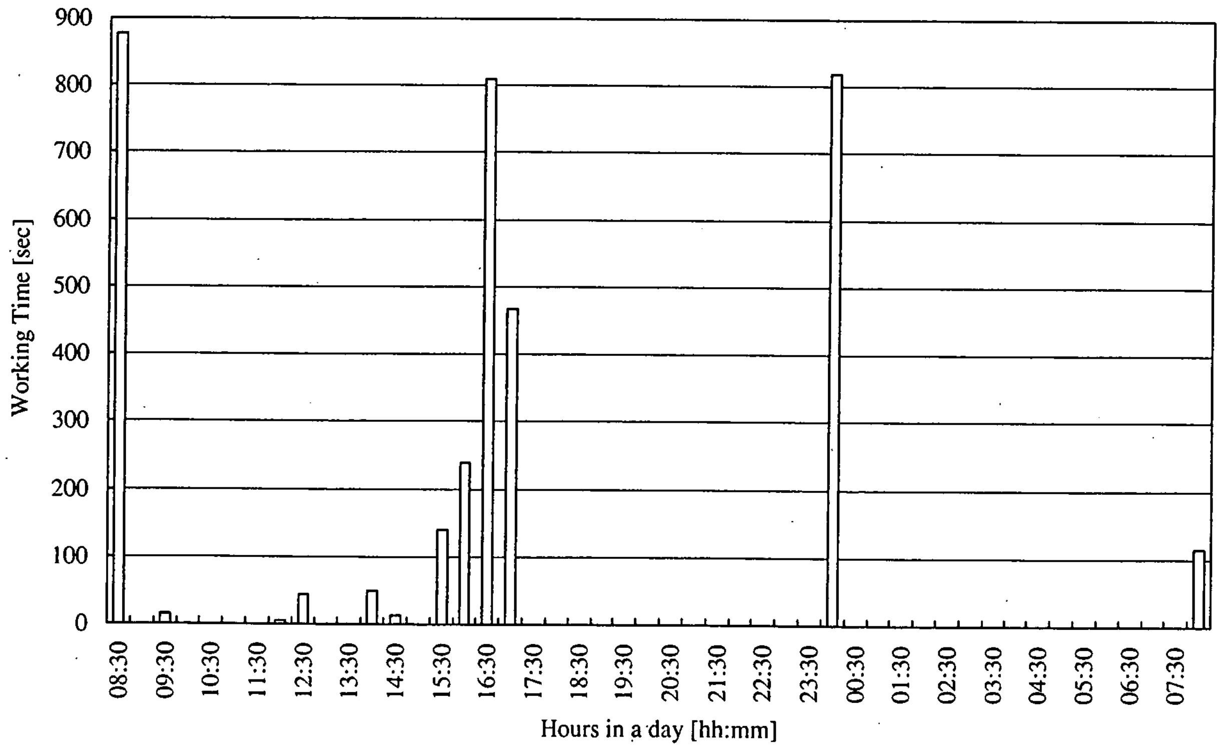

Fig. 3. Example of a histogram (Mixed type job element of nurse: "handing over".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

The difference in the number of cases between the job element of nurses classified as "bed-bath" and "preparation or cleaning up of bed-bath" is shown in Fig. 7. The ratio between these two job elements was 1:1 (The number of cases of "bed-bath" and "preparation or cleaning up of bed-bath" was 21 for both.). This graph shows one peak of RMS

