# A Study of the Determination of External Workload Imposed on a Human Operator in Man-machine Systems

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## Abstract

작업부하 산정 모델을 개발하기 위해 인간-기계 시스템 환경에서 작업자의 작업성취 및 생산성에 영향을 미치는 내적·외적 작업부하 요인들을 발견하여 이를 모델개발에 고려하였다. 이들 작업부하 요인들이 작업자에 감지되는 정도에 대한 반응을 5점 척도를 도입하여 숫자가 아닌 자연어로 할 수 있게 하였으며 이렇게 작업자에 의해 주관적으로 판단된 작업스트레스 요인들은 각기 다른 가중치를 판단하기 위해 AHP(Analytic Hierarchy Process)를 사용하여 작업자가 직접 느끼는 작업부하 스트레스 정도를 비교판단 하게 하였고 이렇게 개념화된 모델을 실제 산업현장에서 사용할 수 있도록 컴퓨터를 통한 시험적인 작업부하 분석시스템을 개발하였다. 본 연구에 대한 검증을 위하여 실제 산업체에 종사하는 작업자들을 대상으로 인간공학적 작업부하 모델을 적용하여 측정하고 이를 작업자의 생리학적인 변화와의 관계를 비교 분석하여 본 결과 본 논문에서 개발된 모델은 작업부하 스트레스를 비교적 정확하게 측정할 수 있어서 앞으로 산업현장에 적용될 수 있는 신뢰성 있는 연구로 판단된다.

## 1. Introduction

It has been widely known that the occupational injuries and incidents are mainly due to improperly designed tasks and workplace. Improperly designed tasks and workplace cause more errors, higher accident rate, increased sick time, faulty judgement, and poor productivity. Reducing of such incidents, frequently associated with Manual Materials Handling(MMH), is one of the most serious concerns to ergonomists or to managers.

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Most forms of man-machine systems require at least some type of physical activities. Even fully automated systems still require human to install, program, reprogram, and maintain the systems[18]. Some work requires substantial physical skills and efforts because the manual carriage of materials is an integral and common part of materials handling occupations[6].

Generally speaking, the measurement of various stressors which influence the performance and responses of a human operator is called workload[19]. According to Hart and Wickens[12], workload is a general term used to describe the cost of accomplishing task requirements for the human element of man-machine systems. They say this "cost" may be reflected in the depletion of attentional, cognitive, or response resources, the inability to accomplish additional activities, emotional stress, fatigue, and performance decrements.

Certain levels of workload are acceptable as long as the stress does not interfere with the worker's functions and his/her capability to operate the system safely and efficiently. In other words, homeostasis, or steady-state, must be maintained in order to preserve the safety and efficiency of the system.

Many aspects of the physical act of MMH have been identified as potentially hazardous to a person's musculoskeletal system. Physical activities, environmental factors, and postural discomforts constitute the sources of physical stress of people at work and thus predetermine their workload. The number of factors considered as potential sources of occupational workload is seemingly limitless. Whether the source of an imposed workload is physical or mental in an industrial environment, it can influence an operator's health, performance, and productivity.

In this study, the 5-point linguistic values(e.g., weight of load: "very light," "light," "medium," "heavy," "very heavy,") of each task and the workplace variable(e.g., physical, environmental, postural, and mental demand stressors) which can obtain the operator's perception on workload are introduced as a value of contributing factors. It must be pointed out that some factors(i.e., task and workplace variables) might be the sources of workload 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 each individual's capacities to adjust or adapt to different external conditions. That is, a person's perception of his or her ability to deal with the job and its external features could cause some people to experience workload but not others.

Since each individual has different perceptions and responses to a workload, the Analytic Hierarchy Process(AHP) is introduced 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 workload in the hierarchy[16]. This approach calculates the ratio of the subjective judgment from each type of workloads and weighs the workloads based on their impact on the subject's perception.

