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The Development of Fuzzy-based Expert System for Analyzing Occupational Stress

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Abstract

This paper illustrates the process of developing and configuring the prototype computer-assisted analysis system named as Work-Expert for analyzing occupational stress. A Work-Expert was developed to allow the nonexperts or line manager to utilize the existing knowledge in the area of occupational stress estimation, and to provide intelligent and computer-aided problem solving. The purpose of the system development is for future prediction and problem solving. Creating preventive measures, such as early detection of stress, proper placement and promotion of employees, job enlargement, employee identification, employee involvement, communication, and training of managers will be possible by using this system effectively.

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1. Introduction

Over the past decade, increasing attention has been paid to the problems of occupational stress since the costs of this occupational stress to individuals and to organizations are innumerable. It is estimated that productivity losses resulting from stress-related physical illness ranged as high as $60 billion per year during the 1970s in the U. S. [16]. Current estimation for this is not available, however, it is assumable that this figure has increased dramatically.

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 the most important concern to ergonomists or to managers.

Thus, the goal of the ergonomist or human engineer is to determine 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 not be safe. If stress is too intense or prolonged, then it may cause anxiety, discomfort, disturbed body function, and finally, actual disease or damage. Excessive or prolonged stress at the workplace causes higher error, higher accident rate, increased sick time, faulty judgement, and poor productivity.

In man-machine systems, various forms of physical and mental stressors cause responses of the human body. These responses could be physiological (e.g., elevated heart rate, blood pressure), performance related (e.g., reduced productivity, increased error rate), or behavioral (e.g., less motivation, lack of attention). Several studies have been conducted in the past to investigate the effects of occupational stress to a human operator in man-machine systems [6, 12, 13].

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 occupational stress through detailed analytical techniques. The major disadvantage of a direct measurement technique is that bulky equipment often must be attached to the subject to get the measurements.

In addition, a critical deficiency in the application of ergonomics to the investigation and design of the workplace is the absence of a computer-assisted system for task and workplace analysis. Therefore, industry fails to derive maximum benefits from ergonomics research. The application of computer-assisted systems in ergonomics is one feasible solution to overcome this obstacle [3]. Such a system should guide an industrial engineer or health and safety practitioner in the analysis and design of tasks through a hierarchy of observational, measurement, analytical, simulation and reference techniques.

Recently, expert systems have been developed to take advantage of advances in artificial intelligence that allow the construction of a knowledge-based program that will provide expert advice to the user and will get feedback from the user [11]. An expert system uses knowledge and inference procedures to solve problems. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. For example, an expert system can provide us with expertise that otherwise might require years of education and experience to acquire. Thus, an expert system can be effectively used as a tool in implementing the various information published in the literature, which will enhance and speed up the managerial implementation of research results provided in the literature.

For these reasons, a prototype computer-assisted analysis system named as Work-Expert for analyzing occupational stress was developed to allow the nonexperts or line manager to utilize the existing knowledge in the area of occupational stress estimation, and to provide intelligent and computer-aided problem solving. This system was designed for commonly available microcomputers and makes use of existing analytical systems and software where appropriate.

The direction and scope of this study is to develop a unique and integrated mathematical model - OSI(Occupational Stress Index) - for determining the existence and level of occupational stress, then apply this model in developing the Work-Expert to identify and solve potential ergonomic hazards by providing alternative solutions to the tasks or workplaces, if necessary.

2. Introducing Fuzziness in Modeling OSI

The specification of a fuzzy system consists of a linguistic description of its behavior and/or assignment of fuzzy parameters to an ordinary mathematical model. Fuzzy set theory deals with the uncertainty in expressions like "hot temperature," "tall person," "heavy object," or "old person." Thus, fuzzy set theory provides the right tool for the manipulation of vague information and evaluation of uncertainty due to fuzziness, rather than randomness alone [17]. Since occupational stress is directly related to human perception and fuzzy set theory deals with human perception, the use of fuzzy set theory is appropriate for the mathematical bases of OSI.

