작업부하 관리를 위한 database와 전문가 시스템의 상호작용 시스템 개발

정화식* · 최진섭*

The Development of Database Interfaced Expert System for Controlling Occupational Workload

Hwa Shik Jung · Jin Seob Choi

〈Abstract〉

This paper illustrates the process of developing and configuring the prototype Computer Analysis System for Controlling Occupational WORKload (CAS-COWORK). The software interface between the database and expert system was attempted. The database is used for storing and retrieving series of data entered by general users and the expert system is used for identifying and solving occupational problem areas. Two theories were applied in developing the algorithm base of CAS-COWORK that were used to calculate overall workload stress level. The fuzzy set theory was introduced to capture the subject's workload stress perception. The Analytic Hierarchy Process (AHP) was introduced to estimate the importance of the task and workplace variables. The purpose of the system development is for future prediction and problem solving which would be highly valuable to the industrial engineer.

1. Introduction

A major obstacle to the widespread application of ergonomics knowledge to the working population is the inability to provide this knowledge to the ergonomics practitioner. 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 [1]. 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 [2]. 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

* 동신대학교 산업공학과

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 Analysis System for Controlling Occupational WORKload (CAS-COWORK) was developed to allow the nonexperts or line manager to utilize the existing knowledge in the area of workload 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 first step of this study is to develop a unique and integrated mathematical model - Ergonomic Workload Stress Index (EWSI) - for determining the existence and level of ccupational workload stress, then apply this model in developing the CAS-COWORK to identify and solve potential ergonomic hazards by providing alternative solutions to the tasks or workplaces, if necessary.

2. Conceptualization of Fuzziness in Modeling EWSI

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 [3]. Since workload 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 EWSI.

In modeling EWSI, 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 Manual Materials Handling (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 [4,5,6,7,8]. The example of linguistic values for these variables are determined as s_1 = weight of load: "very light," "light," "medium," "heavy," "very heavy," and other defined physical job demands are frequency of load, duration of load, and moving distance of load.

The membership function is used to give expression to a fuzzy set. Assumingthat 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:

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

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.

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" [9] 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 (1975):

$$V(7.0) = (0.151, 0.945, 0.641, 0.333, 0.145) = 0.151/MF1 + 0.945/MF2 + 0.641/MF3 + 0.333/MF4 + 0.145/MF5.$$

The element of a vector, to which the maximum membership value relates, is called a "fuzzy number" [10]. 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). 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., "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 througha 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 EWSI.

The interpretation of the "meaning" of workload 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

〈Table 1〉 The Classification of Work Pulse and EWSI as an Indication of Workload

Assessment of Workload	Work Pulse (Pulses/min)	EWSI
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 〈	-

participated. A regression analysis is conducted between the value of EWSI 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 EWSI is set and presented in ⟨Table 1⟩.

For more details regarding modeling EWSI, readers are advised to refer to Chen et al. [11].

3. CAS-COWORK System Development

Before the actual development and configuration of the CAS-COWORK, considerations toward the design and development of the CAS-COWORK 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 ergonomic workload stress for selected workplaces; to provide a tool for ergonomists or safety professionals which will help them manage workload 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 CAS-COWORK. They are as follows:

a. FoxPro Version 2.5 Environment - used for management of pertinent workers' demographic information, calculation of the value of EWSI, and user interface.
b. EXSYS Professional Version 2.0.9 Environment - used for the development of the expert system for occupational workload stress analysis.
c. Operating System (MS-DOS) Environment - used as a communication and data transfer medium between FoxPro and EXSYS Professional environments.

