CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Humanware, Human Error, and Hiyari-Hat: a Casual-chain of Effects and a Template of Unsafe Symptoms

by

Shigeomi Nishigaki, Jeannette Vavrin, Noriaki Kano,
Toshiro Haga, John C. Kunz and Kincho Law

TECHNICAL REPORT
Number 71

August, 1992

Stanford University

If you would like to contact the authors please write to:

c/o CIFE, Civil Engineering,
Stanford University,
Terman Engineering Center
Mail Code: 4020
Stanford, CA 94305-4020

CIFE

Summary: Technical Report #71

Title: Humanware, Human Error, and Hiyari-Hat: a Causal-chain of Effects and a Template of Unsafe Symptoms

Authors:

Shigeomi Nishigaki, Visiting Fellow, CIFE, Stanford University
Jeannette Vavrin, Associate Professor, School of Management, Golden Gate University
Noriaki Kano, Professor, Department of Management Science, School of Engineering, Science University of Tokyo
Toshiro Haga, Professor, Department of Management Science, School of Engineering, Science University of Tokyo
John C. Kunz, Senior Research Associate, CIFE, Stanford University
Kincho Law, Associate Professor, Department of Civil Engineering, Stanford University

Date: August 26, 1992

Subject:

This paper proposes a Hiyari-Hat Model which describes a causal-chain of effects and presents a template that summarizes unsafe symptoms among humanware, human error and Hiyari-Hat.

Objectives/Benefits:

The template being developed enables first-line workers to monitor and diagnose their own behavior systematically on a timely basis and to easily translate the results of the diagnosis into practical day-to-day accident prevention activities.

Methodology:

(1) Method to gather data: questionnaire survey for construction workers

(2) Method to analyze the data:

- Pareto Diagram,

- Automatic Interaction Detector,
- Principal Component Analysis, and
- Cluster Analysis (Ward menthol)

Results:

First, this paper shows the relationship among 35 reported occupational accident cases and the unsafe acts and conditions that precede them. We hypothesize that the unsafe acts and conditions might recur and trigger similar accidents again. Second, this paper shows the drawbacks of the countermeasures that have been used against the unsafe acts and conditions. These countermeasures did not effectively prevent the recurrence of unsafe acts and conditions. Third, we reported that the underlying causes of the most recurrence are humanware. Fourth, this paper derives a causal-chain among humanware, human error and Hiyari-Hat. We call this causal-chain the Hiyari-Hat Model. Fifth, we present a template summarizing unsafe symptoms that are considered important indicators of abnormal unplanned state at construction sites.

Research Status:

Risk assessment consists of hazard identification, hazard evaluation, and risk evaluation Hazard identification is a process to express possible/probable/potential hazards from actual knowledge. Hazard evaluation is a process to evaluate the effects of different hazards on accidents and to find an expression about what kinds of responses could be expected under the exposure conditions. Risk evaluation is a process to estimate the place, route and extent of exposure to the potential hazards. It also evaluates the number of persons exposed to the potential hazards. We developed a template summarizing abnormal unplanned states among humanware, human error, and Hiyari-Hat. A further research problem is to develop a quantitative model to predict what type of Hiyari-Hat occurs, based on the findings of this study. This model could be helpful for workers to understand the results of failure to heed human-error-shaping factors and human error items that the workers have experienced.

Keywords

Humanware is defined as a function of leadership, followership and the reciprocal interaction between the two. Leadership is a leader's willingness to fulfill both task accomplishment and group maintenance. Followership is followers' voluntary desire to follow their leader and to achieve their tasks.

Hiyari-Hat: "Hiyari" (in Japanese) means "Cold." "Hat" (in Japanese) means "Frightening." "Hiyari-Hat" is an incident that, fortunately, does not result in injury, although under slightly different conditions the incident might have led to injury of the worker and/or property damage. "Hiyari-Hat" is called "Near Miss" or "Critical Incident."

Kiken-Yochi-Training (KYT) and Kiken-Yochi-Katsudo (KYK): "Kiken" (in Japanese) means "Hazard." "Yochi" (in Japanese) means "Forecasting." "Katsudo" (in Japanese) means "Activity." Off-the-job education (KYT) is provided to enhance first-line employees' ability to anticipate potential hazards in their workplace. In off-the-job education, an illustration is used to represent abnormal or unplanned states in a workplace. Through the discussion about how to improve the abnormal or unplanned state, the workers learn to anticipate potential hazards in the work procedure and workplace. On-the-job education (KYK), on the other hand, uses crew safety meetings immediately before work begins. In on-the-job education, workers are instructed in safe work practices by discussing possible hazards at crew meetings immediately before real-life work begins. KYT and KYK aim to enhance the first-line employees' ability to:

- anticipate the potential hazards in the workplace;
- discover hazards which they could cause themselves; and
- work in accordance with safety operating procedures.

On-site safety training for each day's work is held at 7:30 am every morning and includes the following steps:

Step 1: Discuss the existing conditions (What dangerous factors are hidden or exist?);

Step 2: Evaluate risk factors;

Step 3: Consider and discuss countermeasures for important risk factors (What do we need to do?); and

Step 4: Secure the individual commitment of all crew members to any countermeasures developed at Step 3 (We will do it this way.).

Humanware, Human Error, and Hiyari-Hat: a Causal-chain of Effects and a Template of Unsafe Symptoms

Shigeomi Nishigaki[1], Jeannette Vavrin[2], Noriaki Kano[3],

Toshiro Haga[3], John C. Kunz[4] and Kincho Law[5]

Abstract: For many years, the Japanese construction industry has practiced several different accident-prevention activities. In spite of these safety prevention activities, occupational accidents recur. Why? This paper reports on a safety survey of construction workers in the Japanese construction industry. The survey had 7955 responses; 2588 responses reported experiencing "Hiyari-Hat," or Near-Miss accidents. These respondents also reported on the nature and apparent causes of their near-miss accidents. In this paper, we found most accidents occur because of "poor humanware," where "humanware" is defined as a function of leadership, followership and the reciprocal interaction between the two. We conclude that the underlying causes of "Hiyari-Hat" often include "poor humanware" and most frequently end with human error of individual workers. This paper proposes a "Hiyari-Hat Model" which describes a "Causal-chain of Effects" and presents a "Template" that summarizes "Unsafe symptoms" among humanware, human error and Hiyari-Hat. It enables first-line employees to monitor and diagnose their own behavior systematically on a timely basis and to easily translate the results of the diagnosis into practical day-to-day accident prevention activities.

---

[1] Visiting Fellow, Center for Integrated Facility Engineering, Stanford University
[2] Associate Professor, School of Management, Golden Gate University
[3] Professor, Department of Management Science, School of Engineering, Science University of Tokyo
[4] Senior Research Associate, Center for Integrated Facility Engineering, Stanford University
[5] Associate Professor, Department of Civil Engineering, Stanford University

1. Introduction

Systematic Accident prevention activities have reduced work related fatalities since 1973, for instance, its death rate (number of fatalities divided by work force) changed 9.8% to 4.4% in Japanese industries. The decrease, however, has recently leveled since 1983. Remarkably, in 1989, there were 1107 fatalities in the Japanese construction industry, a *per capita* rate 2.4 times greater than that of the Japanese manufacturing industry [1]. The construction industry is one of the most dangerous industries in Japan. Furthermore, occupational accidents, for instance, "a person falling," "be struck by falling objects," etc., occur frequently in the Japanese construction industry.

Japanese construction sites have conducted accident prevention activities for many years. For instance, there are safety assessments at the project design and planning stage, on-site safety audits, off- and on-the-job safety education, and the Hiyari-Hat reporting system that identifies near-miss accidents and reports them to workers.

The safety committee inside a Japanese construction company assesses production planning at its design and planning stage. Safety committee members consist of seasoned, knowledgeable and objective construction workers who have extensive experiences and information concerning both planned normal and unplanned abnormal actions at construction sites.

Most safety audits are job-site inspections by the first-line manager or supervisors; safety patrols by knowledgeable and objective professionals; and a third party audit, similar to OSHA in the United States. In this job-site inspection, safety audit professionals use a checklist of safety standard rules and procedures to identify safety problems and their causes. The checklist is a template that includes normal or planned "hardware" items (e.g., machinery equipment) and normal or planned "software" items (e.g., standard work procedures, safety regulations, a regime of safety management, etc.).

Training is conducted to enhance the first-line employees' ability to anticipate potential hazards in the workplace. In off-the-job training, an illustration shows abnormal or unplanned acts and conditions at a workplace. Through the discussion about how to improve the abnormal or unplanned practices indicated by the illustration, the workers learn to anticipate potential hazards in work procedures and the workplace. On-the-job education uses crew safety meetings immediately before work begins. Workers are instructed about safe work practice by discussing possible hazards.

Hiyari-Hat is a worker's experience (a near-miss accident) that, luckily, does not result in injury, although under slightly different circumstances, it might have led to a worker injury and/or property damage. The Hiyari-Hat reporting system collects and analyzes data regarding near-misses to identify potential safety problems. Data are then presented to workers to help them to understand the presence and importance of abnormal and unplanned actions at construction sites.

In spite of safety prevention activities, occupational accidents repeatedly recur. This paper offers data regarding accident occurrence and a model of the underlying causes of occupational accident recurrence at construction sites. Using this model, we developed a template summarizing unsafe symptoms that indicate important abnormal or unplanned states at construction sites.

