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Application of Fuzzy Theory and Analytic Hierarchy Process(AHP) for Developing Occupational Stress Index

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ABSTRACT

This paper illustrates the application of Fuzzy Theory and Analytic Hierarchy Process(AHP) for developing Occupational Stress Index(OSI). The purpose of the OSI development is for future prediction and problem solving of prevailing occupational stress. In developing OSI, the concept of fuzzy set theory was introduced to determine the existence and level of perceived occupational stress instead of actually measuring the strain parameters. The AHP is adopted to collect different weighting factors, since there exist various perceptions and responses to the occupational stress by different individuals. The validation study revealed that the OSI is a reliable predictor of work-related accident and illness and the physiological health of employees. Creating preventive measures, such as early detection of stress, proper placement and promotion of employees, and job enlargement will be possible by using this OSI effectively.

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1. Introduction

From an ergonomics perspective, occupational injuries and incidents are mainly due to an excessive workload imposed on the operator. Reduction of such incidents, frequently associated with Manual Materials Handling (MMH), is one of the most important concerns to ergonomists or to managers. Thus, the goal of the ergonomist or human engineer is to determine the maximum levels of workload that do not violate the steady-state. While workloads below this "optimum" level will be inefficient, higher workload levels will lead to destabilization of the steady-state and, therefore, will cause occupational stress. If occupational stress is too intense or prolonged, then it may cause anxiety, discomfort, disturbed body function, and finally, actual disease or damage. In addition, excessive or prolonged occupational stress at the workplace causes higher error, higher accident rate, increased sick time, faulty judgement, and poor productivity.

Wallis(1987) stated that occupational stress can occur when people are aware of a mismatch between the occupational and organizational demands at work and their ability to overcome, circumvent or find other ways of adequately coping with these demands. Therefore, stress is the body's response to any demand made on it(Adams, 1988). That is, stress refers to some undesirable condition, circumstance, task, or other factor that impinges upon the individual.

There are numerous techniques which can measure the level of perceived stress. According to Weiner(1982), the measurement of workload can be performed with respect to one or all four of the following parameters: the imposed load or stressor, the internal stress response without loss of homeostasis, the intensity of homeostatic disturbance or strain, and the stress response associated with disturbance of homeostasis.

The existence of perceived stress can be directly found by measuring the strain. Some examples of various measures of strain are listed below:

(1) Physiological Measures: heart rate, blood volume,
(2) Electrical Measures: Electroencephalogram (EEG), Electromyogram(EMG),
(3) Physical Measures: blood pressure, temperature of body,
(4) Activity Measures: work rate, errors, and
(5) Attitude Measures: boredom, frustration, anger.

The major disadvantage of a direct measurement technique is that bulky equipment often must be attached to the subject to get the measurements. Instead of trying to measure occupational stress by physiological techniques or by the output measurement techniques of work study, many past attempts have been made to assess workload stress through detailed analytical techniques. Some of these techniques were designed for the work study engineer and require a certain amount of basic training in work study methods.

Despite the tremendous amount of information published in the literature on predicting and estimating workload stress, there are not many reliable theories that can assist a practitioner in predicting the levels and composite effects of different forms of stress due to a separation of workload elements.

Traditionally, the emphasis has been made on estimating either physical or mental workload only, without taking into account both types of workload elements. Since the workload stress has either physical or mental origin, there is a critical need to develop a workload standard estimation technique which takes into account both mental and physical elements of a man-machine system.

In order to develop such workload estimation standards, one must consider all types of internal and external stressors and their corresponding stresses. The stressors may be physical or psychological and their responses may be qualitative or quantitative. All stressors and their responses must be considered if the effectiveness of a man-machine system is to be optimized. In an industrial environment, the performance and productivity of an individual is affected, whether the imposed stressor is physical or mental.

For all these reasons, the development of a better analytical workload stress prediction model which is a comprehensive, accurate, and easy to use measurement technique is highly desired because the determination of workload plays an important role in designing and evaluating an existing man-machine system.

2. Direction and Scope of Study

As described earlier, the possible sources of occupational workload stress can have either external or internal origins or some combination of these. In this study, we consider the stresses that have external origin only. Examples of these types of stress originate from the physical, environmental, postural, and mental aspects of the work situation.