3.1 Database Development

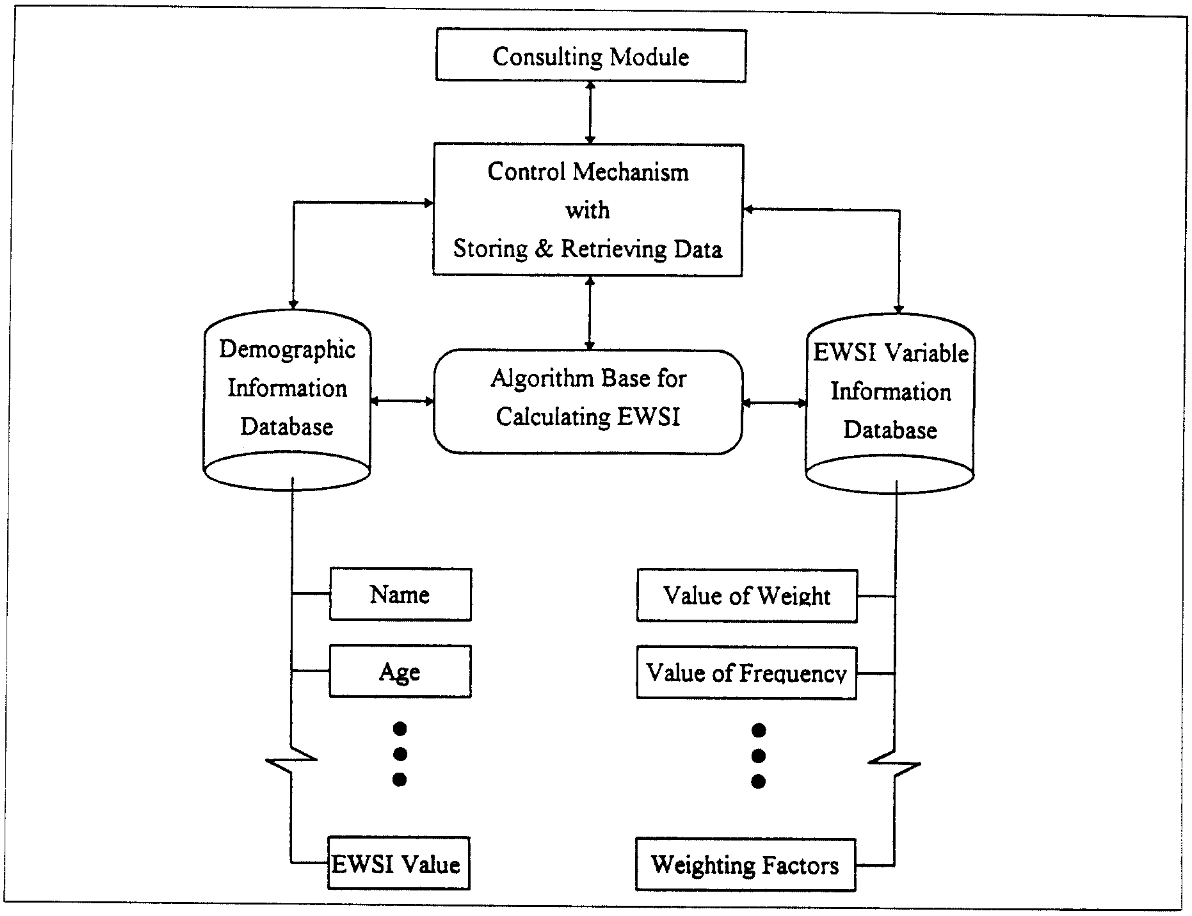
In the development of a database management module, a thorough understanding and knowledge of the data which needs to be analyzed is required from the beginning. The database structure shown in ⟨Figure 1⟩ was thus designed and configured with considerations of all the necessary data and calculation procedures for performing EWSI analysis.

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

It can be seen from ⟨Figure 1⟩ that the demographic information database contains general worker information such as name, age, gender, job title, date of analysis, and the value of calculated EWSI. The EWSI 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 EWSI. The ⟨Figure 2⟩ shows the consulting module which includes demographic and EWSI variable information database for the general users. These two relational databases help perform the ergonomic workload stress analysis in the CAS-COWORK.

3.2 Knowledge Base Development

The knowledge base of the expert system developed in this study is based on information available in the literature and in technical textbooks. The reasoning or inference mechanism contains the control or meta-