First, this paper shows the relationship among 35 reported occupational accident cases and the unsafe acts and conditions that preceded them. We hypothesize that the unsafe acts and conditions might recur and trigger similar accidents again. Second, this paper shows the drawbacks of the countermeasures that have been used against the unsafe acts and conditions. These countermeasures did not effectively prevent the recurrence of the unsafe acts and conditions.

Third, we report that the underlying cause of the most recurrence is humanware, where humanware is defined as a function composed of leadership, followership and the reciprocal interaction between the two [2]. Fourth, this paper derives a causal-chain among humanware, human error and Hiyari-Hat. We call this causal-chain the "Hiyari-Hat model." Fifth, we present a template summarizing unsafe symptoms that are considered as important indicators of abnormal or unplanned state at construction sites. Finally, we conclude with a summary of this study and discuss anticipated results and further research.

2. Survey Results

A safety patrol professional inspected the construction sites in a branch office (that we call [T]) of a Japanese general constructor at least once a month without notice from 1981 to 1985. Figure 1 shows a typical safety patrol checklist. Safety patrol inspections were designed to assure good job-site safety policy and practice.

Insert Figure 1 about here

35 occupational accident cases, however, occurred from 1981 to 1985 in the [T] branch office. Figure 2 shows the different types of accidents among these 35 reported cases.

Insert Figure 2 about here

It is normal practice for the concerned first-line manager and supervisors to rectify any potentially unsafe practices identified by a safety patrol. Because accidents recur, as shown in Figure 2, we conclude that fixing the unsafe practices identified in the safety patrol survey does not necessarily eliminate occupational accidents, such as the 35 reported accidents. Apparently, the unsafe acts and conditions do recur, even after safety patrol detection and manager attention, and they can trigger an occupational accident.

3. Statistical Analysis

As mentioned above, the unsafe acts and conditions are deemed to do recur, even after safety patrol detection and manager attention, and they can trigger an occupational accident. To statistically confirm that the recurrence of the unsafe practices might trigger additional accidents, we used the Automatic Interaction Detector (AID) method ([3], [4]). AID is an illuminating way of looking at the set of unsafe practices that, together, predict the occurrence and non-occurrence of accidents.

The AID method constructs a "Binary Tree" to predict the outcome, i.e., the occurrence of the 35 occupational accidents, given the inputs, i.e., the inspection results "x_j" $(j = 1,2,\cdots,14)$ by safety patrols. The basic approach is to choose a question repeatedly (one of $x_1,\cdots,x_{14}$ in Figure 2) to best separate the output into the two classes. This section presents our use of the AID method in detail.

Step 1: Normalize the collected data.

Both the explanatory variables "x_j" $(j = 1,2,\cdots,14)$ and the dependent variable "y" are dichotomous variables that denote presence or absence of the factor as reported by the survey respondent. The dependent variable "y" is coded with the entry "1" to indicate that an occupational accident occurred within one month at the job site after having received the inspections and instructions by a safety patrol, or the entry "2" to indicate the absence. The explanatory variables "x_j" $(j = 1,2,\cdots,14)$ are coded with the entry "1" to denote the finding and rectification of an unsafe act and condition, or the entry "2" to denote the absence of any inappropriate safety practices..

<u>Step 2:</u> Split the data into outcome subgroups, i.e., assign data records to an "accident occurred within 1 month" or "no-accident" class:

(1) Calculate each "Sum of Squares Between Two Subgroups (S_B)" for the dependent variable "y_{ig}", for $i = 1,2,\cdots,n_g$ and $g = 1,2$, where n_g denotes number of cases belonging to a subgroup "g". The subgroups are classified by the category "1" and "2" of each explanatory variable "x_j" $(j = 1,2,\cdots,14)$, respectively; and

(2) Decide to split the dependent variable "y_i" for $i = 1,2,\cdots,n$ -- $n = 452$ in this study; see Figure 3 -- into two subgroups "y_{ig}" for $i = 1,2,\cdots,n_g$ and $g = 1,2$ by the explanatory variable "x_k" that has the largest S_B.

Here, "Total Sum of squares (S_T)," "Sum of squares Between Two Subgroups (S_B)" and "Sum of squares Within Subgroup (S_W)" are given by the following equations, respectively:

$$S_T = \sum_{g=1}^{2}\sum_{i=1}^{n_g}(y_{ig} - \bar{y}_0)^2, \tag{1}$$

$$S_B = \frac{n_1 n_2}{n}(\bar{y}_1 - \bar{y}_2)^2, \tag{2}$$

$$S_W = S_T - S_B, \tag{3}$$

where "n" denotes total number of cases; n_g $(g = 1,2)$ denotes number of cases belonging to each subgroup; $\bar{y}_0$ denotes the total average value of "y_i" $(i = 1,2,\cdots,n)$; $\bar{y}_1$ and $\bar{y}_2$ are the average values corresponding to each subgroup "y_{ig}", $(i = 1,2,\cdots,n_g;\ g = 1,2)$, respectively. If the values of "y_i" $(i = 1,2,\cdots,n)$, that is, "1" or "2" are treated as continuous, the averages $\bar{y}_1$ and $\bar{y}_2$ are given by the following equation:

$$\bar{y}_1 = 1 + \frac{m_{21}}{n_1}, \tag{4}$$

$$\bar{y}_2 = 1 + \frac{N_2 - m_{21}}{n_2}, \tag{5}$$

where m_{ij} $(i, j = 1,2)$ denotes the number of misclassifying a category "i" as a category "j" and N_2 is the number of entry "2" for the dependent variable "y." It can be seen from Equations (4) and (5) that each fraction of these average values could be regarded as a measure to evaluate misclassification.

Step 3: Select the combination of each subgroup "y_g" $(g = 1,2)$ and the explanatory variable "x_k" concerned which has the largest S_B.

Step 4: Repeat steps 1 and 2 to split each subgroup selected at step 3 into descendent subgroups, until satisfying one of the following stop-splitting rules:

(1) maximum number of subgroups = 40,

(2) minimum number of cases belonging to each subgroup = 10,

(3) $S_w / S_T = 0.05$,

(4) $S_B / S_T = 0.01$.

Step 5: Construct binary-tree, based on steps 1 to 4.

The binary tree in Figure 3 is the result of applying steps 1 to 5 above.

Insert Figure 3 here

Figure 3 shows that, for the collected data sample, it is possible to predict the presence of occupational accidents with an accuracy of 86% by following the critical discrimination path as failure or not failure to:

- use appropriate covers, handrails and clear passageways in order to prevent worker falls (X5);
- provide appropriate on-site safety training (X2);
- provide common safety training, inspection and reporting measures (X1).

These three unsafe acts and conditions--"Prevent falls," "on-the-job training" and "Common items" --are the major risk factors for occupational accident occurrence. The results of Figure 3 show that unsafe acts or conditions might be detected at a site, fixed, and then again recur at the site within a short period of time and trigger an occupational accident. In the other words, Figure 3 tells us that while the instructions to the first-line manager and supervisors to rectify unsafe acts and conditions probably do help with safety, alone these top-down instructions are not sufficient to prevent the recurrence of unsafe acts and conditions.

4. Drawbacks of Current Safety Prevention Activities

This section discusses the countermeasures against the unsafe acts and conditions identified in the previous section that have been used from 1981 to 1985 at the [T] branch office.

Figure 4 shows the usual countermeasures against "Person Falling" that have been used at the [T] branch office. Most countermeasures concern hardware such as installations of "handrail," "safety devices" and the like, or software such as "safety operating procedures" and "being in compliance with these procedures."

Insert Figure 4 about here.

On-site safety training -- called Kiken-Yochi-Katsudo, KYK in Japanese (see appendix: glossary) -- is a crew safety meeting that is conducted immediately before work begins. It aims to enhance the first-line employees' ability to:

- anticipate the potential hazards in the workplace;
- discover hazards which they could cause themselves; and
- work in accordance with safety operating procedures.

Since on-site safety trainings are dispersed at many workplaces by each crew and are held early in the morning, it is hardly possible for safety patrol professionals to observe each training. As a result, they tend to compromise by saying "Pay attention," "Take more care" and the like.

Even if safety professionals find some drawbacks (i.e., no training conducted, no record kept, no motivation instilled, etc.) of the on-site safety trainings and the safety awareness program and they instruct first-line managers and supervisors to improve these activities, it will take time to eliminate the drawbacks and improve these activities. Meanwhile, the safety risk continues.

Taken together, it can be said that safety patrol professionals do not completely prevent underlying causes of unsafe acts and conditions. They inspect installations of hardware and software and order the rectification of the differences between the existing conditions of the installations and the normal planned conditions. Often their inspections and instructions regarding on-site training and common items are perfunctory. Thus, the safety patrol leads to rectification of detected unsafe acts and conditions, but it has not been adequate to make the construction process safe.

5. Underlying Causes of Accident Recurrence

Generally speaking, production systems consist of hardware, software and humanware. We define "Humanware" as the function consisting of leadership, followership and the reciprocal interaction between the two, where leadership is defined as the leader's willingness to fulfill both task accomplishment and group maintenance; followership is defined as the followers' voluntary desire to follow their leader's instructions and their voluntary desire to do their work and to achieve their tasks.

Following from the observations until now, we should focus on humanware to find the underlying causes of accident recurrence. This section considers the underlying causes of the 35 occupational accident cases.