In this study, the task and workplace variables that have the most influence on workload stress are defined for developing the Occupational Stress Index(OSI) model.

Two theories were applied in developing the OSI model. The fuzzy logic and set theory was introduced to capture the subject's stress perception. The Analytic Hierarchy Process (AHP) was introduced to estimate the importance of the task and workplace variables.

In modeling OSI, the linguistic values(e.g., "heavy," "high," "moderate,") of the task and the workplace variables(e.g., physical job demand, environmental, postural, and mental demand stressors) which can capture the operator's perception on stress are introduced as a value of variables.

It must be recognized that some factors(i.e., stressors) might be sources of stress for some individuals but not for others. These differences can arise from various individual characteristics of a physical, mental, attitudinal, or emotional nature. Individual differences in such characteristics might be reflected, for example, in differences in capacities to adjust or adapt to different external conditions. In addition, a person's perception of his or her ability to deal with the job and its external features could cause some people to experience stress but not others.

Since there exist various perceptions and responses to a stress by different individuals, the AHP is adopted to collect the different weighting factors. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then guides subjects through a series of pairwise comparison judgements to express the relative strength or intensity of impact on a subject's stress in the hierarchy. This approach calculates the ratio of the subjective judgment from each type of stressors and weights the stressors based on their impact on the subject's perception.

The primary objective of this research was to develop and validate a comprehensive and integrated model that is capable of predicting occupational stress from the various workplaces.

3. The Application of Fuzzy Theory and AHP for Developing OSI

The proposed procedure for developing OSI involves the following steps:

Step 1. Select and define the stressors that exist in a man-machine system(i.e., tasks and workplace variables which have most influential factors on stress).

Step 2. Introduce fuzzy set parameters for the selected variables.

Step 3. Utilize the principle of "maximum meaningfulness"(Goguen, 1976; Wang, 1983) in determining the level of workload stress.

Step 4. Determine the weighting factors (which are used as coefficients) by applying Analytic Hierarchy Process (AHP).

Step 5. Calculate the composite value of workload stress which is the OSI.

3.1 Variable Selections and Definitions

Some of the job risk factors which are the most influential to occupational workload stress in a man-machine system are selected to form a strong basis for developing the OSI.

(1) Physical Job Demand Stressors(S_1): stresses that come from the physical job demand(i.e., physical activities) which is the manual part of materials handling, such as weight of load, frequency of handling load, duration of physical activity, and moving distance with load.

(2) Environmental Stressors(S_2): stresses

from working environment, which include improper temperature, lighting, noise, vibration, exposure to chemicals (including dust and fumes).

(3) Body Motion and Postural Stressors(S_3): stresses which are induced by improper body motion and posture(i.e., standing, stooping, squatting, and twisting).

(4) Mental Job Demand Stressors(S_4): stresses caused by the mental and perceptual activity that is required in performing a job(e.g., calculating, thinking, deciding, communicating, remembering, looking, and searching).

These selected stressors with their contributing factors are shown in the later part of this paper(Figure 1).

3.2 OSI Developing Procedure by Introducing a Fuzzy Set Theory

Fuzzy logic allows information to be approximately summarized in a humanlike fashion, that is, ill-known data can be modeled. Fuzzy set theory provides the right tool for the manipulation of vague information and evaluation of uncertainty due to fuzziness, rather than randomness alone. Thus, it can be a powerful tool to deal with human-based uncertainty(Evans et al., 1989). From this point of view, the specification of a fuzzy system consists of a linguistic description of the behavior and/or the assignment of fuzzy parameters to an ordinary mathematical model. Since stress is directly related to human perception, the use of fuzzy set theory is appropriate for this study.

The construction of the membership function starts with identifying and acquiring the properties of the numerical assignments of the membership values within the confines of the theory of measurement(e.g., most people perceived heaviness of load with over 25 kg).