The primary objective of this research was thus to develop a method which can estimate the Overall Workload Level(OWL) for problem solving of widespread occupational workload because the determination of workload factors plays an important role in designing and evaluating an existing man-machine system.

In addition, a prototype computer analysis system for determining OWL was developed to make it possible for nonexperts or line managers to utilize the existing knowledge in the area of workload estimation and to provide an intelligent and computer-aided problem solving method. Moreover, the OWL was implemented in actual industrial environment from the physiological view point to determine the validity of the model.

## 2. Variable Selections and Definitions

As briefly mentioned in the previous section, some of the job risk factors which are the most influential to occupational workload in a man-machine system are selected in this study[1, 2, 9, 18].

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

(2) Environmental Workloads($S_2$): workloads from working environment, which include improper temperature, lighting, noise, vibration, exposure to chemicals(including dust and fumes).

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

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

There has been an extensive research progress made in assessing the workload imposed on a human operator in man-machine systems. Questionnaires and rating scales have been used quite extensively in both psychological and ergonomics investigations to provide researchers with quantitative judgements of stimulus qualities. These methods are easy to administer and are widely accepted by those asked to complete them[18]. Needless to say, the questionnaire and rating scale approaches present some methodological problems as do the physiological approaches. However, well-designed questionnaires and appropriate rating scale techniques are practical and powerful tools, especially when objective assessment methods are unavailable and impractical[20].

Perhaps the oldest and most extensively validated subjective measure of workload is the Cooper-Harper scale[5]. It was originally developed to assess handling methods of aircraft. Wierwille and Casali[20] reported that the scale can be used, with only minimal rewording, for a wide variety of motor or psychomotor tasks. They presented a modified Cooper and Harper scale that combines a decision tree and unidimensional 10-point rating scale for evaluating perceptual, cognitive, and communication tasks. This technique was applied by Bielski et al.[3] to investigate physical and physiological workload, by Gomer et al.[8] to assess operator workload in performing keyboard functions, and by Hancock[11] to find the effects of workload on sustained attention and/or vigilance.

Many studies have proved that the five-point scale and five linguistic variable sets are able to efficiently obtain the meaning of the subjective judgements[3, 8, 15]. Without exceptions, many models applied rating scale methods to estimate the external workload imposed on a human operator in man-machine systems. As discussed so far, workload is directly related to human perception, the use of five linguistic variable sets is appropriate for this study.

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 sets of linguistic values for each workload contributing factor are constructed. The linguistic values of these workload contributing factors 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 meaning of the linguistic word is quantified over a specific range; that is, the weight of load ranges from 0 to 1.0 with interval of 0.2 in this term. These intervals represent the value for each workload contributing factor's linguistic variable in the set "weight perception." For example, the linguistic value is greatest(1.0) when the weight is "very heavy". The frequency of handling load, the duration of handling load, the moving distance of load are derived in a similar way as the weight of load and used in OWL.

By using this process, the environmental workloads such as improper temperature, lighting, noise, vibration, and exposure to chemicals can be assessed in the same manner. The same method could be applied to the postural workload stresses which originated from various object and workplace variables. Along with the variables above, OWL 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).

# 3. Determination of the External Workloads Imposed on a Human Operator

In this study, the AHP technique was employed to obtain the different weighting factors, since there exist different individual perceptions and responses to workloads. The weighting factors are derived by making pairwise comparisons of objects with respect to a common goal or criteria(e.g., intensity of workload)

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

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

The matrix for the contributing factors of each workload, $S_1$, $S_2$ and $S_3$, will be formed by a similar method. The number of pairwise comparisons that are required to be made by an individual when comparing N alternatives is N(N-1)/2. The computer analysis system written in Visual Foxpro 6.0 for entering and storing the workloads based on their impact on the subject's perception is shown in Figure 2. This system is developed to allow the nonexperts or line manager to utilize the existing knowledge in the area of workload estimation, and to provide intelligent and computer-aided problem solving.