The professionals at the [T] branch office discussed the causes of these occupational accident cases and classified the causes into the categories shown in Figure 5.

Insert Figure 5 about here.

Summarized below are the causes of the accidents as assessed by construction staff and the number of accidents attributed to each cause.

Cause	Number
• Leadership:	77
• Followership:	53
• Software:	27
• Hardware:	18

P. W. Griffin, K. D. Shivington and G. Moorhead described the reciprocal interaction between a leader and a follower [5]. The follower responds to the leader's action either positively or negatively. For instance, a follower's level of effort, approval or resistance to a leader's actions, the contents of communication among followers and being or not being in compliance with regulations and procedures are all part of the follower's reaction or proaction. That is, there is a reciprocal interaction between the leader and the follower. Misumi [6] reported that safety achievement is high when the task accomplishment and group maintenance are carried out effectively.

Evidently, the best opportunity for improved safety comes from improving the safety process concerning leadership and the way in which staff follows the leaders. In comparison with hardware and software, humanware -- leadership and followership -- causes a much greater proportion of the recurrence of the unsafe act and conditions. Specific humanware failures include:

- inadequate instruction;
- some kinds of willful transgression;
- risk-taking; and
- peer acceptance of poor humanware.

6. Hiyari-Hat Model

Sections 2-5 presents descriptive statistics concerning accidents and their causes. In addition to describing these results for Construction Engineering researchers, we wanted to use them to develop guidelines that would be useful to help workers on construction sites to reduce accidents. This section presents the "Hiyari-Hat Model" which we hope will help field workers to understand and to prevent the causes of accidents.

The findings of the previous sections can be summarized as follows:

- There are probable precursors of occupational accidents, such as the 35 reported cases. Normal inspections detect these precursors. However, they recur and trigger recurring occupational accidents;
- Ordinary safety countermeasures at job-sites undoubtedly reduce precursors to accidents and actual accidents, but they do not completely prevent the recurrence of the undesirable precursor conditions or accidents; and
- Poor humanware causes most recurrence of precursors to safety problems.

The observations of this study suggest the following causal-chain for the occupational accident occurrence process:

1. Leadership has an influence on followership, and vice versa;
2. Poor humanware causes human error regarding safe practice;
3. A near-miss accident (called "Hiyari-Hat" in Japanese) is a consequence of human error; and
4. Industrial injury may occur if the routine safety countermeasures malfunction or are ineffective when the worker experiences the Hiyari-Hat.

Figure 6 shows a graphic schema of the Hiyari-Hat model.

Insert Figure 6 about here.

7. Unsafe Symptoms Template

Workers at construction sites of a Japanese general constructor were surveyed to determine the incidence of Hiyari-Hat occurrences and the conditions that occurred just before the Hiyari-Hat. Using a questionnaire, data was collected during July 1988 to identify recent Hiyari-Hat incidents. 7955 workers responded to the questionnaire. Respondents had an average age of 40 years. About 33% (2586) of the respondents reported that they experienced Hiyari-Hat. Data analysis results are shown in detail below.

7.1 Data collection

The questionnaire identified the type of Hiyari-Hat occurrence (H1-H11 in Figure 7), the date and time of the Hiyari-Hat occurrence, the type of work, the type of worker, the years of experience of the worker, and the unsafe symptoms, or risks (C1-C40 in Figure 8), when the worker experienced the Hiyari-Hat. The leftmost portion of Figure 8 shows the way that symptoms were classified as

- Human error shaping factors ("Poor Humanware" in the table column), and
- Human error, i.e., perception, judgment, action errors.

The unsafe symptom items in the questionnaire referred to the leadership items reported by Misumi [6], human errors discussed by Hashimoto [7] and the cases of Hiyari-Hat gathered at the [T] branch office.

Insert Figure 7 about here.

Insert Figure 8 about here.

Questionnaire respondents chose "Yes" or "No" for each item in Figure 8. The questionnaire items were laid out in a randomized order to avoiding carry-over-effects, where the carry-over-effect is the effect of the former item on the answer of the next item.

7.2 Data Analysis and Results

Figure 9 shows frequency of occurrence of each type of Hiyari-Hat. Figure 10 shows frequency of occurrence of worker unsafe practices.

Insert Figure 9 about here

Insert Figure 10 about here

Figure 9 shows that half of the Hiyari-Hat was of three types: person falling (21%), stumbling or slipping (14%), and being struck by falling objects (13%).

Figure 10 shows that the highest frequency categories were of:

- Followership:

  Absorption in work (C1),

  Poor housekeeping (C23);

  Anticipation of mild consequence or overconfidence (C7); and

- Leadership:

  No or inadequate instruction (C25 and C28),

  Excessive emphasis on productivity (C22).

The Principal Component Analysis (PCA) method used in this paper is presented in greater detail below. The basic objective is to reduce the 40 variables in Figure 8 to a much smaller number of variables while retaining as much as possible of the variation in the 40 original variables and to cluster the risk factors that correlate best with each other.

The statistical value r_{ij} given in Equation (1) is the correlation coefficient between category z_i and category z_j and is related to χ^2 statistic given in Equation (2):

$$r_{ij} = \frac{z_{ij} - f_i f_j / n}{\sqrt{(f_i - f_i^2 / n)(f_j - f_j^2 / n)}}, \tag{1}$$

$$\chi^2 = n r_{ij}^2 \tag{2}$$

Let the data given in Figure 8 be denoted as an n by q matrix, $\mathbf{Z}$; let $\mathbf{F} = [f_i]$, $(i = 1,2,\cdots,q)$ be the column vector in which each element represents the frequency of each category; let $\mathbf{D}$ be the diagonal matrix in which the diagonal elements are $[f_i - f_i^2 / n]$, $(i = 1,2,\cdots,q)$. The (i, j) element of the matrix in Equation (3) equals to the correlation coefficient r_{ij} in the equation (1). The matrix $\mathbf{R}$ is a correlation matrix between z_i and z_j $(i, j = 1,2,\cdots,q)$:

$$\mathbf{R} = \mathbf{D}^{-1/2}\mathbf{B}\mathbf{D}^{-1/2}, \tag{3}$$

where

$$\mathbf{B} = \mathbf{Z}^T\mathbf{Z} - \mathbf{F}\mathbf{F}^T / n. \tag{4}$$

Subsequently, calculate the eigenvalue and eigenvector that satisfy the equation (5):

$$\mathbf{RL} = \mathbf{L}\Lambda, \tag{5}$$

where Λ is the diagonal matrix of the eigenvalues $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_q$; $\mathbf{L}$ is the q by q matrix consisting of the eigenvector; let the eigenvector be denoted by the column vector $\mathbf{l}_k = [l_{1k}, l_{2k}, \cdots, l_{qk}]$ $(k = 1, 2, \cdots, q)$.

To show the groupings of unsafe symptoms, i.e., the correlation of Humanware (human-error-shaping risk factors) and human error items in Figure 8, the data were analyzed using PCA and the Ward method ([8], [9], [10], [11], [12]).

PCA is one of the descriptive dimension-reducing techniques while retaining as much as possible of the variation in the original dimensions. Our cut-off criterion for choosing the first few, high variance dimensions is that the selected eigenvalues satisfy $\lambda_k > 1$, $|\lambda_k - \lambda_{k+1}| > 1$ for $k = 1, 2, \cdots, q-1$. We chose the highest three eigenvalues. The highest three eigenvalues are shown below. The three dimensions corresponding to the highest three eigenvalues account for 45% of the variation in the original 40-dimensions.

Dimension	Eigenvalue	Proportion
A	13.8	35%
B	2.5	6%
C	1.4	4%
Total	17.7	45%

The factor loading values corresponding to the A, B, C groups are shown in Figure 11. The A, B, C groups in Figure 11 correspond to the three highest eigenvalues. Our interpretation of each is as follows:

- A: this is a dimension which shows a reciprocal interaction among "Production Emphasis," "Willful Transgression," and "Distrust Safety Commitment";
- B: this is a balance dimension of leadership and followership; the plus side accounts for "Poor Initiative and Consideration"; the minus side for "Inadequate Knowledge or Unskilled" and "Poor Physical or Mental Conditions";
- C: this is a dimension which shows a reciprocal interaction between leadership and followership; the plus side accounts for "No on-the-job education," "Lack of Compliance," and the minus side for "Inadequate Instruction," and "Poor Housekeeping."

Consequently, the dendrogram in Figure 12 that depicts the relationship among each category can be obtained by applying the Ward method to the factor loading values (Figure 11). This dendrogram consists of three large clusters. The categories involved in a cluster are strongly related to each other.

Insert Figure 12 about here.

The leftmost portion of Figure 12 shows χ^2 contingency tables to find the most important associations between individual types of Hiyari-Hat (i.e., H1 - H11 in Figure 7) and safety risks (i.e., C1 - C40 in Figure 8). The method is to calculate the difference between each frequency and the expected frequency. The values "1" and "2" in these χ^2 contingency tables show significant cells, i.e., cells with a χ^2 value given by Equation (6) greater than one, or greater than two, respectively.

$$cell\chi^2 = \frac{(frequency - \exp ected\ value)^2}{\exp ected\ value} \qquad (6)$$

As shown in Figure 12, the risks cluster into three principal groups:

A: Worker knew but did not follow well-established rules;

B: Failure to follow defined procedures; and

C: Inadequate knowledge to do work properly.