The physical job demand basically implies MMH which includes lifting, lowering, carrying, pushing, and pulling tasks. Thus, the job risk factors due to MMH are defined and five fuzzy sets of membership functions for these variables are collected from several sources(Chaffin et al., 1975; NIOSH Technical Report, 1981; Ayoub et al., 1983; Ciriello and Snook, 1983; Karwowski et al., 1986). The linguistic values of these variables are determined as follows:

s_1 = Weight of load: "very light," "light," "medium," "heavy," "very heavy,"

s_2 = Frequency of load: "very low," "low," "medium," "high," "very high,"

s_3 = Duration of load: "very short," "short," "medium," "long," "very long," and

s_4 = Moving distance of load: "very close," "close," "medium," "far," "very far."

The membership function is used to give expression to a fuzzy set. Assuming that we have a finite support set for subjective heaviness, which is sometimes called a base variable or universe of discourse, the following expression can be established:

$$s_1 = \{x_1, x_2, ..., x_n\}.$$

The fuzzy subset A(e.g., "heavy") of s_1(i.e., weight of load) is then expressed by

$$A = \sum_{i=1}^{n} \frac{\mu_A(x_i)}{x_i} =$$

$$\left[\frac{0}{1}, \frac{0}{15}, \frac{0.1}{20}, \frac{0.5}{25}, \frac{0.9}{30}, \frac{1.0}{32}, \frac{0.95}{34}, \frac{0.7}{40}, \frac{0.1}{50}, \frac{0}{60}\right].$$

The numerator indicates the grade of membership and the denominator denotes the elements of the support set in kilograms. The terms may be discarded for which either the grade of membership function is 0 or the base variable is 0 because they are meaningless. The equation given above can be used to express the degree of membership functions of stress from each stressor.

The meaning of the word is quantified over a specific range; that is, the weight of load ranges from 1 to 60 kilograms in this example. Fuzzy logic attempts to express the meaning of the word by means of the concept of sets. These intervals represent the grade of membership for each linguistic variable in the set "weight perception." For example, the membership function is greatest when the weight is 32 kilograms for "heavy" load. The membership functions are estimated over the 10 base variable positions for each fuzzy subset. These variable positions are transformed into the normalized range of the support set, [0, 1].

The sigma symbol used in the subset A(i.e., "heavy") expression means the union in fuzzy operation in which the grade is a maximum when the corresponding elements of the support set have the same value. It should be noted that either the plus symbols or the commas can be used for the representation of the membership functions in fuzzy subset.

Other parts of membership functions for the weight of load are derived as follows:

Very Light =

$$\left[\frac{1.0}{1}, \frac{1.0}{3}, \frac{0.7}{5}, \frac{0.1}{15}, \frac{0}{20}, \frac{0}{30}, \frac{0}{40}, \frac{0}{50}, \frac{0}{55}, \frac{0}{60}\right].$$

Light =

$$\left[\frac{1.0}{1}, \frac{1.0}{5}, \frac{0.7}{10}, \frac{0.4}{15}, \frac{0.25}{17.5}, \frac{0}{25}, \frac{0}{30}, \frac{0}{40}, \frac{0}{50}, \frac{0}{60}\right].$$

Medium =

$$\left[\frac{0}{1}, \frac{1.0}{5}, \frac{0.5}{10}, \frac{0.8}{125}, \frac{1.0}{17.5}, \frac{0.6}{25}, \frac{0.2}{27.5}, \frac{0.1}{30}, \frac{0}{33}, \frac{0}{60}\right],$$

and

Very Heavy =

$$\left[\frac{0}{1}, \frac{0}{10}, \frac{0}{20}, \frac{0.1}{30}, \frac{0.3}{35}, \frac{0.5}{38}, \frac{0.85}{42}, \frac{0.9}{44}, \frac{1.0}{45}, \frac{1.0}{60}\right].$$

The frequency of handling load, duration of handling load, moving distance of load are derived by a similar way as the weight of load and used in OSI.

3.3 Utilization of "Maximum Meaningfulness" Principle

The next step is to collect the value for the level of stress from each linguistic variable. When the term must designate a precise object of universe of discourse, the principle of "maximum meaningfulness"(Goguen, 1976) states that the "meaning" of the term is the object that has the maximum membership value in the fuzzy set named by the term. Since we define the universe of discourse over the normalized region, [0, 1], the level of stress could be the support set corresponding to the highest grade of membership function. For example, if we select the linguistic value "heavy" for the weight of load, the level of stress for this variable will be 0.6.