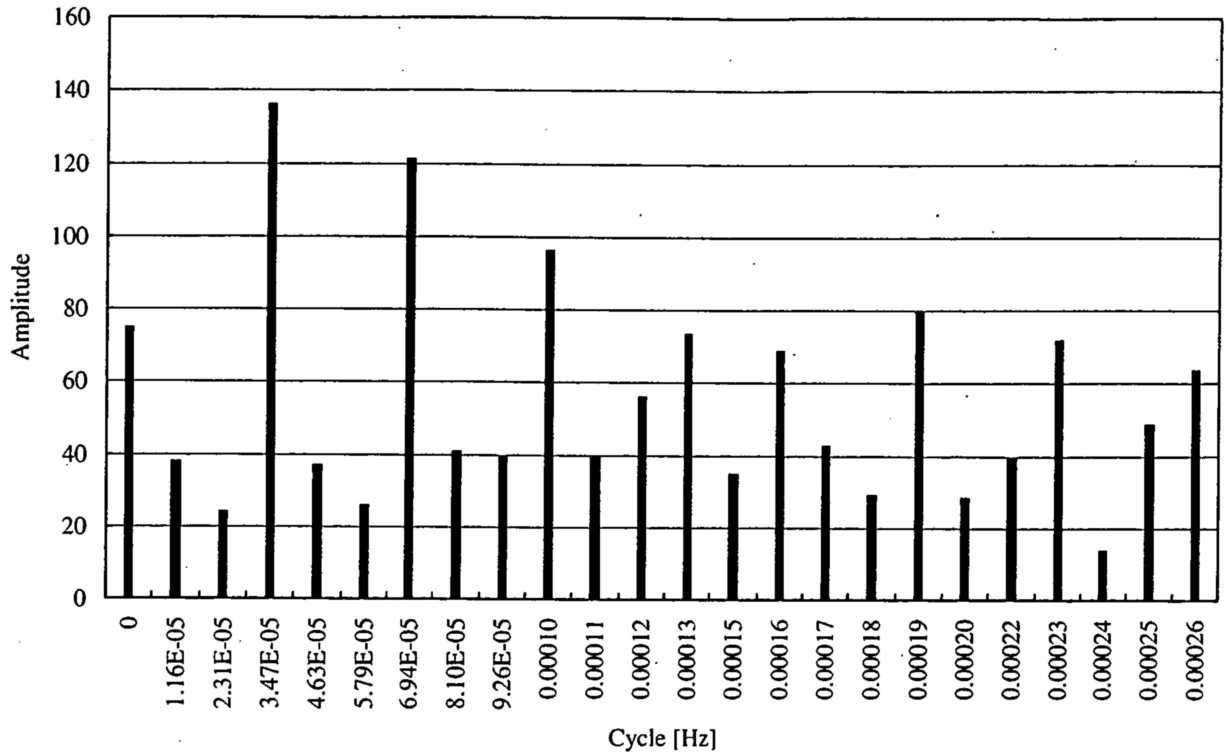

Fig. 4. Example of the result of DFT (Mixed type job element of nurse: "handing over".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