The proposed procedure for modeling 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" [5, 15] 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.

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.

For instance, 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 [1, 2, 4, 9, 14]. 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 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 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:

$$s_1 = (x_1, x_2, \ldots, x_n).$$

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

$$A = \sum_{i=1}^{n} \frac{u_{A(x_i)}}{x_i} = \left[\frac{0}{1}, \frac{0}{15}, \frac{0.1}{20}, \frac{0.5}{25}, \frac{0.9}{30}, \frac{1.0}{32}, \frac{0.95}{34}, \frac{0.7}{40}, \frac{0.1}{50}, \frac{0}{60} \right]$$

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 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. The equation given above can be used to express the degree of membership functions of stress from each stressor.

Figure 1 shows a graphical representation of five fuzzy sets for subjective heaviness. The horizontal axis is the quantification of the word, "very light," "light," "medium," "heavy," and "very heavy," and the vertical axis is the quantification of the degree of ambiguity, which is called the "membership function;" that is, we make the weight of load correspond to degree $u(0 \leq u \leq 1)$.

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

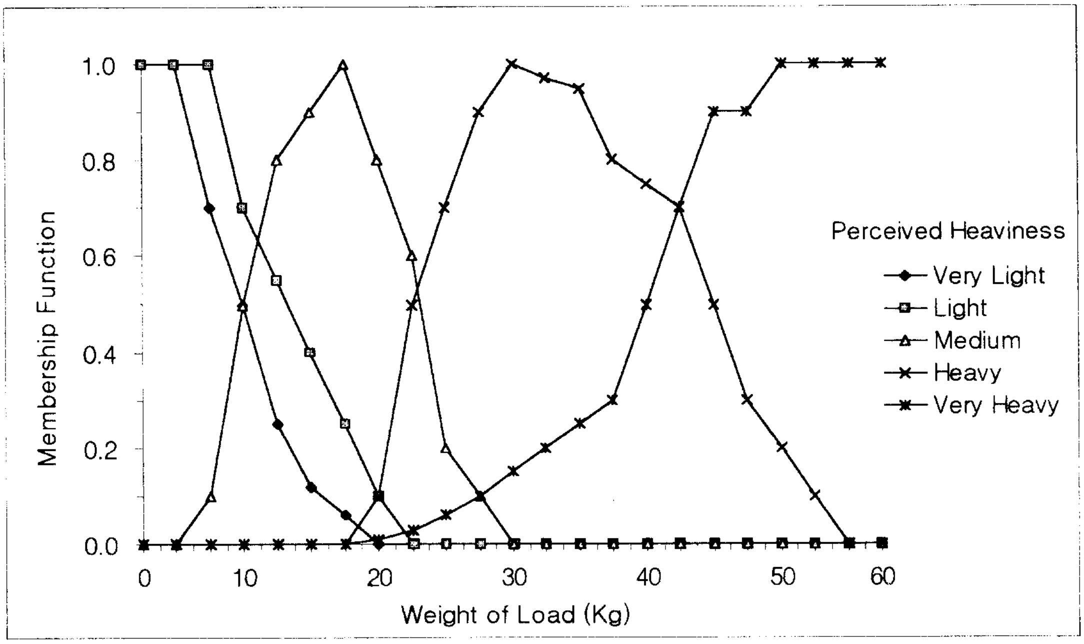

Figure 1. The Grade of Membership Function for the Weight of Load

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 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" [5] states that the "meaning" of the term is the object that has the maximum membership value in the fuzzy set named by the term. If 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.

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. For example, the Membership Function (MF) for 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 [17]:

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

The element of a vector, to which the maximum membership value relates, is called a "fuzzy number" [15]. The fuzzy number of V(7.0) is then MF2, FN(V(7.0)) = MF2 = "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). It means that the weight 7.0 kg belongs to "light" with the greatest grade of membership value. It does not mean that it absolutely does not belong to the other classes. In contrast, it also belongs to, e.g., "medium," but with a smaller grade (0.641).