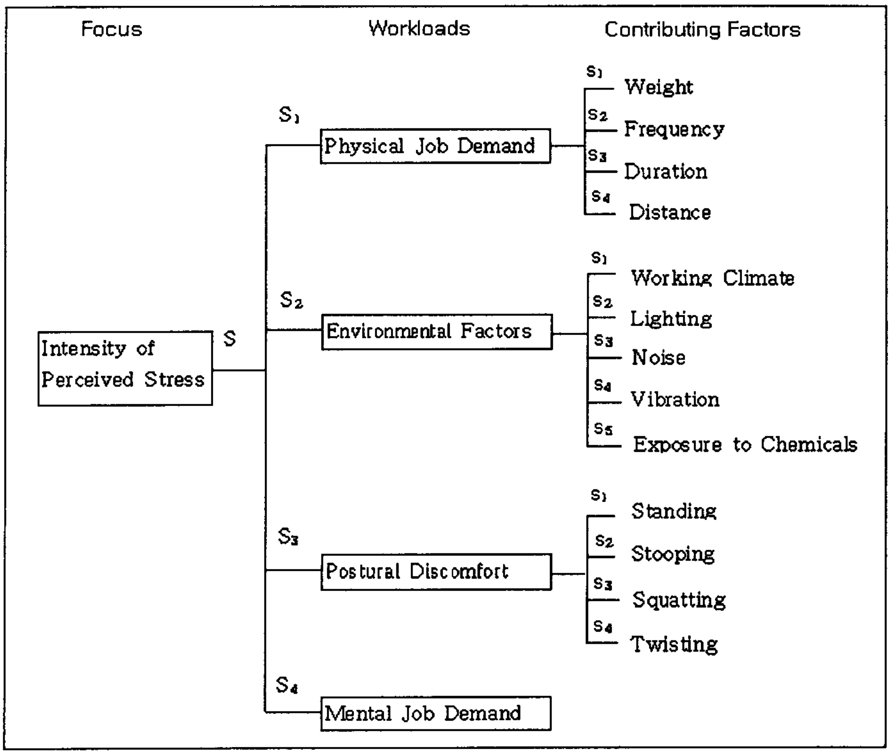


Figure 1. Decomposition of Task and Workplace Variables with Respect to a Intensity of Perceived Workload

Generally, the 1 to 9 scale can obtain 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 obtain perception, Saaty[16] 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 at the bottom of Figure 2.

The third step is to compute a vector of weights or priorities, $W = (W_1, W_2, ..., W_n)$ and $W_i = (w_1, w_2, ..., w_n)$, for both workloads 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.

Saaty[16] defines the S is a positive reciprocal matrix. If S is consistent, then the principal eigenvector of S is given by any of its columns. If the judgements were perfectly consistent, then the entries of the matrix S would contain no inconsistent judgements and could be expressed as

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

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

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

**COMPUTER EVALUATION SYSTEM FOR PRIORITIZING TASK AND WORKPLACE VARIABLES BASED ON SUBJECTIVE PERCEPTION OF WORKLOAD**

LAST NAME: Hong　　FIRST NAME: Gildong　　DATE: 12/05/1999
AGE: 25　　GENDER: Male　　DEPARTMENT: Milling

<< PERCEPTION OF WORKLOAD FROM VARIOUS TASK AND WORKPLACE VARIABLES >>

| | | | |
|---|---|---|---|
| PHYSICAL WORKLOAD | Weight:<br>Duration: | VERY LIGHT<br>LIGHT | Frequency:<br>Moving Distance: |
| ENVIRONMENTAL CONDITION | Climate:<br>Noise:<br>Exposure t | MEDIUM<br>HEAVY<br>VERY HEAVY | Lighting:<br>Vibration: |
| POSTURAL DISCOMFORT | Standing:<br>Squatting: | | Stooping:<br>Twisting: |
| MENTAL WORKLOAD | Mental Workload: | | |