Humans often make errors while working at job-sites. In general, the more workers experience error, the less likely they are to repeat the same errors, because humans learn from their errors. Error, not corrected in time, causes a Hiyari-Hat or an occupational accident, and then the error is called a human error. Classifying by the occurrence process of human error, it can be classified into the following categories [7]:

A. perceptional/cognitive error, which is an error that occurs in the process from the perception to cognition of information at the sensory center;
B. misjudgment/ memory lapse, which is an error that occurs in the processing of information in the cerebrum; and
C. action/handling error, which is an error that occurs in the process of action or operation.

The three levels of cognitive control can be identified, being related to a decreasing familiarity with environment ([14], [15]; [16]). The three levels are:

A. skill-based level: skill-based behavior is based on highly automated sensory-motor; human error at this level is a deviation from the expected behavior mainly due to mental fatigue or to some kinds of attention loss;
B. rule-based level: at this level, an action is selected by activating a hierarchy of rules in familiar working memory; human error at this level is a wrong application of well-known rules/procedures; and
C. knowledge-based level: knowledge-based behavior is evoked when entirely new, unstructured, or complex problems are encountered; human error at this level is an improper recognizing and judging structure of a problem.

From the observations in all the clusters--[A], [B], [C]--described above, we derived the template shown in Figure 13. This template represents the causal-chain among humanware, human error and type of Hiyari-Hat, and reflects well the fundamentals of a Hiyari-Hat model. Here people pay attention to the consistency between their behavior and abnormal unplanned behavior shown in this template.

Insert Figure 13 about here.

8. Remarks

The anticipated results of this study are:

- First-line employees can systematically keep track of and diagnose current unsafe states of their own behavior on a timely basis, comparing their own behavior with the template in Figure 13;
- Workers can easily translate the results of the diagnosis into practical day-to-day safety prevention actions. This template could be a tool to integrate off-the-job education, on-the-job education and the report system of Hiyari-Hat.

To prevent occupational accidents caused by human error, it is very important to enhance the ability of workers and management to anticipate possible hazards in the workplace and the ability to work properly and safely. Human-error-shaping factor and Human error are not distant from oneself, but it is one's own problem.

Physicians can diagnose human body conditions regarding diseases by capturing symptoms (blood pressure, cholesterol, and the like) and by their template indicating causal-effect relationships among diseases (e.g., arteriosclerosis) and the symptoms. Similarly, workers can diagnose dangerous states latent in their own behavior, by gathering data as to human-error-shaping factors and human error items, and by self-monitoring so that their actions could be monitored and compared with the baseline scale of Principal Component Score and the template in this study.

The Hiyari-Hat report system is very useful for first-line managers, supervisors and workers for identifying their own behavior and to gather and share Hiyari-Hat data. It helps worker's self-inspection, and therefore helps motivate them to work safely. On-the-job education is a small group activity in which the worker discusses the latent or actual hazard in the workplace and so helps identify possible hazards. The Hiyari-Hat model, the analysis scheme and the template presented in Figure 13 could augment on-the-job education and the Hiyari-Hat report system by highlighting occurrences of and ways to prevent human-error-shaping factors and human error items. Consequently, it is anticipated that this template will provide first-line employees with opportunities to:

- get them to think,
- recognize potential hazards,
- do something to protect themselves, and
- start a process of questioning their own behavior.

A further research problem is to develop a quantitative model to predict what type of Hiyari-Hat occurs, based on the findings of this study. This model could be helpful for workers to understand the results of failure to heed human-error-shaping factors and human error items that the workers have experienced.

Acknowledgment

We had many discussions with Visiting Fellows, Center for Integrated Facility Engineering, Stanford University. Professor Paul Teicholz and Professor Raymond Levitt, Department of Civil Engineering, Stanford University gave valuable comments on the revised draft of this paper.

Appendix: Glossary

Humanware is defined as a function of leadership, followership and the reciprocal interaction between the two. Leadership is a leader's willingness to fulfill both task accomplishment and group maintenance. Followership is followers' voluntary desire to follow their leader and to achieve their tasks.

Hiyari-Hat: "Hiyari" (in Japanese) means "Cold." "Hat" (in Japanese) means "Frightening." "Hiyari-Hat" is an incident that, fortunately, does not result in injury, although under slightly different conditions the incident might have led to injury of the worker and/or property damage. "Hiyari-Hat" is called "Near Miss" or "Critical Incident."

Kiken-Yochi-Training (KYT) and Kiken-Yochi-Katsudo (KYK): "Kiken" (in Japanese) means "Hazard." "Yochi" (in Japanese) means "Forecasting." "Katsudo" (in Japanese) means "Activity." Off-the-job education (KYT) is provided to enhance first-line employees' ability to anticipate potential hazards in their workplace. In off-the-job education, an illustration is used to represent abnormal or unplanned state of a workplace. Through the discussion about how to improve the abnormal or unplanned state, the workers learn to anticipate potential hazards in the work procedure and workplace. On-the-job education (KYK), on the other hand, uses crew safety meetings immediately before work begins. In on-the-job education, workers are instructed in safe work practice by discussing possible hazards at crew meetings immediately before real-life work begins. KYT and KYK aim to enhance the first-line employees' ability to:

- anticipate the potential hazards in the workplace;
- discover hazards which they could cause themselves; and
- work in accordance with safety operating procedures.

On-site safety training for each day's work is held at 7:30 am every morning and includes the following steps:

Step 1: Discuss the existing conditions (What dangerous factors are hidden or exist?);

Step 2: Evaluate risk factors;

Step 3: Consider and discuss countermeasures for important risk factors (What do we need to do?); and

Step 4: Secure the individual commitment of all crew members to any countermeasures developed at Step 3 (We will do it this way.).

References

[1] The Ministry of Labor in Japan (1989). General Guide Book on Industrial Safety, Japan Industrial Safety and Health Association.

[2] Nishigaki, S. (1988). "The Application of Discriminant Analysis to Safety Patrol System," Reports of Statistical Application Research, Union of Japanese Scientists and Engineers, Vol. 35, No. 1, pp. 24-34.

[3] Morgan, J. N. and Sonquist J. A.(1963). "Problems in the analysis of survey data, and a proposal," J. Amer. Statist. Assoc., Vol. 58, pp. 415-434.

[4] Breiman, L., Friedman, J. H., Olshen, R. A. and Stone, C. J. (1984). Classification And Regression Trees, Wadworth, Inc..

[5] Griffin, R. W., Moorhead G. and Shinvington, K. D.(1987). "Symbolic and Perspective on Leadership: An Interaction Framework," Human Factors, Vol. 40, No. 4, pp. 199-218.

[6] Misumi, J. (1984). The Behavioral Science of Leadership, Yuhikaku.

[7] Hashimoto, K. (1986). Human engineering for safety, Japan Industrial Safety and Health Association.

[8] Jolliffe, I. T. (1986). Principal Component Analysis, Springer-Verlag.

[9] Flury, B. (1988). Common Principal Components and Related Multivariate Models, John Wiley & Sons.

[10] Greenacre, M. J. (1983). Theory and Applications of Correspondence Analysis, Academic Press.

[11] Lebart, L., Morineau A. and Warwick, K. M. (1984). Multivariate Descriptive Statistical Analysis, John Wiley & Sons.

[12] Romesburg, H. C. (1984). Cluster Analysis for Researchers, Robert E. Krieger Publishing Company.

[13] Dubes, C. R. and Jain, A. K. (1988). Algorithms for Clustering Data, Prentice Hall.

[14] Reason, J. (1987). "Generic Error-Modeling System (GEMS): "A Cognitive Framework for Locating Common Human Error Forms," Rasmussen, J., Duncan, K. and Leplat, J. edited: New Technology and Human Error, John Wiley & Sons, pp. 63-83.

[15] Rasmussen, J. (1987). "Cognitive Control and Human Error Mechanisms," J. Rasmussen, K. Duncan and J. Leplat edited: New Technology and Human Error, John Wiley & Sons, pp. 53-61.

[16] Bagnara, S. Rizzo, A. and Visciola, M. (1988). "Human error detection processes," E. Hollnagel, G. Mancini, D. D. Woods edited, Cognitive Engineering in Complex Dynamic Worlds, Academic Press. pp. 99-144.

[17] Mosteller, F. and Tukey, J. W. (1977). Data Analysis and Regression, Addison-Wesley.

[18] Hoaglin, D. C., Mosteller, F. and Tukey, J. W. (1983). Understanding Robust and Exploratory Data Analysis, John Wiley & Sons.

No.	Item	Example
X1	Common items	• Creating and enforcing a safety and health program. • Compliance with regulations on record keeping, posting, and reporting.
X2	On-the-job training, or Kiken-Yochi-Katsudou (KYK)	• Discussion about any safety or health hazard in the workplace at crew meetings.
X3	Safety operating procedures	• Documentation of safety operating procedures. • Being in compliance with safety operating procedures.
X4	Safety management of subcontractors	• Reports, record keeping and posting. First aid procedure.
X5	Prevent worker falling	• Provide covers and handrails when necessary to protect personnel. • Aisles and passway kept clear and in good condition.
X6	Prevent falling objects	• Signs warn of clearance limits • Safety nets and toe boards.
X7	Prevent collapse	• Earth fall, slope failure and retaining wall failure.
X8	Prevention of breaking down	• Scaffolding, temporary enclosure properly used. • Safe material storage.
X9	Operation and maintenance of machinery & vehicles	• Test and approval of machinery & vehicles; • Avoiding: contact with a moving part, clothing getting caught in a moving part, random ejection of materials.
X10	Operation and maintenance of cranes	• Safety clearances and sufficient space for operation and maintenance.
X11	Operation and maintenance of electrical equipment	• Compliance with the National Electric Code, • Access space around electrical equipment, approval of electrical equipment.
X12	Prevent traffic accidents	• Overhead and condition of gantry crane. • Safety clearances and sufficient space for operation and maintenance.
X13	Prevent explosion and fire	• Approved containers and proper safety valves for compressed gas.
X14	Personal Protective Equipment (PPE)	• PPE is an approval type and in the proper condition.