A certain weight cannot be assigned with absolute certainty to one class or another. More frequently, one weight belongs to several or even all five classes with different membership values. Previous studies indicate that human decision making obeys different rules(Goguen, 1976; Wang, 1983; Sen, 1984). One of them is the so called "maximum membership principle". For example, the weight of 7.0 kg can be expressed as MF1 = "very light" = 0.151, MF2 = "light" = 0.945, MF3 = "medium" = 0.641, MF4 = "heavy" = 0.333, and MF5 = "very heavy" = 0.145.
It can be rewritten as a vector according to Zadeh(1975):

$$\begin{aligned} V(7.0) &= (0.151, 0.945, 0.641, 0.333, 0.145) \\ &= 0.151/MF1 + 0.945/MF2 + 0.641/MF3 \\ &\quad + 0.333/MF4 + 0.145/MF5. \end{aligned}$$

The element of a vector, to which the maximum membership value relates, is called a "fuzzy number"(Wang, 1983). The fuzzy number of V(7.0) is then MF2,

$$FN(V(7.0)) = MF2 = \text{"light"}.$$

The "maximum membership principle" means that the decision which a human makes refers to the fuzzy number. According to that, the weight of 7.0 kg will be decided to be "light"(MF2). That means that the weight 7.0 kg belongs to "light" with the greatest grade of membership value. That does not mean that it absolutely does not belong to the other classes. In contrast, it also belongs to, e.g., "moderate," but with a smaller grade(0.641).

In contrast, one certain subjective heaviness class or set, e.g., "moderate," has no absolute or certain boundary. If 11.0 kg feels "moderate" when lifted, then 10.0 kg cannot feel "very light". That means that the change from membership to non-membership develops with physical weight gradiently, not abruptly. Note that the fuzzy sets defined here are all convex fuzzy sets. The convex fuzzy set is defined as when the support set is a real number set and the following applies for all x ∈[a,b] over any interval [a,b],

$$u_A(x) \geq u_A(a) \wedge u_A(b),$$

A is said to be convex(Terano et al., 1992).

By applying all the concepts discussed, the fuzzy set S_1, stress induced by physical job demand, can be expressed as

$$S_1 = \left[\frac{\max\ u'_{A_1}(X_j)}{X_j}, \frac{\max\ u'_{A_2}(X_j)}{X_j}, \frac{\max\ u'_{A_3}(X_j)}{X_j}, \frac{\max\ u'_{A_4}(X_j)}{X_j} \right],$$

where

$\frac{\max\ u'_{A_k}(X_j)}{X_j}$ is the collection of normal fuzzy sets for k = 1, 2, 3, and 4.

A fuzzy set with a membership function that has a grade of 1 is called "normal". In other words, A is called "normal" when

$$\max_{x \in X} u_A(x) = 1.$$

The grade in a fuzzy set can be anything from 0 to 1, and this range is different from the crisp set that has only two grades(0 and 1). In crisp set, the grade is binary, either 1 or 0. If x is included in Y_1 then the membership function will be 1, and 0 for otherwise. By using this concept, the environmental stressors such as improper temperature, lighting, noise, vibration, and exposure to chemicals can be assessed. If the subject feels that the working climate is "uncomfortable," then the membership function with their corresponding support set will be 1; in contrast, the function will be 0 if the answer is "comfortable".

The same method could be applied to the postural workload stresses which originated from various object and workplace constraints. It can be assessed by directly asking the subject, "Do you feel any postural discomfort from frequent or long standing ?" If the answer is "Yes" then the membership function with their corresponding support set will be 1 and 0 if the answer is "No." Other factors that affect the postural stress could be stooping, squatting, and twisting.

Along with the above variables, OSI also includes the Mental Job Demand. The objective is to find how much mental and perceptual activity is required in performing a job(e.g., calculating, thinking, deciding, communicating, remembering, looking, and searching). Kalsbeek(1968) originally defined mental workload as the amount of central information handling per time unit. However, Wierwille(1979) suggest that operational definitions of mental workload should replace a single definition, in order to accommodate the diversity of approaches to this subject.