<< PAIRWISE COMPARISONS FOR WORKLOAD PERCEPTION >>

| | PHYSICAL | ENVIRON. | POSTURAL | MENTAL |
|---|---|---|---|---|
| PHYSICAL | 1 | 1/9 | 1/3 | 1/4 |
| ENVIRON. | 9 | 1 | 3 | 2 |
| POSTURAL | 3 | 1/3 | 1 | 1/2 |
| MENTAL | 4 | 1/2 | 2 | 1 |

<< INTENSITY SCALE >>

1 = EQUAL, 3 = MODERATE, 5 = STRONG, 7 = VERY STRONG, 9 = EXTREME
2, 4, 6, 8 = INTERMEDIATE, SHADED AREA = RECIPROCALS

Figure 2. Data Entry Screen for Intensity of Perceived Workload

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. In addition to Saaty's method, there is the method of least squares[13] which finds the vector of weights $w = (w_1, w_2, \ldots, w_n)^T$ 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[7] 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 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[17] suggests that this method is the best at uncovering the true rank-order of a set of alternatives.

Saaty[16] also defines the 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,

$$w_i=\lim_{k\to\infty}\frac{S_{ih}^{(k)}}{\sum_{j=1}^{n} S_{ij}^{(k)}}, \quad \text{for all } i, h = 1, 2, \ldots, n[16].$$

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 workload $S_1$, $S_2$, and $S_3$ to get the priority.

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

$$CI = \frac{\lambda_{max} - n}{n-1}.$$

For each size of matrix n, random matrices were generated and their mean CI value, or the Random Index(RI), was computed and these values are shown in Table 1.

Table 1. Random Index(RI)

| 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 |

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

$$CR = \frac{CI}{RI}.$$

For example, assume that the pairwise comparison was made between the task and workplace variables, such as physical job demand, environmental conditions, postural discomfort, and mental job demand, and a common goal which determines the major impact on workload. Thus, the example of ratio scale judgements on the relative impact on workload of each job demand variables are shown in pairwise comparisons for workload perception in Figure 2.

Furthermore, assume that it is estimated that the environmental workload has "extreme intensity" on subject's stress over physical stress. It is expressed as "1/9" which is placed in the second column of first row. The reciprocal of this is "9" which is placed in the opposite of the matrix.

The priority weighting for each workload factor can be calculated by simply adding each column of matrix and dividing by each element of that column. The normalized S becomes

$$S^1 = \begin{bmatrix} 0.0588 & 0.0571 & 0.0526 & 0.0667 \\ 0.5294 & 0.5143 & 0.4737 & 0.5333 \\ 0.1765 & 0.1714 & 0.1579 & 0.1333 \\ 0.2353 & 0.2571 & 0.3158 & 0.2667 \end{bmatrix}.$$

Notice that the paths of length 1 yield different relative intensities because this matrix is inconsistent. The purpose of normalization is to make the comparison between the subjective and objective results under the same scale.

Squaring $S^1$ yields

$$S^2 = \begin{bmatrix} 4 & 0.4583 & 1.5 & 0.8889 \\ 35 & 4 & 13 & 7.75 \\ 11 & 2.25 & 4 & 2.4167 \\ 18.5 & 2.1111 & 6.8333 & 4 \end{bmatrix}, \text{ and}$$

$$\text{normalized } S^2 = \begin{bmatrix} 0.0584 & 0.0586 & 0.0592 & 0.0590 \\ 0.5109 & 0.5115 & 0.5132 & 0.5147 \\ 0.1606 & 0.1598 & 0.1579 & 0.1605 \\ 0.2700 & 0.2699 & 0.2697 & 0.2657 \end{bmatrix}.$$

Since every column of the normalized $S^2$ does not match we need to go to next path by raising $S^1$ to the power of 3, which yields different relative values. This process is continued until all the columns of the normalized $S^k$ match each other. For this problem, the process has converged in five iterations, normalized $S^5$ = $[0.0588, 0.5126, 0.1597, 0.2688]^T$.