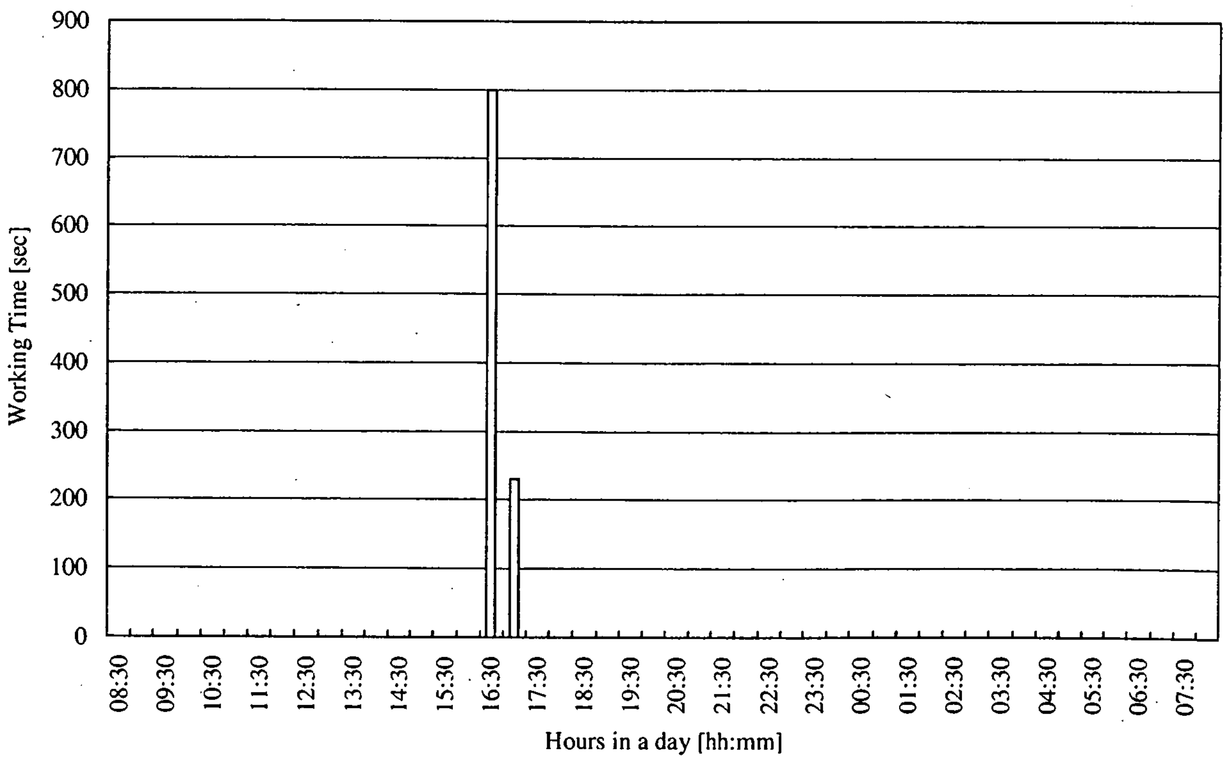

Fig. 5. Example of a histogram (Time-dependent type job element of nurse: "conference".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

value at a time difference of [+00 : 20] ([hh:mm],) which means that the job element of "preparation or cleaning up of bed-bath" was considered to occur about 20 min after the occurrence of the job element of "bed-bath."

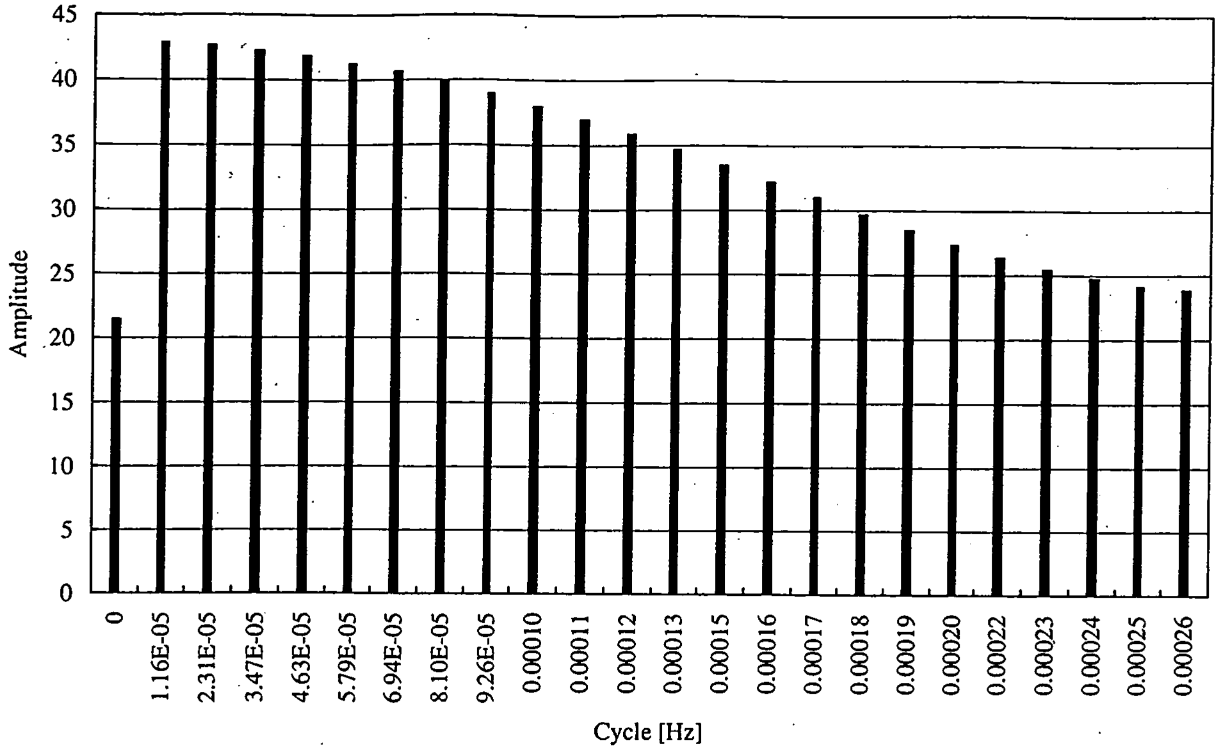

Fig. 6. Example of the result of DFT (Time-dependent type job element of nurse: "conference".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