Wierwille and Casali(1983) presented a modified Cooper-Harper rating scale that can be used for perceptual, cognitive, and communication tasks. A rating scale with a uni-dimensional 10-point rating scale was used in their study. On the basis of their scale, the membership function for each linguistic variable is derived.

3.4 The Analytic Hierarchy Process(AHP) Weighting Technique

In the OSI model, the AHP theory was adopted to collect the different weighting factors, since there exist different individual perceptions and responses to stressors. The weighting factors are derived by making pairwise comparisons of objects with respect to a common goal or criteria(e.g., intensity of stress). These weighting factors serve as coefficients in the equation.

The first major task in the AHP is the decomposition of the problem into a hierarchy of perspectives, criteria, or alternatives. Thus, the stressors with contributing factors are decomposed and shown in Figure 1. The focus of the pairwise comparison is the intensity of perceived stress from different stressors.

The second task involves the estimation of the weights of a set of objects(criteria or alternatives) from a matrix of pairwise comparisons S $=(S_{ij})$ which is positive and reciprocal. Thus, the matrix S is given by

$$S=\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix},$$

where

$$S_{ij}=\frac{1}{S_{ji}}, \quad \text{for all } i, j = 1, 2, 3, \text{ and } 4.$$

The matrix for the contributing factors of each stressor, S_1, S_2 and S_3, will be formed in a similar method.

The number of pairwise comparisons that are required to be made by an individual when comparing N alternatives is