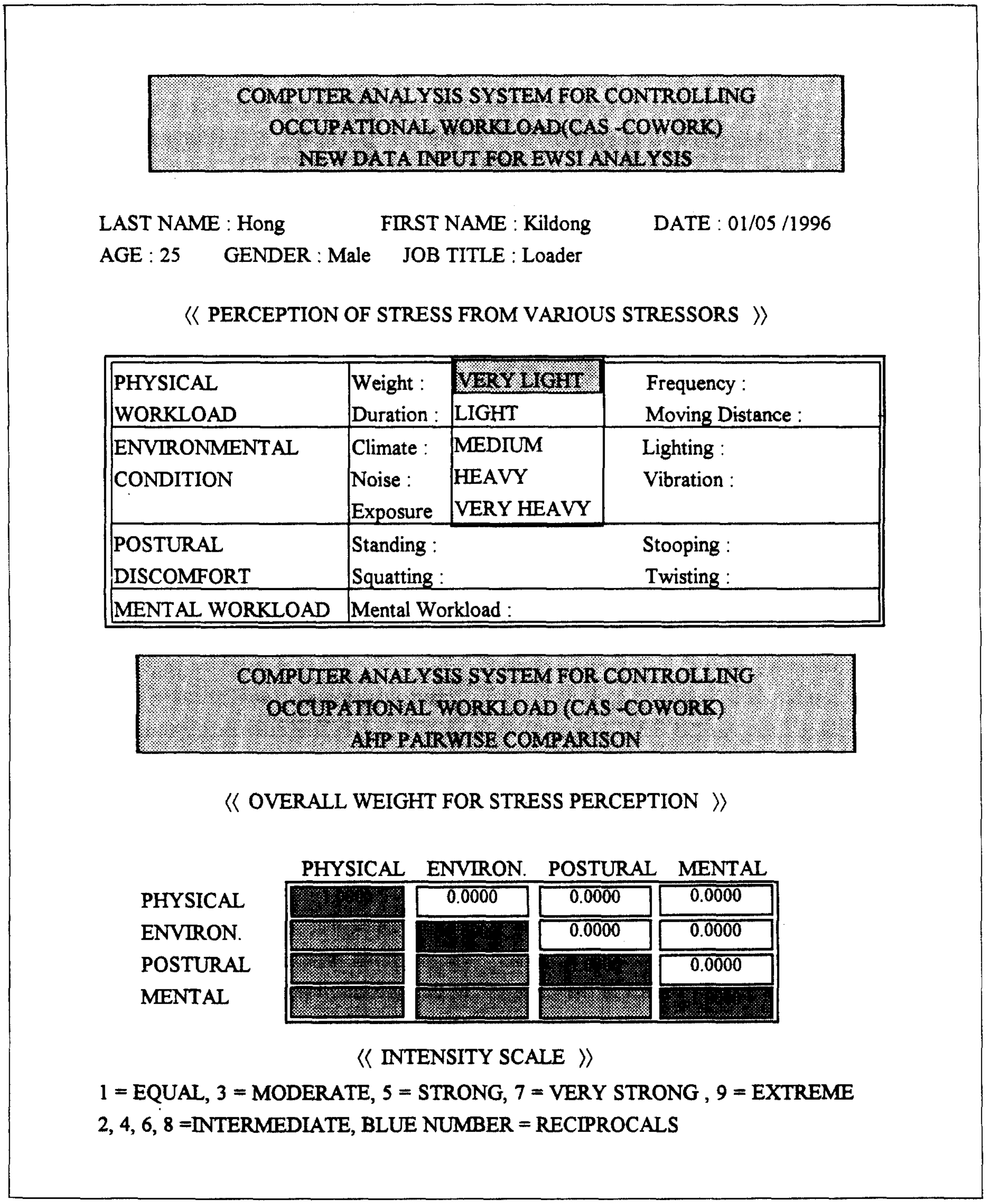


〈Figure 1〉 The Database Structure of the CAS-COWORK

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 CAS-COWORK. 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 CAS-COWORK deals with a typical "construction" problem [12], 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-



〈Figure 2〉 The Consulting Module of CAS-COWORK 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.

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 workload 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 workload stress is divided into three parts as follows:

(1) Analysis of operator's demographic factors-related workload stress: The workload stress refers to the specific worker. The use of task variables in combination with worker characteristics allow for the systematic assessment of the comprehensive ergonomic workload 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 workload stress

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

(2) Analysis of the priority level-related (importance weighting between variables) workload stress: The workload 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 workload stress. As an example, part of Rule 47 is given below : Rule 47-Priority level-related workload 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) workload stress: This mode assesses the potential risk of workload stress by analyzing the index of workload stress and its task-related variables. As an example, part of Rule 5 is given below: Rule 5-Operators perception-related workload stress