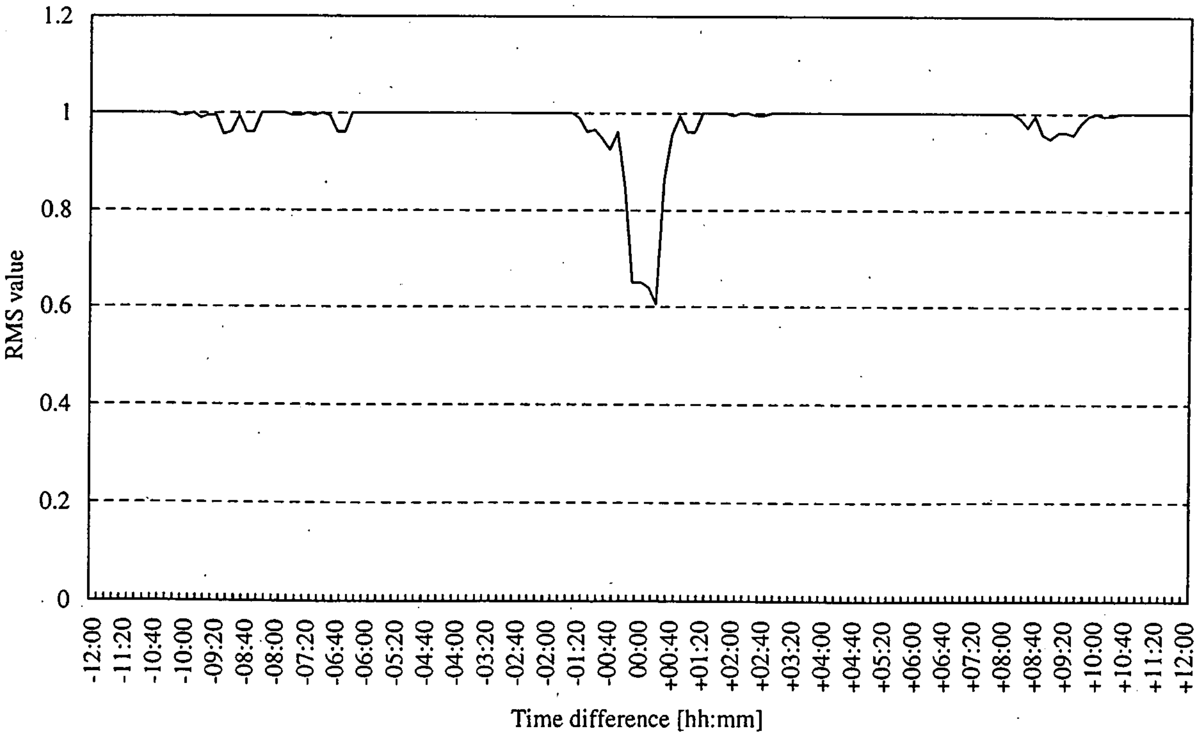

Fig. 7. Example of the calculation result of RMS value of the difference in number of cases between the job element of "bed-bath" and "preparation or clearing up of bed-bath". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

The RMS value of the difference in the number of cases between the job element of nurses classified as "collecting information from a chart" and "handing over" is shown in Fig. 8. The ratio between these two job elements was 3:1 (The number of cases of "collecting information from a chart" and "handing over" was 107 and 36, respectively.).