$$\frac{N(N-1)}{2}.$$

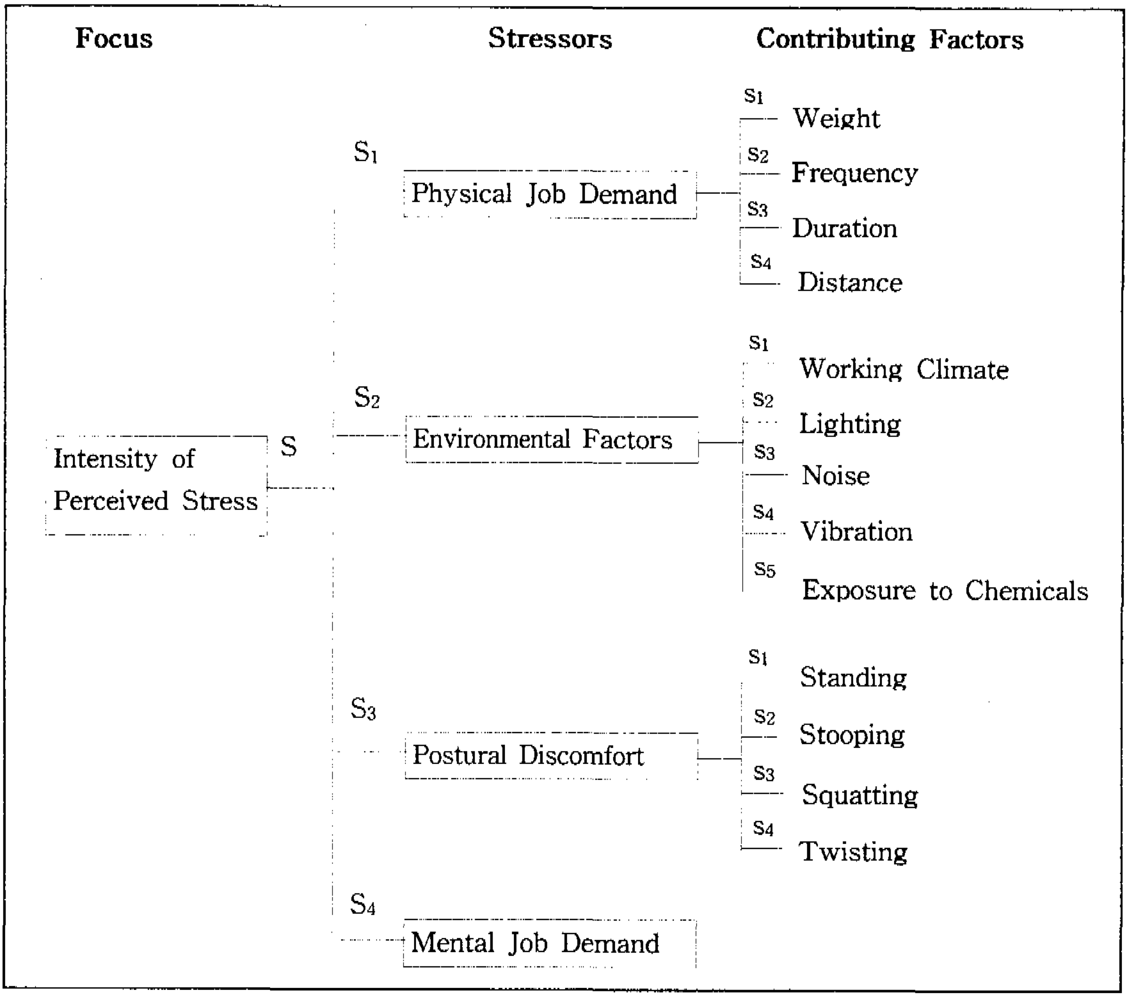

Figure 1. Decomposition of Stressors with Respect to a Intensity of Perceived Stress

Generally, the 1 to 9 scale may be able to capture a great deal of information and has proven to be extremely useful due to the fact that the AHP is somewhat scale independent. In order to illustrate that the 1 to 9 scale of measurement does capture perception, Saaty (1980) showed after various experiments in practice that the 1 to 9 scale can accurately portray an individual's intensity of preference. The recommended 1 to 9 scale is shown in Table 1.

The third step is to compute a vector of weights or priorities, $W = (W_1, W_2, \ldots, W_n)$ and $W_i = (w_1, w_2, \ldots, w_n)$, for both stressors and their contributing factors, respectively. Note that by using ratio scales, the estimated weights are only up to the multiplication by a positive constant. Thus, the weights, W_i and w_i, need to be normalized so that it conveniently sums to 1.

Theorem 1.

Let S be a positive reciprocal matrix. If S is consistent, then the principal eigenvector of S is given by any of its columns(Saaty, 1980).

If the judgements were perfectly consistent, then the entries of the matrix S would contain no inconsistent judgements and could be expressed as

$$S_{ij} = \frac{W_i}{W_j}, \quad \text{for all } i, j = 1, 2, \ldots, n.$$

In this case, simply normalize any column j of S to come up with the final weights shown as

$$W_i = \frac{S_{ij}}{\sum_{k=1}^{n} S_{kj}}, \quad \text{for all } i, j = 1, 2, \ldots, n.$$

However, if there exists an error in judgement, then the final result using the column normalization would depend on which column is chosen. Several alternative methods for synthesizing the information contained in matrix S have been suggested and developed.

Table 1. Intensity Scale of Workload Stress Measurement for AHP

Numerical Values	Definition
1	Equal Intensity
3	Moderate Intensity
5	Strong Intensity
7	Very Strong Intensity
9	Extreme Intensity
2, 4, 6, 8	Intermediate Intensities
Reciprocals	Dominance of the second alternatives as compared with the first

In addition to Saaty's method(1980), there is the method of least squares(Jensen, 1983) which finds the vector of weights w =(w_1, w_2, ..., w_n)^T by minimizing the Euclidian matrix,

$$\sum_{i,j=1}^{n}\left(S_{ij}-\frac{w_i}{w_j}\right)^2,$$

and the method of logarithmic least squares (Fitchner, 1983) which minimizes the following objective,

$$\sum_{i,j=1}^{n}\left(\log S_{ij}-\log\frac{w_i}{w_j}\right)^2.$$

Saaty's method(1980) computes w as the principal right eigenvector of the matrix S: $Sw=\lambda_{\max}w$, where $\lambda_{\max}$ is the maximum eigenvalue of the matrix,

$$w_i=\frac{\sum_{j=1}^{n}S_{ij}w_j}{\lambda_{\max}},\quad \text{for all } i = 1, 2, \ldots, n.$$