The Analytic Hierarchy Process (AHP) is adopted to collect the different weighting factors since there exist various perceptions and responses to a stress by different individuals. 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 judgments 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, then multiplied by the "fuzzy number" to produce 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

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

where

$\hat{S}_i$ 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

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

where

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

$\hat{S}_i$ 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

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

The interpretation of the "meaning" of occupational stress level or effect of different forms of stress is 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 are participated. A regression analysis is conducted between the value of OSI and the value of work pulse (the difference between baseline heart rate before the task and heart rate during the task) as an indication of workload. The classification of OSI is set and presented in Table 1.

Table 1. The Classification of Work Pulse and OSI as an Indication of Workload

Assessment of Workload	Work Pulse (Pulses/min)	OSI
Very Low (resting)	0 - 10	0.00 - 0.31
Low	10 - 40	0.31 - 0.51
Moderate	40 - 65	0.51 - 0.67
High	65 - 90	0.67 - 0.83
Very High	90 - 115	0.83 - 1.00
Extremely High	115 <	-

3. The Development of Work-Expert System

In recent years, there has been substantial interest in the application of computer-assisted systems (e.g. expert systems, decision support systems) to support problem solving and decision-making activities. The application of computer-assisted systems in the ergonomics / human factors area is to deliver the widespread application of ergonomics knowledge to the working population [3].

The programming languages used for computer-assisted system applications are generally either problem-oriented languages, such as FORTRAN, BASIC, and PASCAL, or symbol-manipulation languages, such as LISP and PROLOG. Whatever system or language is used, the computerized problem solving technique is needed to improve problem solving efficiency particularly for inexperienced diagnosticians.

There are some examples of successful application areas in the field of workload assessment. For example, Chen et al. [3] have developed a prototype expert system for physical work stress analysis. This prototype expert system was built by applying models and guidelines from experts to build a knowledge based system to diagnose and solve physical work stress problems.

Several other knowledge-based systems have been developed in the analysis and design of manual materials handling tasks. Karwowski et al. [10] developed an experimental expert system entitled LIFTAN to analyze manual lifting tasks.

Kabuka et al. [8] developed an expert system for the design of new and existing Repetitive Manual Materials Handling (RMMH) tasks. Laurig et al. [11] developed an expert system entitled ERGON-EXPERT to detect and minimize health risks in manual materials handling tasks.

Before the actual development and configuration of the Work-Expert, considerations toward the design and development of the Work-Expert are as follows: to develop an information management module which will save, store, and retrieve pertinent information, whenever required, with acceptable speed and accuracy; to develop and implement a computer system to help ergonomists or safety professionals analyze occupational stress for selected workplaces; to provide a tool for ergonomists or safety professionals which will help them manage occupational stress. Such a tool would be provided in the form of an expert system, which could be updated and maintained with ease by the knowledge engineer; to incorporate a goal-driven inference structure in the above mentioned expert system; and to develop a friendly user interface which will facilitate use.

To achieve the design considerations and the other objectives of this study, two different development environments along with the operating system environment were selected to create the Work-Expert. They are as follows:

a. FoxPro Version 2.5 Environment - used for management of pertinent workers' demographic information, calculation of the value of OSI, and user interface.

b. EXSYS Professional Version 2.0.9 Environment - used for the development of the expert system for occupational stress analysis.

c. Operating System (MS-DOS) Environment - used as a communication and data transfer medium between FoxPro and EXSYS Professional environments.

3.1 Development of Database

In the development of a database management module, a thorough understanding and knowledge of the data which needs to be analyzed is required from the beginning. The database structure was thus designed and configured with considerations of all the necessary data and calculation procedures for performing OSI analysis.

This database portion of the Work-Expert has the capacity of storing and retrieving data. It also serves as a "consulting" mode and algorithm base.