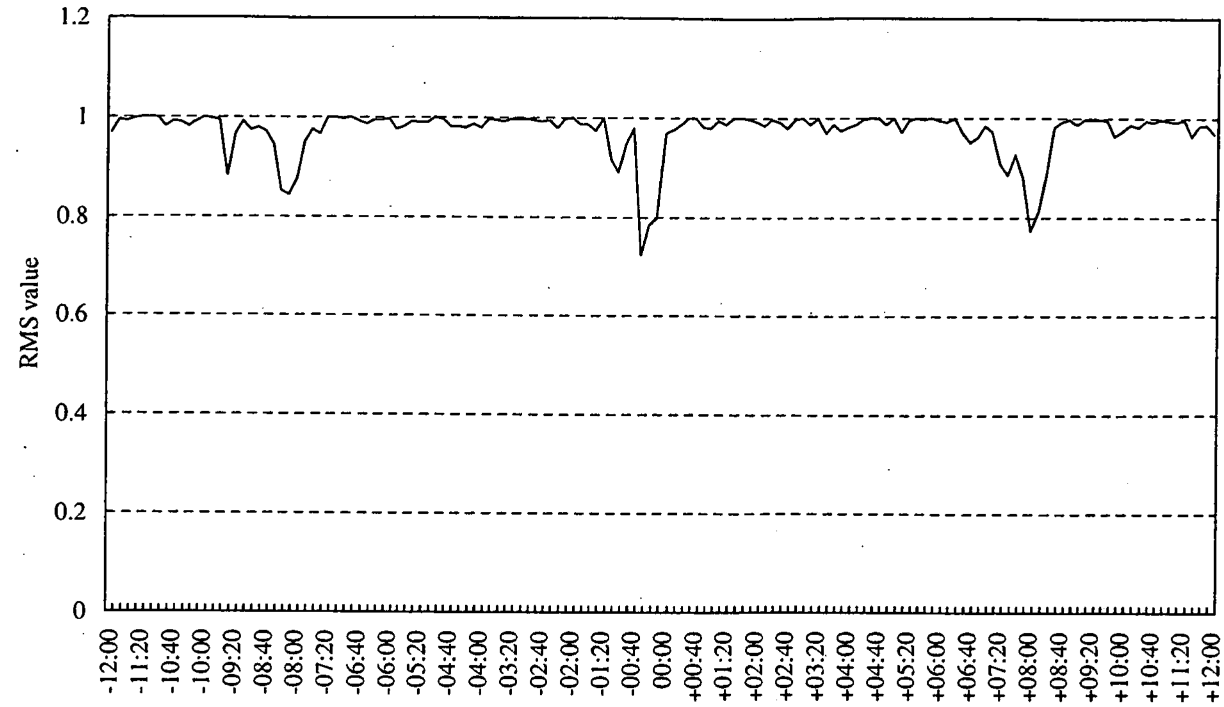

Fig. 8. Example of the calculation result of RMS value of the difference in number of cases between the job element of "collecting information from a chart" and "handing over". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

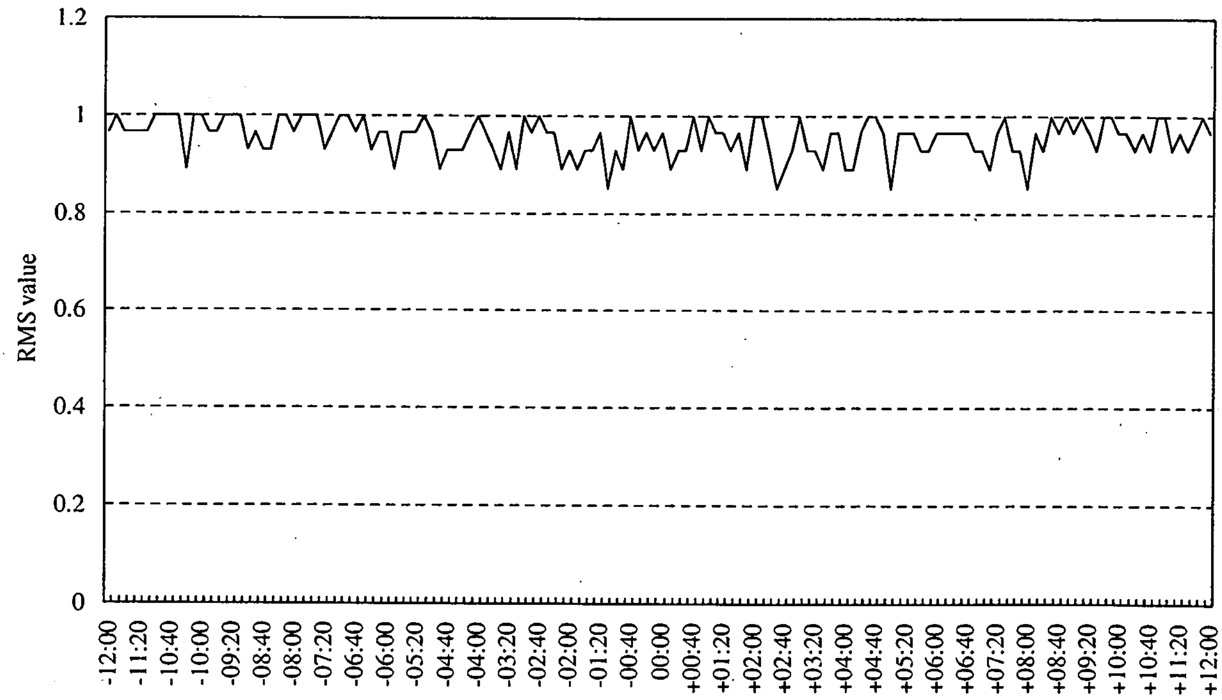

Fig. 9. Example of the calculation result of RMS value of the difference in number of cases between the job element of "answer patient–nurse call system" and "answer phones". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

This graph demonstrates three peaks of RMS value with time differences of [−08 : 10], [−00 : 20], and [+07 : 50] ([hh:mm].)