Figure 1: Checklist used by a Safety Patrol in the [T] Branch Office of a Japanese General Constructor. A safety patrol inspector makes unannounced visits of construction sites and looks for the safety practices shown in the rightmost column.

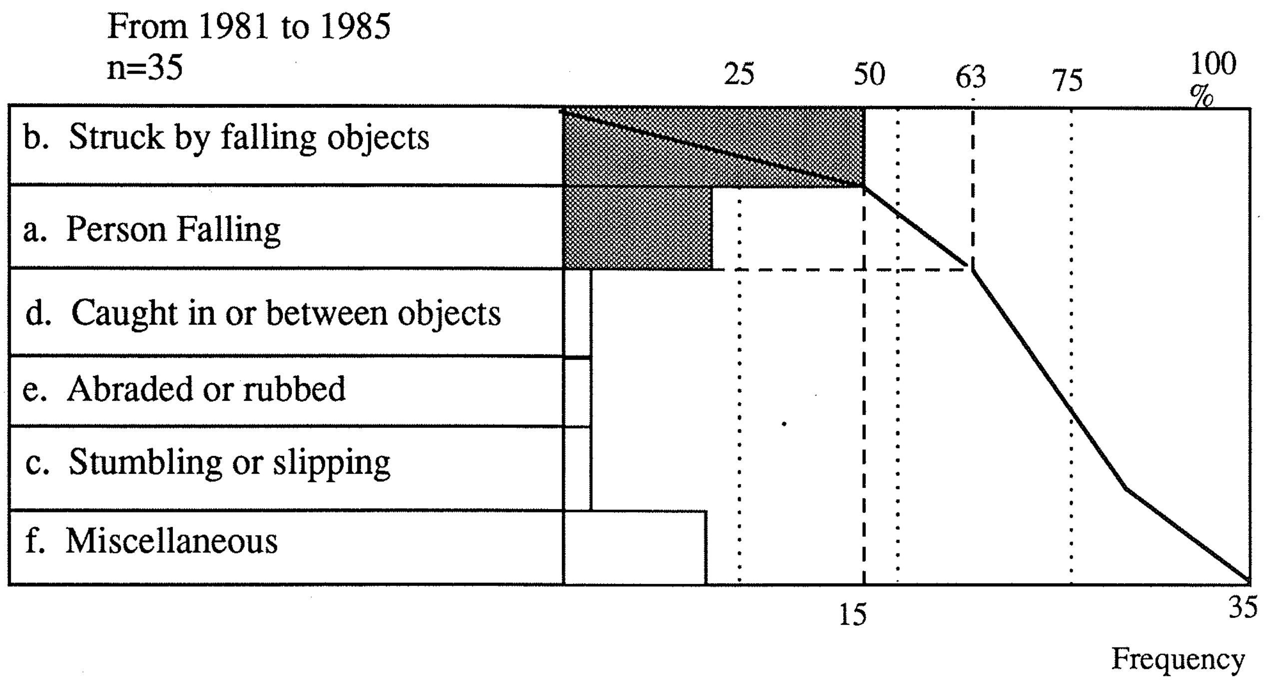

Figure 2: 35 occupational accidents reported in a construction office over a 5-year period. 63% of these occupational accidents were of two types:

- Worker struck by falling objects (43%);
- Person Falling (20%).

All other type of accidents had relatively low frequencies. The notations a-f are used below in Figure 5.

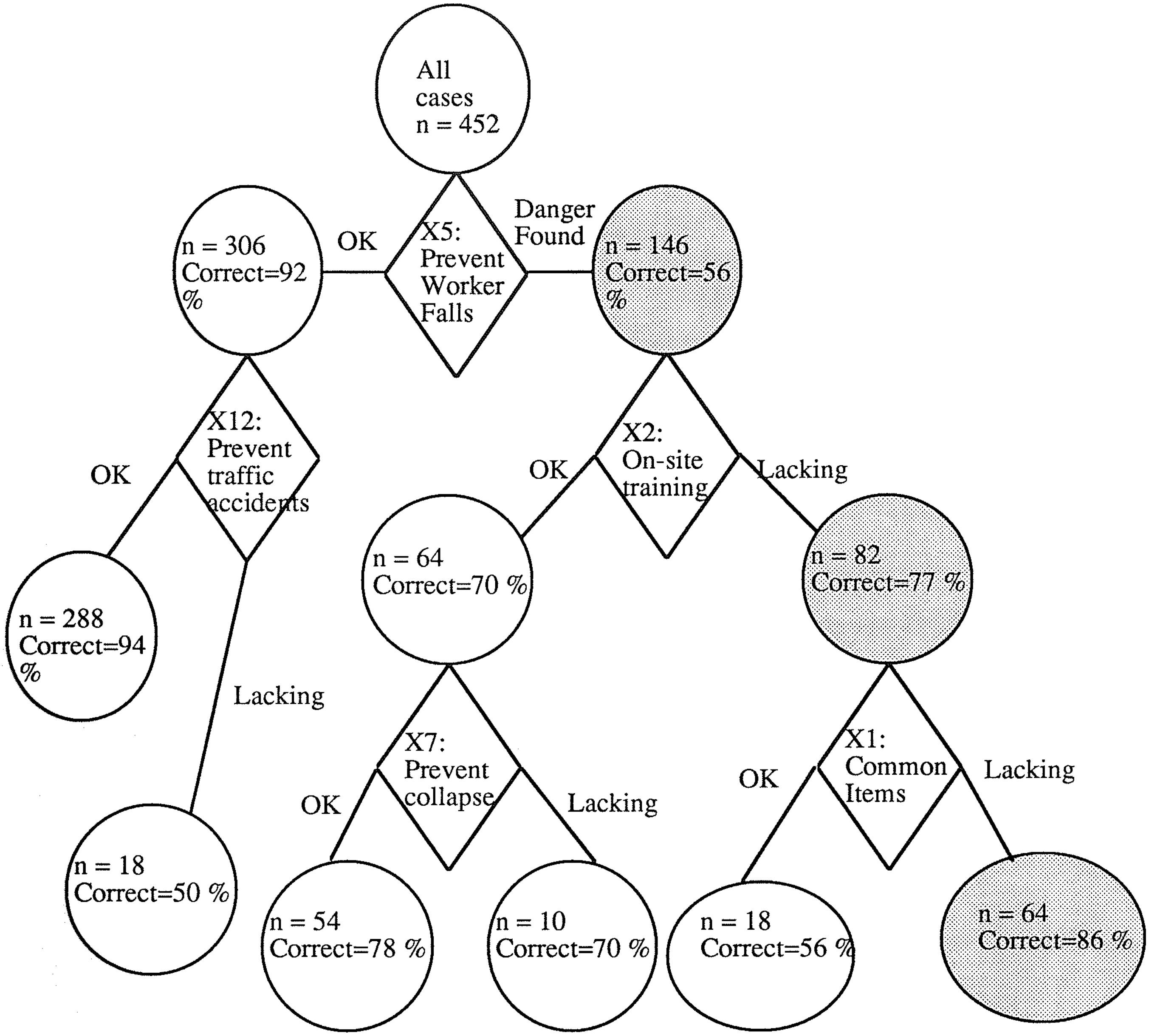

Figure 3: Binary tree to discriminate between the presence and absence of occupational accidents based on job-site inspection survey results. X1, etc. refer to questions in the survey shown in Figure 2. "Correct" indicates the percentage of responses that are correctly classified, i.e., accident occurred or did not occur within 1 month after safety patrol survey. 64 safety patrol surveys preceded accidents accidents by one month or less. As shown in Figure 1, a total of 35 accidents were reported. Stippled circles represent groups classified as having accidents.

Type of Work	Type of Condition	Countermeasure	HW	SF	HM
Erection of scaffolding	Plumbing up or topping out	Secure scaffolding erection procedure	√		
	Supervise work	Attention to footings and surroundings		√	
	No guide rope	Install guide rope	√		
	Not wearing Personal Protective Equipment (PPE)	Order worker to wear PPE			√
	No handrail	Install handrail	√		
	No compliance with safety operating procedures	Order workers to comply with safety operating procedures			√
Formwork-ing	Lifting or transport of materials	Secure formworking erection procedures		√	
		Install safety net	√		
		Install guide rope	√		
		Install handrail	√		
		Order workers to wear PPE			√
		Placement enough to work safely		√	

Figure 4. Example of the ordinary countermeasures to prevent falls. Legend: HW=Hardware, SF=Software, HM=Humanware; "√" denotes a relationship between the two.