The demographic information database contains general worker information such as name, age, gender, job title, date of analysis, and the value of calculated OSI. The OSI variable information database stores all the necessary data such as the value of each stressor variable (e.g., the linguistic value for weight of load, the linguistic value for frequency of handling load) and the values of pairwise comparison (i.e., numerical values for each stressor and its contributing factors) for calculating the composite value of the OSI. These two relational databases help perform the occupational stress analysis in the Work-Expert.

3.2 Development of Knowledge Base

3.2.1 Knowledge Acquisition Method

Normally, there are three ways to acquire expert knowledge [7]. The first is to acquire knowledge from domain experts who develop their decision making strategies from long periods of experience in dealing with problems of their specific domain. The second method is to deduce knowledge from historical records of successful decision making. These two methods can be defined as "shallow knowledge." The third method is to utilize knowledge which is obtained from books, manuals, and service guides. This method can be defined as "deep knowledge."

A great deal of formal academic research has been conducted to develop heuristic procedures that are superior to human experts and historical records. Therefore, the knowledge base of the expert system developed in this study used the third method which is based on information available in the literature and in technical textbooks.

3.2.2 Inference Engine Development

The reasoning or inference mechanism contains the control or meta-knowledge that plans the strategy needed to reach a conclusion. An inference mechanism which collects facts directly or through questioning the user and then applies rules in succession until a conclusion is reached is said to be of forward chaining or data-driven control type. This type of inference mechanism is used in the Work-Expert. By contrast, backward chaining or goal-directed control starts with a hypothesis and proceeds to prove or disprove each hypothesis until a conclusion is found.

Since the expert system part of the Work-Expert deals with a typical "construction" problem [7], the inference engine is designed to implement forward chaining strategy. If more than one rule is triggered, the inference engine always fires the rule whose premise clause matches the most recently added working memory element. In addition, the inference engine is designed such that the user has the option of tracing the rule firing sequence and working memory changes. In this process, the names of the fired rules and the names of variables which are moved in and out of working memory will appear on the computer monitor screen. This is very helpful for understanding the inference process and debugging the system.

The inference engine contains two major sections. The first section initializes working memory for starting the first firing. The second section executes the recognize-act-cycle for continuous inference. The recognize-act-cycle is a rule firing procedure, in which "recognize" means that any rule with all its premise clauses matching with the current working memory element is identified, and "act" means to fire the "recognized" rule.

3.2.3 Rule Base Development

To develop an efficient, transparent, and proper rule base, several important techniques were applied in this rule module. These techniques are: (1) utilization of rule grouping and partition variables; (2) utilization of the fault-tree method; and (3) consistency and completeness check of the rule base.

The rule-based part of the CAS-COWORK consists of a total of 85 production rules. The rule base is represented by a separated rule module. This module consists of 37 rules related to occupational stress analysis with priority weighting for each variable and 48 rules used to produce explanations of the reasoning process as well as messages regarding the potential for job redesign. This rule base is constructed to deal with both numeric and symbolic variables.

Based on the major functions of these rules, the analysis of occupational stress is divided into three parts as follows :

(1) Analysis of operator's demographic factors-related occupational stress : The occupational stress refers to the specific worker.

The use of task variables in combination with worker characteristics allow for the systematic assessment of the comprehensive occupational stress. They are examined for their effects on the overall work-related risk. As an example, part of Rule 28 is given below :

Rule 28 - Operator's demographic factors-related occupational stress

IF AGE is > [50], and
GENDER is {FEMALE}.
THEN Based on this workers demographic factors, the {JOB REQUIREMENTS} should be kept in {MINIMUM}.

(2) Analysis of the priority level related (importance weighting between variables) occupational stress: The occupational stressors are prioritized in terms of their impact on each individual worker or intensity. The prioritized variables will be used to investigate the important variable which leads to increasing occupational stress. As an example, part of Rule 47 is given below:

Rule 47 - Priority level-related occupational stress

IF [WEIGHT] > [FREQUENCY], and
[WEIGHT] > [DURATION], and
[WEIGHT] > [DISTANCE].
THEN The {weight of handling load} is the most stressful factor in {physical job demand stressors} for this worker.