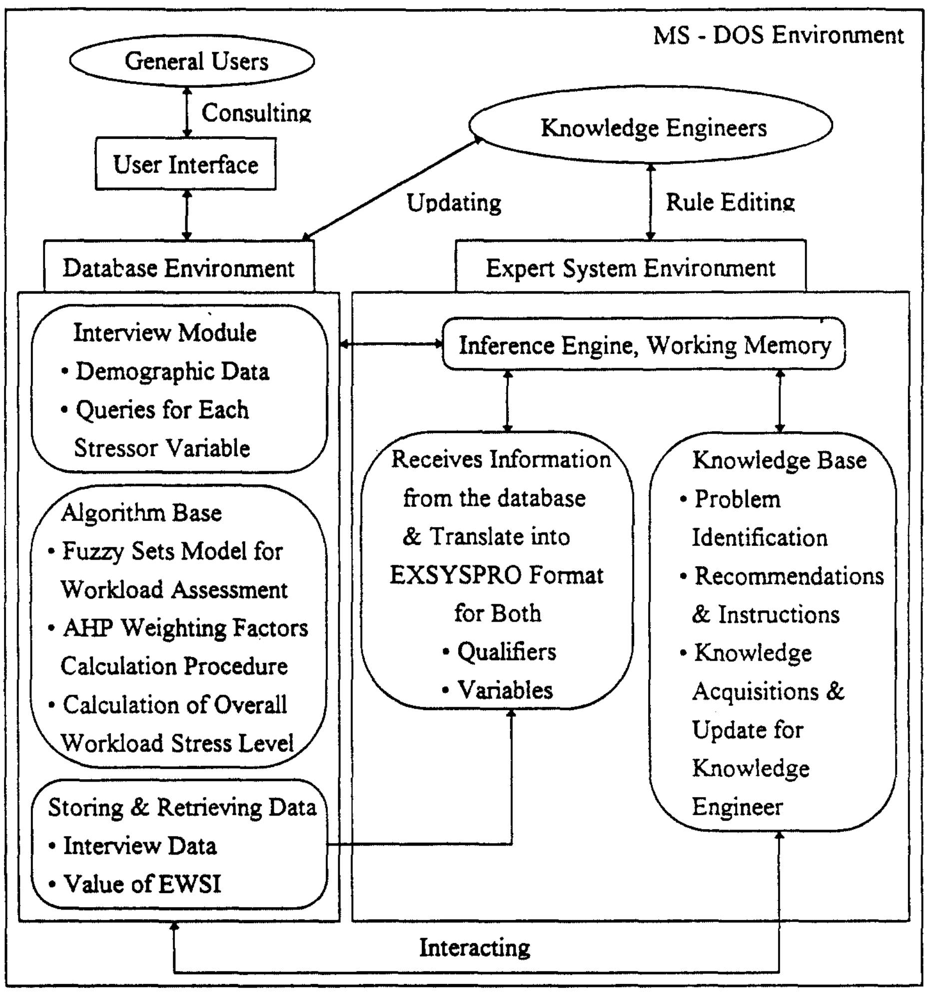
IF The weight of load is {Heavy}, and
The distance of handling load is {Far}, and
The duration of handling load is {Long}, and
The value of [EWSI] is 〉 [0.67].
THEN The workload stress is high.
There exists risk of back injury.
Provide cart to reduce the physical workload on operator.
The working hours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

The production rules for the CAS-COWORK 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.

During the rule base development, the rule base consistency and the rule completeness are checked simultaneously by means of the rule dependency matrix method [12]. 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.

The final configuration of the CAS-COWORK after going through the development stages is depicted in 〈Figure 3〉.



〈Figure 3〉 CAS-COWORK System Configuration

As mentioned earlier, the CAS-COWORK 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 workload stress using the data created by FoxPro 2.5. The FoxPro 2.5 environment handles the user interface and database management features.

THE RESULTS OF AHP WEIGHTINGS FOR EACH STRESSOR

PHYSICAL WORKLOAD WEIGHT	
WEIGHT OF LOAD	: 0.4286
FREQUENCY OF LOAD	: 0.3794
DURATION OF LOAD	: 0.1268
MOVING DISTANCE	: 0.0651
CONSISTENCY RATIO(C.R.)	: 0.0984

ENVIRONMENTAL COND. WEIGHT	
WORKING CLIMATE	: 0.3975
LIGHTIONG	: 0.2868
NOISE LEVEL	: 0.1546
VIB. : 0.1067 CHEMICAL	: 0.0544
CONSISTENCY RATIO(C.R.)	: 0.0822

POSTURAL DISCOMFORT WEIGHT	
STANDING	: 0.4422
STOOPING	: 0.3450
SQUATTING	: 0.1233
TWISTING	: 0.0895
CONSISTENCY RATIO(C.R.)	: 0.0767

OVERALL WEIGHT	
PHYSICAL WORKLOAD	: 0.5179
ENVIRON. CONDITION	: 0.2123
POSTURAL DISCOMFORT	: 0.1643
MENTAL WORKLOAD	: 0.1055
CONSISTENCY RATIO(C.R.)	: 0.2334