The RMS value of the difference in the number of cases between the job element of nurses classified as "answer patient–nurse call system" and "answer phone" is shown in Fig. 9. The ratio between these two job elements was 1:1 (The number of cases of "answer patient–nurse call system" and "answer phone" was 13 and 14, respectively.). This graph demonstrates no peak of RMS value.

Table 3
Example of classification result by occurrence tendency for each job element (Classified job elements of nurse in 1999: 121 job elements in 169 job elements.)

	Independent type		Interdependent type	Random type
	Without time zone restrictions	With time zone restrictions		
Emergent type	24	6	10	9
Routine type	6	2	1	1
Time-dependent type	10		7	4
Arbitrary-provided type		9		
Mixed type		33		

From all the results, we found three types of relationships among the job element sequences.

(1) Independent type: job elements that did not show any relationship with any other job elements.
For the job elements classified as emergent type and routine type, we classified into additional two patterns by constraint of time in execution.
  1.1 Job elements with the constraint of time zone in execution
  1.2 Job elements without constraint of time zone in execution
(2) Interdependent type: job elements that had a conjunctive sequence with other job elements.
(3) Random type: job elements which were influenced the day of the week. Table 3 shows the integrated results of the job element classification of nurses in 1999.

5. Discussion

Many time-motion studies have been reported for job workflows concerning clinical medical staff in the United States, reports in this field, especially for physicians, are still quite rare in Japan. One of the reasons for this situation could be related to the passive attitude of some Japanese physicians toward hospital management.

The time-motion data used in this study was, for the first time, conducted at a surgical ward of a university hospital in Japan, and the database structure developed for this study is the most detailed and precise database currently in use. On the basis of this database a quantitative mathematical analysis was accomplished.

The advantage of this study is the new mathematical method proposed for the classification of the job elements, namely the periodicity and the strength of the relationships between the job elements. Until now, in the medical field, job elements based on classification by frequency have not been reported. By using frequency analysis, the job elements of the medical staff were clearly classified according to the distribution of their occurrence. Thus, as the relationship between the job elements was mathematically investigated, the strength of job element sequence was discussed quantitatively. In daily ward job elements, the periodicity can find influence on the job workflow and the feeling of busyness.

The results clarified the five types of job element (emergent type, routine type, time-dependent type, arbitrary-provided type and mixed type.) There is a chance that the proportion of each type would be different among wards, even in the same hospital. For example, the proportion of the emergent type job elements would be increased in an emergency ward, and the proportion of the arbitrary-provided type job would be increased in a chronic disease ward. The classification that we have proposed would be applicable to all the analyses of all clinical job elements.

Generally, the correlation between two job elements following the signal waveform $f(t)$ and $g(t)$ can be determined using a cross-correlation function. A cross-correlation function is obtained from the following formula:

$$R_{fg}(t) = \lim_{T \to 0} \frac{1}{T} \int_{-T/2}^{T/2} f(t)g(t+\tau)\,\mathrm{d}t,$$

$$R_{fg}(t) = \frac{1}{N} \sum_{t=1}^{N} f(t)g(t+\Delta t). \quad (2)$$

Since the waveform of each job element is different, the phase difference (time difference) shows a high cross-correlation function and does not show the phase difference with the strongest correlation. In this study, the RMS value of the difference of the amplitude (number of cases) between two job elements was calculated, and found the correlation of some job elements.

It is important to completely understand the job workflow as a job element sequence. The proposed method in this paper enables the use of relational analysis, and the proposed three classifications are applicable to almost all types of job analyses.

In the case of nurses, the correlation of every job element was investigated using 24 h as one cycle. In the ward under this study, the nurses worked in 8 h shifts. Thus, it would be better not to use an RMS value of more than about 8 h. Normally, the job element contents or working time of staff members vary according to the scale of an institution or the environment of a ward. Therefore, it is difficult to optimize the medical staff's job workflow in general. However, in this study, the quantitative methods to evaluate the ward job workflow were proposed. And these methods would be applicable to any ward or job analysis, and the job workflow of any medical staff members would be optimized.

6. Conclusion

The job element classification of data obtained by a time-motion study was carried out, and a specified database structure and coding format were developed. Using the data, the occurrence periodicity of job elements was investigated, and five groups were detected. The relationships among the job elements were evaluated by RMS value, and three classifications were found.

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