(3) Analysis of operator's perception-related (i.e., task-related) occupational stress: This mode assesses the potential risk of occupational stress by analyzing the index of occupational stress and its task-related variables. As an example, part of Rule 5 is given below:

Rule 5 - Operator's perception-related occupational stress

IF The weight of load is {Heavy}, and
The distance of handling load is {Far}, and
The duration of handling load is {Long}, and
The value of [OSI] is > [0.67].
THEN The occupational stress is high.
There exists risk of back injury.
Provide cart to reduce the physical workload on operator.
The working hours and pace should be reduced.

The production rules for the Work-Expert system are based on a checklist used to investigate potential problems from the worker's self-evaluation. These rules trace through various stressors, determine possible causes, and provide suggestions where appropriate. The general design guidelines related to the investigation item are provided concurrently to teach the user how to avoid unnecessary problems and improve performance. The design principles forming the basis for Rule 5 are as follows:

(1) shortening the distance to be reached at each side;
(2) lowering the working level;
(3) using mechanical aids to reduce the load on the hands; and
(4) reorganizing the work, with a rotation between different operations.

3.2.4 Consistency and Completeness Check of the Rule Base

During the rule base development, the rule base consistency and the rule completeness are checked simultaneously by means of the rule dependency matrix method [7]. Since the forward chaining inference strategy is used, the rule base consistency checking is only concerned with redundant rules, conflicting rules, subsumed rules and unnecessary premise clauses. The rule completeness check is concerned with the unreferenced attribute values (i.e., working memory element values) and illegal attribute values.

3.3 Work-Expert System Configuration

The final configuration of the Work Expert after going through the development stages is depicted in Figure 2. As mentioned earlier, the Work - Expert runs under two software environments : FoxPro 2.5 and EXSYS Professional 2.0.9. The expert system module is handled by the EXSYS Professional environment. EXSYS Professional shows the results and recommendations of the occupational stress using the data created by FoxPro 2.5. The FoxPro 2.5 environment handles the user interface and database management features.

The Operating System (MS-DOS) environment, is the control system of the Work-Expert program. This is an essential part of the Work-Expert, and it is especially important for the Work - Expert system. FoxPro 2.5 is opened and the data created by FoxPro 2.5 is stored and read by EXSYS Professional when necessary. The controlling batch file that executes the Work Expert is also resident in this environment.

3.4 User Interface

An important part of the Work-Expert is its user interface. For system execution, the user must follow through the sequence of data entries in the FoxPro 2.5 environment. The system will ask the user to enter his or her perception of various stressor variables and his or her demographic factors. The system processes these responses to calculate the overall occupational stress level for each of the designated jobs.

The system has 6 control menus to allow the user to enter and save new data to the database,