	Occupational accident cases Type of cause	a	b	c	d	e	f	Total
L	Lack of or inadequate safety education	7	13	2	3	0	5	30
	Inadequate instruction	7	8	2	3	0	1	21
	Passive meeting	6	6	1	0	0	0	13
	Insufficient inspection	5	4	2	0	0	0	11
	PPE* Deficiency	1	1	0	0	0	0	2
F	Poor housekeeping	2	3	0	3	1	1	10
	Fatigue	3	4	1	0	0	1	9
	Not in compliance with SOP**	4	3	1	0	0	1	9
	No proposals from staff to improve safety	1	6	1	0	0	0	8
	Not wearing PPE	4	1	2	0	0	0	7
	Work without qualification	3	1	1	0	0	0	5
	Unsafe clothing	1	0	0	2	0	0	3
SF	Inappropriate SOP for handling materials	3	5	1	3	1	1	14
	Poor emergency preparedness	2	3	2	0	0	0	7
	Obsolete written standard procedures	4	0	1	0	0	0	5
	Inappropriate layout	1	0	0	0	0	0	1
HW	Defective passways	4	3	1	0	3	1	12
	Defective machinery	1	0	1	0	0	1	3
	Defective safety devices	2	0	0	0	0	0	2
	Defective equipment	1	0	0	0	0	0	1

Figure 5. Causes of the Occupational Accidents at the [T] Branch Office, judged by professional construction staff.

Legend: Type of accident cases (as shown in Figure 1) a = Person Falling, b = Struck falling objects, c = Stumbling or slipping, d = Caught in or between objects, e = Abraded or rubbed, f = Other;
L = Leadership; F = Followership; SF = Software; HW = Hardware;
*PPE = Personal Protective Equipment; **SOP = Safety Operating Procedures.

Notice that most accidents have a humanware (leadership or followership) cause.

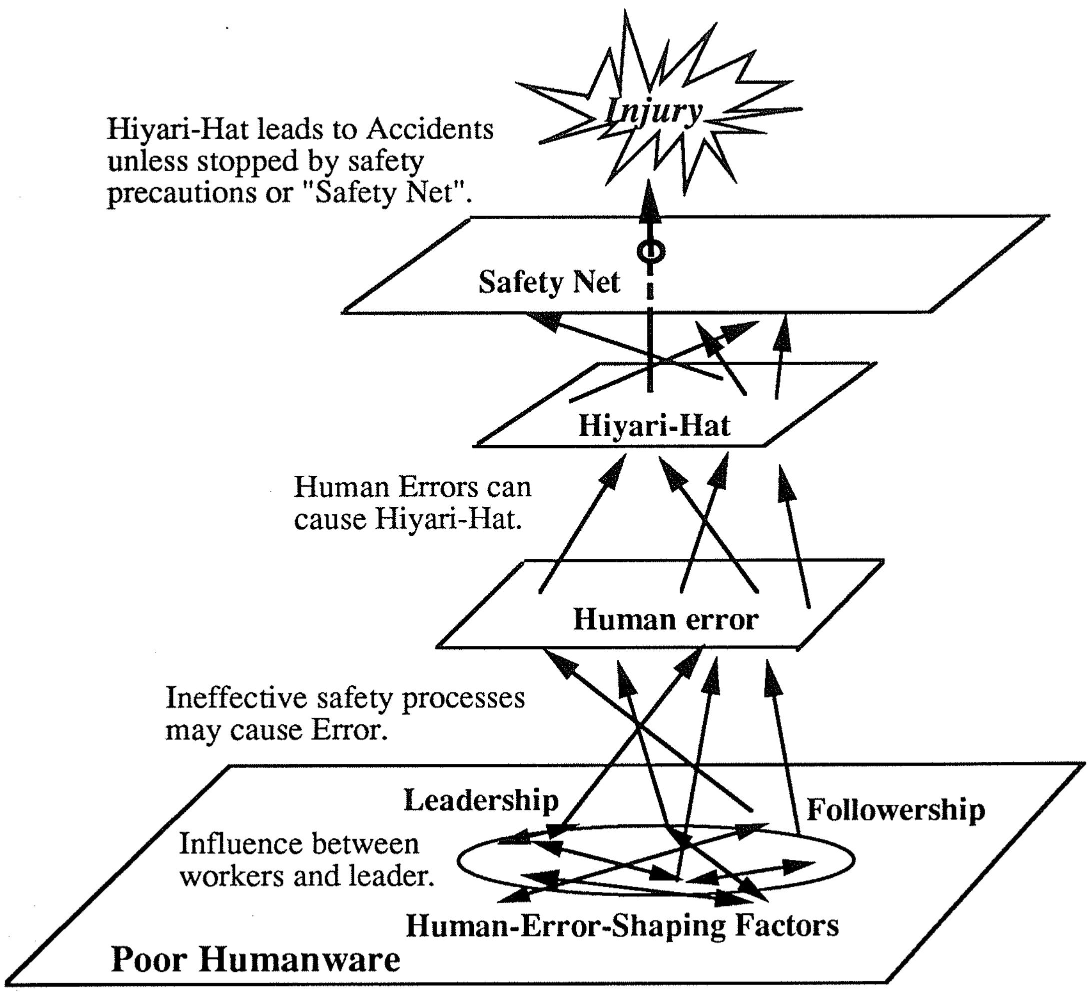

Figure 6. "Hiyari-Hat" is the Japanese word for near-miss accident. Accidents are caused by a cascade of effects: poor human processes leading to safety-related error leading to near-miss Hiyari-Hat accident and, if not stopped by in-place precautions, ultimately to an occupational accident.

H1	a Person Falling
H2	Stumbling or Slipping
H3	Striking or struck by objects, excluding falling objects
H4	Being struck by falling objects
H5	Collapsing (e.g., earth fall, slope failure)
H6	Being caught in or between objects
H7	Stepping sharp objects
H8	Being exposed to electric shock
H9	Traffic accidents
H10	Backache, Sprain, or Strain
H11	Other

Figure 7. Workers were asked if they had encountered a near-miss accident, i.e., a "Hiyari-Hat," of any of the above types of accidents. Figure 9 shows the frequency of occurrence of each. 7955 workers responded to the questionnaire.

Legend: "•" denotes relationship between each other.

Poor Humanware: Leadership	Poor Humanware: Followership	Human Error: Perceptionnal/Cognitive Error	Human Error: Misjudgement/Memory Lapse	Human Error: Action/Handling Error	The categories related to human-error-shaping factors, human error
	•	•			C1 I was absorbed in my work.
•					C2 Requested equipment or tools were not available.
	•	•			C3 I have somthing to worry about.
•					C4 On-the-job training was not held on the day.
	•			•	C5 I ommitted the current step, being tired of complying with the work procedure.
				•	C6 I was not wearing protection equipment.
	•		•		C7 I knew it was dangerous, but I forgot it was dangerous then.
•					C8 Constructor's personnel did not inspect a job-site.
			•	•	C9 My work routine was upset by a request to do additional work.
	•				C10 I have been feeling that this work was dangerous.
•					C11 Safety supervisor did not inspect a job-site.
			•	•	C12 I did not warn my peers, judging that they knew about the current condition.
			•	•	C13 I started the next step, because I thought I was finished the current step
			•		C14 I forgot the procedures decided at on-the-job training.
	•		•	•	C15 I felt it was dangerous, nevertheless I dared to work.
					C16 The responsibility rests with me.
					C17 Dangerous/Defective workplace or walkway.
					C18 The job method was unsuitable.
	•			•	C19 Unsafe dress or apparel.
	•			•	C20 I did not comply with a standard procedure.
•					C21 on-the-job training before work was not held.
•	•	•			C22 I feel pressure to work too quickly.
	•				C23 Poor housekeeping
				•	C24 I reflexively held out my hand.
•					C25 Constructor's personel did not provide instruction to subcontractor's personel.
					C26 Defective machinery or instruments.
•					C27 Instruction for a work procedure were not given.
•	•				C28 Ways to improve work were not given.
			•		C29 I forgot for the moment the instructions.
	•	•			C30 My physical condition was poor.
			•		C31 I jumped to a conclusion.
	•	•			C32 I was tired.
	•	•			C33 I was lost in thought about my complicated work.
	•			•	C34 I took a shortcut, being tired of using the proper walkway.
	•		•		C35 I was not able to judge anything, because I was straind and/or excited.
		•	•		C36 I did not recognize the hazard because I was distracted by an unforeseen events.
					C37 The responsibility rests with a peers.
			•	•	C38 I did not inspect it, judging it was unnecessary.
	•	•			C39 I became irritated.
			•	•	C40 I started the next step, because I mistook the current step for being finished.

Figure 8. Workers who encountered a near-miss accident, i.e., a "Hiyari-Hat," were asked to identify all safety-related factors of this table that preceded their Hiyari-Hat occurrence. The factors are classified as Leadership, etc., as shown in the left part of the table. Figure 10 shows the actual reported frequency of each factor.