The methods given above are for estimating the weights when errors in judgement exist. All of them have their own advantages. However, the eigenvector method has the interpretation of being a simple process by which the final weights, w, are taken to be the average of all possible ways of comparing the alternatives when S is an inconsistent matrix; that is, when S does not satisfy the relation,

$$S_{ik}S_{kj}=S_{ij}, \quad \text{for all } i, j, k = 1, 2, \ldots, n.$$

Thus, the eigenvector is a "natural" method for computing the weights. Furthermore, some theoretical evidence found by Saaty and Vargas(1984) suggests that this method is the best at uncovering the true rank-order of a set of alternatives.

Theorem 2.

Let A be a positive reciprocal matrix. If A is inconsistent, the principal eigenvector is given by the limit of the normalized intensities of paths of length k,

$$w_i=\lim_{k\to\infty}\frac{S_{ih}^{(k)}}{\sum_{j=1}^{n}S_{ij}^{(k)}},$$

for all i, h = 1, 2, ..., n(Saaty, 1980).

The computation of the principal right eigenvector is accomplished by raising the matrix S to increasing powers k and then normalizing the resulting system. The same procedure needs to be repeated for the contributing factors of each stressor S_1, S_2, and S_3 to get the priority.

After estimating the weight, the inconsistency of the given pairwise comparisons must be measured. The Consistency Ratio(C.R.) provides a way of measuring how many errors occurred when providing the judgements. A rule-of-thumb is that if the C.R. is below 0.1, then the errors are fairly small and thus, the final estimate can be accepted. As shown by Saaty(1980),

Table 2. Random Index(R.I.)

N	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$\lambda_{\max}$ is always greater than or equal to n for positive, reciprocal matrices, and is equal to n if and only if S is a consistent matrix. $\lambda_{\max}$ can be calculated by finding the eigenvalue. The eigenvalue can be found by solving $Sw = \lambda_{Iw}$. To have a non-trivial solution, $S - \lambda I$ must be singular so that the determinant of $(S - \lambda I)$ can be solved. $\lambda_{\max}$ can be chosen from the equation.

Saaty defined the Consistency Index(C.I.) as

$$\text{C.I.} = \frac{\lambda_{\max} - \text{n}}{\text{n} - 1}\ .$$

For each size of matrix n, random matrices were generated and their mean C.I. value, or the Random Index(R.I.), was computed and these values are shown in Table 2.

Using these values, the Consistency Ratio(C.R.) is defined as the ratio of the C.I. to the R.I. Thus, C.R. is a measure of how a given matrix compares to a purely random matrix in terms of their C.I.'s. Therefore, C.R. is defined by

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}}\ .$$

3.5 Calculation of Overall OSI

To get each occupational stressor level, respective weighting factors for each contributing factors are multiplied by their corresponding workload stress levels and summed. Thus the equation becomes

$$\widehat{S}_i = \sum_{i=1}^{3} \sum_{j=1}^{n} W_{ij} \cdot \widetilde{X}_{ij}\ , \quad \text{for } \widetilde{X}_{ij} > 0,$$

where

$\widehat{S}_i$ indicates the stress level of total contributing factors for each stressor(S_1, S_2, S_3),

w_{ij} indicates respective priority weighting factors associated with n contributing factors, and

$\widetilde{X}_{ij}$ denotes the element of the support set corresponding to the $u(x_{ij})=1$.

The pairwise comparison needs to be performed again for the physical job demand(S_1), body motion and posture(S_2), environmental condition(S_3), and mental job demand(S_4) to get the overall workload stress level for the specific job. The results will show the relative importance of these variables regarding the impact on stress. The overall workload stress level will then be calculated by using an equation which can be expressed as

$$OSI = \sum_{i=1}^{3} W_i \cdot \widehat{S}_i + W_4 \cdot \widehat{S}_4\ ,$$

where

W_i denotes weighting factors for physical, environmental, and postural stressor,

$\widehat{S}_i$ indicates the workload stress level of total contributing factors for S_1, S_2, and S_3,

W_4 denotes weighting factors for mental job demand stressor, and

$\widehat{S}_4$ indicates the support set of the normal fuzzy set in S_4.