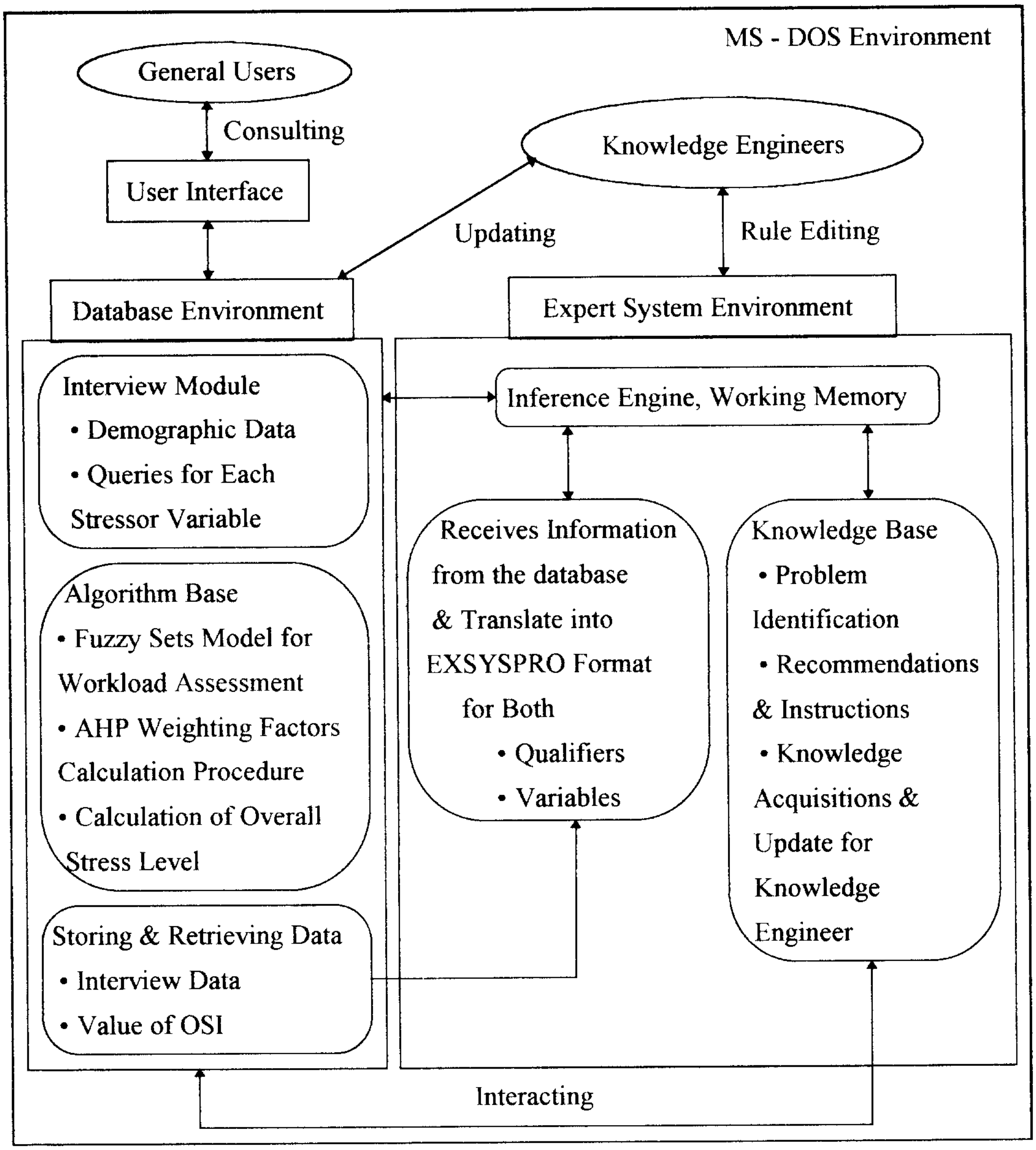

Figure 2. Work-Expert System Configuration

to review and perform OSI analysis with data retrieved from the database, edit the data stored in the database, delete the data stored in the database, print the original data and the results of OSI analysis, and quit.

4. Conclusions and Recommendations for Further Research

The purpose of the Work-Expert system development is to predict the potential occupational stress and recommend solutions more efficiently. Creating preventive measures will be possible by using this system effectively. Such measures include the early detection of stress, proper placement and promotion to ameliorate existing stress on employees, instituting job enlargement, increasing employee identification, increasing employee involvement, improving communication, and training management. The Work-Expert would be highly valuable in the following roles: as an aid to the industrial engineer; as a decision support tool for the non-expert user; and as a quick reference for identifying occupational stress and remedy.

After the practical applications are administered, the knowledge base of the Work-Expert system developed here needs to be modified, expanded, and validated whenever necessary so that more reliable problem identification and recommendations can be provided. At present, it is believed that the proposed system can be used to more effectively determine the existence and level of occupational stress. 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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