COMPUTER ANALYSIS SYSTEM FOR CONTROLLING OCCUPATIONAL WORKLOAD (CAS - COWORK) THE CALCULATED EWSI VALUE

THE VALUE OF EWSI FOR "HONG, KILDONG" = 0.66

〈Figure 4〉 The Results of AHP Weighting Ractors for Each Stressor and the Calculated Value of EWSI

The Operating System (MS-DOS) environment, is the control system of the CAS-COWORK program. This is an essential part of the CAS-COWORK, and it is especially important for the CAS-COWORK 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 CAS-COWORK is also resident in this environment.

The database environment stores the fuzzy membership functions and corresponding support sets for all stressor variables and contains an algorithm base to calculate the value of EWSI. For example, the frequency of load is expressed by the possibility distribution "very low," "low," "medium," "high," and "very high," and is stored with membership functions over the defined support sets.

3.3 System Requirements and User Interface

The CAS-COWORK requires at least 13 MB of hard disk space. Version 2.5 of FoxPro, developed by Fox Softwares, Inc. and the professional version of EXSYS Professional, developed by Exsys, Inc. are the necessary environments, which must be resident in the same drive. The overall hard disk requirement will be of the order of 20 MB. Any IBM PC, AT, XT or compatible with the above configuration will be sufficient.

An important part of the CAS-COWORK is its user interface, completely developed in FoxPro 2.5, which allows the user to communicate easily and effectively

RESULTS OF ANALYSIS AND RECOMMENDATIONS

1. The overall Ergonomic Workload Stress Index (EWSI) for this worker is 0.66 which is classified as "moderate" to "high" range.
2. The review of this job is recommended.
3. The physical job demand is the most stressful factor.
4. The potential high risk of back and musculoskeletal injury exists.
5. The long duration of handling load is very stressful factor.
6. The noise is the stressful factor.
7. The potential irritation on skin or respiratory system exists.
8. The stooping is the most stressful factor in postural discomfort.
9. The aid of mechanical device should be provided (e. g. , rollers, jacks, platforms). Other types of mechanical aids are conveyors, cranes and hoist, and industrial trucks.
10. The working pace should be reduced or more frequent rest pauses should be given.
11. The noisy environment should be controlled or isolated - personal sound protective equipment recommended.
12. The exposure to chemical can be protected with gloves, masks, safety glasses, etc.

〈Figure 5〉 The Results of Workload Stress Analysis and Recommendations with the system. Most of CAS-COWORK's interface is in the form of pull-down or pop-up menus.

The system has 6 control menus to allow the user to enter and save new data to the database, to review and perform EWSI 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 EWSI analysis, and quit.

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 demographic factors, his or her perception of various stressor variables, and the intensity scale of AHP pairwise comparison. The example of entering data in the CAS-COWORK environment is shown in 〈Figure 2〉. The system processes these responses to calculate the overall workload stress level for each of the designated jobs. 〈Figure 4〉 shows the results of AHP weighting factors for each stressor and the calculated value of EWSI. All these information are then transfered to the EXSYS Professional and read by EXSYS Professional. EXSYS Professional processes these information to display the results of workload stress analysis and recommendations as shown in 〈Figure 5〉.

4. Conclusions and Recommendations for Further Research

The purpose of the system development is to predict the potential workload 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.

After the practical applications are administered, the knowledge base of the CAS-COWORK 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 workload stress. This information can then be used as an aid for routine job analysis and problem identification and treatment where any form of workload stress exists in the workforces.

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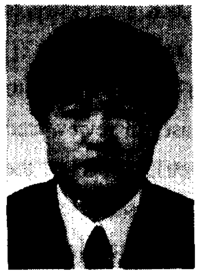

정화식(鄭和植)

1983년 단국대학교 건축공학과 학사

1987년 Murray State University, Industrial Engineering 석사

1993년 University of Houston, Industrial Engineering 박사

현 재 동신대학교 산업공학과 조교수

관심분야: Ergonomics, Expert Systems

최진섭(崔眞燮)

1986년 서울대학교 기계설계학과 학사

1988년 한국과학기술원 생산공학과 석사

1994년 전북대학교 정밀기계공학과 박사

1988년-1990년 금성사 생산기술연구소

현 재 동신대학교 산업공학과 전임강사

관심분야: CAD/CAM, Robotics

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