4. Results and Conclusions

The interpretation of the "meaning" of the occupational stress index is an essential procedure in determining usefulness to the end users. This interpretation of the "meaning" of occupational stress level or effect of different forms of stress is thus accomplished by validation process to provide meaningful scales or indices with supporting explanation of workload or stress.

To do this, many subjects(N=167) from different areas of the operation environment were participated. The OSI was implemented in three actual industrial environments using several different jobs and workplaces to determine how well the model predicts the existence and the intensity of stress.

In validation methodology, two objective measures were used: epidemiological measurements and physiological measurements. Epidemiology as a science is concerned with identification of the incidence, distribution, and potential controls for illness and injuries in a population. The severity of injury and illness record(i.e., Occupational Safety and Health Administration(OSHA) Log No. 101 and 200) was reviewed as an epidemiological measurement in terms of total number of cases and lost workdays to find the relationship with the value of OSI. For the physiological measurements, Heart Rate(HR) and Blood Pressure(BP) were measured to estimate the relationship with the value of OSI.

A statistical analysis was administered to find the relationship between OSI and the accident and illness rate. The analysis between OSI and HR and between OSI and BP was also performed. A regression analysis was conducted between the value of OSI and the value of HR as an indication of workload.

HR is used to classify the meaning of occupational stress because the HR measure has undoubtedly been proven to be the most versatile measure of occupational stress (Grandjean, 1985).

It is assumed from the reaction measured at various work loads by Grandjean(1985) that the baseline HR is 60 pulses/min. This HR, 60 pulses/min, is also classified as "resting" or "very low." The work pulse is then set by subtracting the baseline HR from the classified HR as an indication of work load.

A regression analysis was conducted between the value of OSI and the value of work pulse as an indication of workload. From the regression analysis between the value of OSI as dependent variable and work pulse as independent variable, the linear regression equation forms as

$$\text{Unnormalized OSI} = 0.4427 + 0.0118 \times \text{Work Pulse}.$$

Using this regression equation, the unnormalized OSI was calculated corresponding to the work pulse and normalized based on the highest OSI, 1.80. The classification of OSI is set and presented in Table 2.

High workload, in this model, can certainly be considered to result in a stress state, and give rise to either strain(from the high levels of effort required to maintain task goals under increasingly difficult task conditions) or to accident and illness rate. If the recorded rating is above the safety threshold, (i.e., a rating value of 0.67), investigation or attention is necessary. Conversely, it can be argued that a low workload is not stressful(at least in the sense meant here, in which stress only occurs in response to perceived demands). Rather, low workload is associated with a passive or constrained response to the environment, involving boredom, lack of challenge, and low job satisfaction.

In summary, the findings of the present study show a direct main effect of the value of OSI on accident and illness involvement. Accident incidence was found to be associated with OSI. These results reveal that there exist close relationship between OSI and epidemiological measurements. The high occupational stress to which workers in those categories are subjected is manifested in significant HR and BP increments over resting HR and BP. These findings suggest that the assigned OSI effectively reflects the ergonomic workload.

The OSI examined here appeared to be a reliable predictor of work-related accident and illness and the physiological health of employees, and the OSI should be developed for systematic use in various industries.

At present, it is believed that the proposed model can be used to more effectively determine the existence and level of stress.

Table 2. Classification of Work Pulse and OSI as an Indication of Workload

Assessment of Workload	Heart Rate (Pulses/min)	Work Pulse (WP)	Unnormalized OSI	OSI
Very Low (resting)	60 - 70	0 - 10	0.00 - 0.56	0.00 - 0.31
Low	70 - 100	10 - 40	0.56 - 0.91	0.31 - 0.51
Moderate	100 - 125	40 - 65	0.91 - 1.21	0.51 - 0.67
High	125 - 150	65 - 90	1.20 - 1.50	0.67 - 0.83
Very High	150 - 175	90 -115	1.50 - 1.80	0.83 - 1.00
Extremely High	175<	115<	-	-

This information can then be used as an aid for routine job analysis and problem identification and treatment where any form of occupational stress exists in the workforces.

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