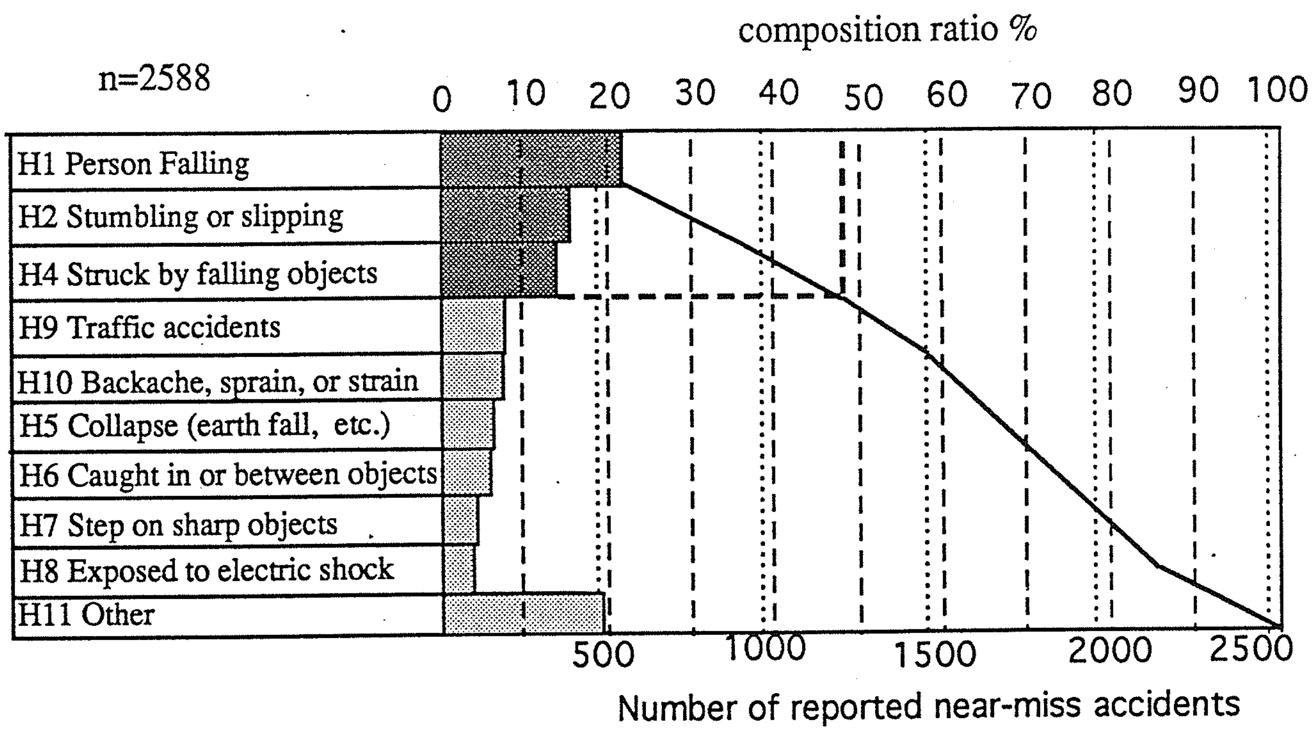

Figure 9. Workers who encountered a near-miss accident, i.e., a "Hiyari-Hat," were asked to identify all safety-related factors of this table that preceded their Hiyari-Hat occurrence. This figure shows the actual reported frequency of each factor.

The categories related to human-error-shaping factors, human error	Frequency	ratio to number of respondents
C1 I was absorbed in my work.	2227	0.28
C2 Requested equipment or tools were not available.	740	0.09
C3 I have somthing to worry about.	444	0.06
C4 KYK was not held on the day.	164	0.02
C5 I ommitted the current step, being tired of complying with the work procedure.	846	0.11
C6 I was not wearing protection equipment.	447	0.06
C7 I knew it was dangerous, but I forgot it was dangerous then.	1464	0.18
C8 Constructor's personnel does not inspect a job-site.	747	0.09
C9 My work rootine was upset by a request to do additional work.	653	0.08
C10 I have been feeling that this work was dangerous.	1049	0.13
C11 Safety supervisor does not inspect a job-site.	477	0.06
C12 I did not warn my peers, judging that they knew about the current condition.	719	0.09
C13 I started the next step, because I thought I was finished the current step	918	0.12
C14 I forgot the matters decided at KYK.	405	0.05
C15 I felt it was dangerous, nevertheless I dared to work.	1069	0.13
C16 The responsibility rests with me.	1362	0.17
C17 Dangerous/Defective workplace or walkway.	977	0.13
C18 The job method was unsuitable.	834	0.10
C19 Unsafe dress or apparel.	192	0.02
C20 I did not comply with a standard procedure.	245	0.03
C21 KYK before work was not held.	274	0.03
C22 I feel pressure to work too quickly.	1562	0.20
C23 Poor housekeeping	1557	0.20
C24 I reflexively held out my hand.	1009	0.13
C25 Constructor's personel did not provide instruction to subcontractor's personel.	1358	0.17
C26 Defective machinery or instruments.	484	0.06
C27 Instruction for a work procedure were not given.	566	0.07
C28 Ways to improve work were not given.	1156	0.15
C29 I forgot for the moment the instructions.	627	0.08
C30 My physical condition was poor.	454	0.06
C31 I jumped to conclusion.	787	0.10
C32 I was tired.	791	0.10
C33 I was lost in thought about my complicate work.	421	0.05
C34 I took a shortcut, being tired of going the right walkway.	772	0.10
C35 I was not able to judge anything, because I was straind and/or excited.	470	0.06
C36 I did not recognize the hazard because I was distracted by an unforeseen events.	577	0.07
C37 The responsibility rests with a peers.	500	0.06
C38 I did not inspect it, judging it was unnecessary.	1023	0.13
C39 I became irritated.	534	0.07
C40 I started the next step, because I mistook the current step for being finished.	690	0.09
Average	789.78	0.099

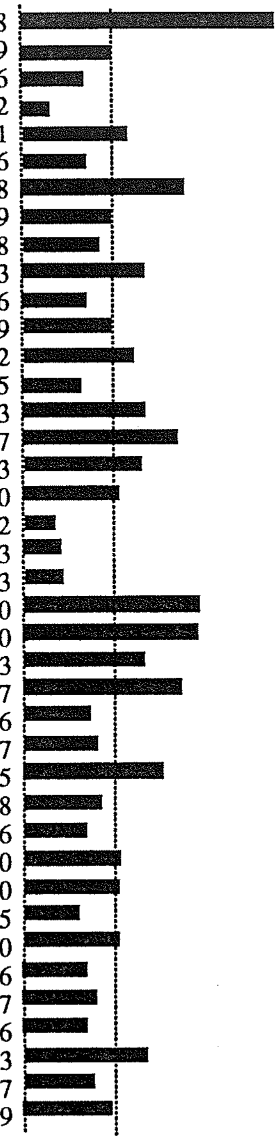

Figure 10 Frequency Bar Chart of Human-Error-Shaping Factor and Human Error Items

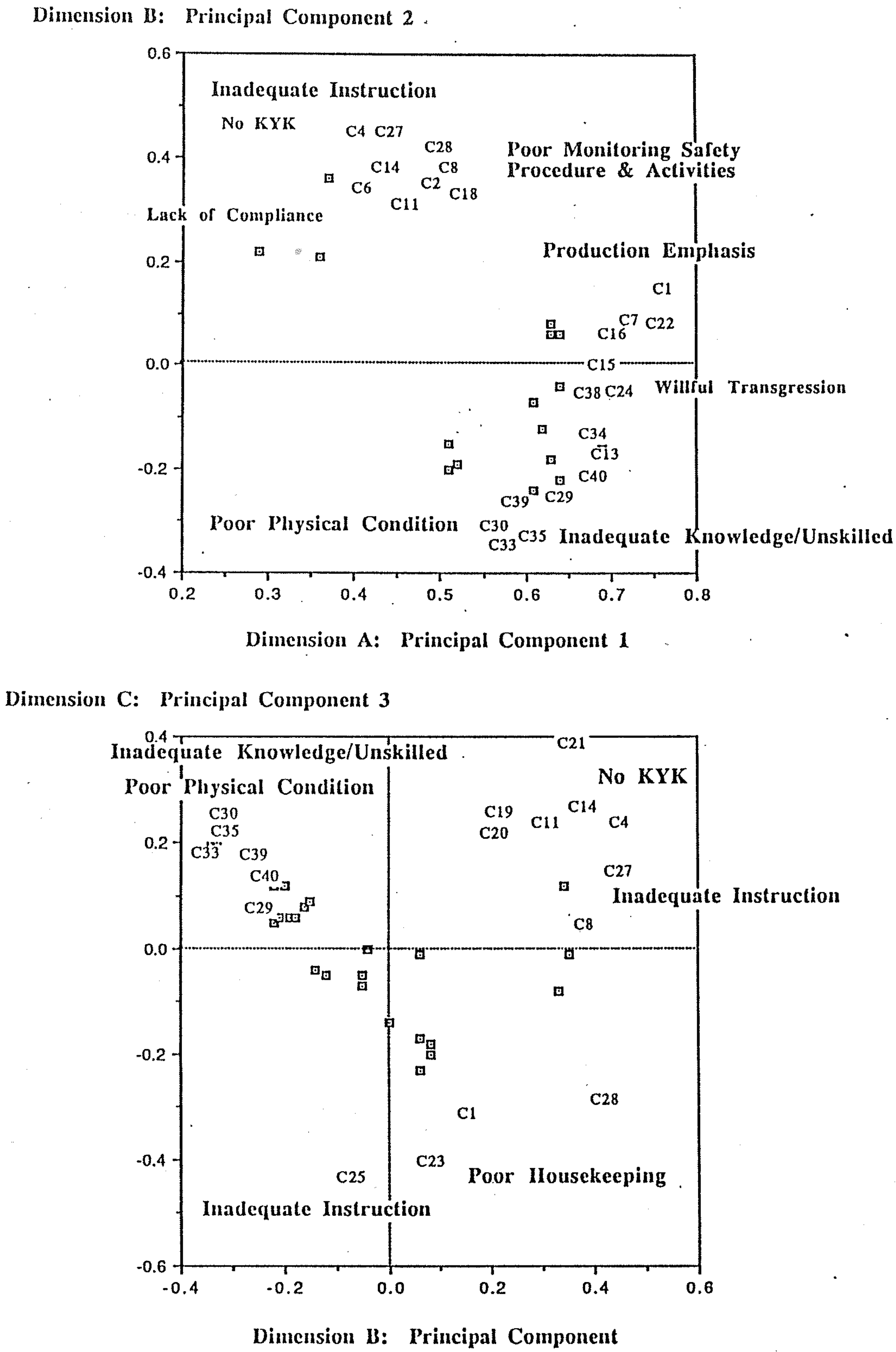

Figure 11 The Scattered Graph of Factor Loading Values

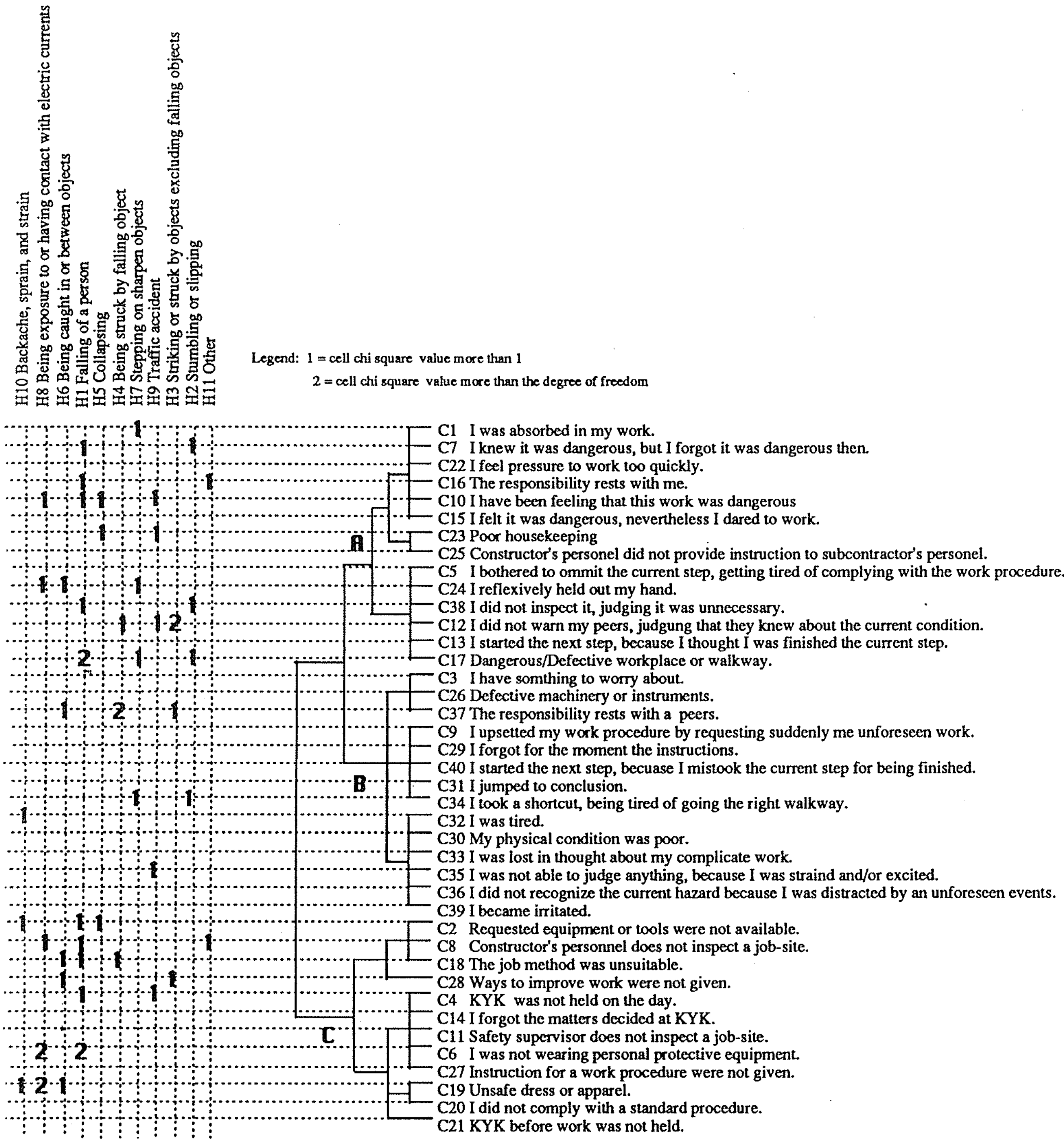

Figure 12. χ_2 contingency tables show the most important associations between individual types of Hiyari-Hat (i.e., H1 - H19 in Figure 7) and types of human-error-shaping risk factors (i.e., C1 - C40 in Figure 10). "1" in a cell entry indicates a significant correlation (i.e., $\chi_2 > 1$). As explained in the main text, the PCA method was used to cluster related risk factors into groups (e.g., A, B, C).

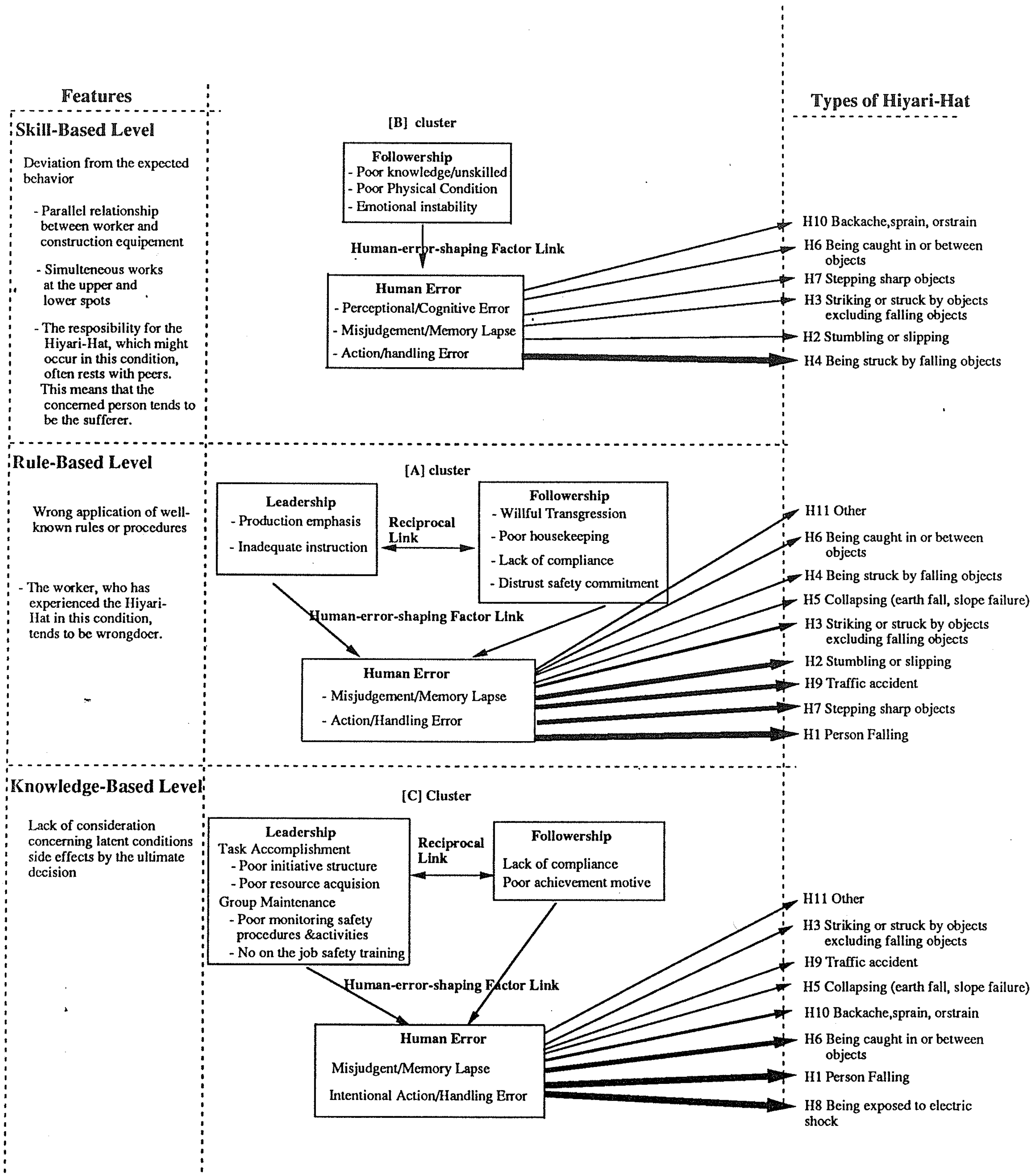

Figure 13 Template summarizing the Symptoms considered as Important Indicators of the Relationships among Abnormal or Unplanned Conduct and Hiyari-Hats