Therefore, the normalized path intensities as $k \rightarrow \infty$ are equivalent to the normalized columns of $S^k$. The sum of weight will be 1.

Once we have computed the weights as $w = w^5$, the consistency measures can be computed as follows:

$$\lambda_{max} = \frac{\left( \sum_{j=1}^{4} S_{1j}\, w_j \right)}{w_1} = 4.0164,$$

$$CI = \frac{(4.0164 - 4)}{3} = 0.0055, \text{ and}$$

$$CR = \frac{0.0055}{0.90} = 0.006.$$

Thus, this matrix is very consistent. As a general rule, the more inconsistent the matrix, the greater the errors in the matrix and, thus, the longer the computational procedure will take to converge. The results of this analysis are shown in Figure 3.

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

$$\widehat{S}_i = \sum_{i=1}^{3} \sum_{j=1}^{n} W_{ij} \cdot R_{ij}\ , \qquad \text{for } R_{ij} > 0,$$

where $\widehat{S}_i$ implies the workload level for all contributing factors of each workload factor($S_1$, $S_2$, $S_3$),

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

$R_{ij}$ denotes the value of the 5-point linguistic variables(i.e., 0.2, 0.4, 0.6, 0.8, or 1.0).

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 level for the specific job. The results will show the relative importance of these variables regarding the impact on workload. The overall workload level will then be calculated by using an equation which can be expressed as

$$OWL = \sum_{i=1}^{3} W_i \cdot \widehat{S}_i + W_4 \cdot R_4\ ,$$

where $W_i$ denotes weighting factors for physical, environmental, and postural workload,

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

$W_4$ denotes weighting factors for mental job demand workload, and

$R_4$ indicates the rating scale of $S_4$.

**THE RESULTS OF AHP PRIORITIZATIONS**
**FOR A GIVEN TASK AND WORKPLACE VARIABLES**

| PHYSICAL WORKLOAD WEIGHT | |
|---|---|
| WEIGHT OF LOAD | : 0.3000 |
| FREQUENCY OF LOAD | : 0.3000 |
| DURATION OF LOAD | : 0.3000 |
| MOVING DISTANCE | : 0.1000 |
| CONSISTENCY RATIO(CR) | : 0.0000 |

| ENVIRONMENT COND. WEIGHT | |
|---|---|
| WORKING CLIMATE | : 0.0769 |
| LIGHTING LEVEL | : 0.0769 |
| NOISE LEVEL | : 0.3846 |
| VIB.: 0.0769 CHEMICAL EXPOSURE | : 0.3846 |
| CONSISTENCY RATIO(CR) | : 0.0000 |

| POSTURAL DISCOMFORT WEIGHT | |
|---|---|
| STANDING | : 0.1250 |
| STOOPING | : 0.6250 |
| SQUATTING | : 0.1250 |
| TWISTING | : 0.1250 |
| CONSYSTENCY RATIO(CR) | : 0.0000 |

| OVERALL WEIGHT | |
|---|---|
| PHYSICAL WORKLOAD | : 0.0588 |
| ENVIRON. CONDITION | : 0.5126 |
| POSTURAL DISCOMFORT | : 0.1597 |
| MENTAL WORKLOAD | : 0.2688 |
| CONSISTENCY RATIO(CR) | : 0.0060 |

**THE OVERALL WORKLOAD LEVEL(OWL)**

**THE VALUE OF OWL FOR "Hong, Gildong" = 0.75**

Figure 3. The Result Screen of Computer Analysis System for Overall Workload Level(OWL)

Figure 3 shows the example results of AHP prioritizations and OWL for a given task and workplace variables. This application of computer-assisted systems in the ergonomics/human factors area is to deliver the widespread application of ergonomics knowledge to the working population.

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.

# 4. Validation of OWL

In this section, the field validation was conducted to test the validity of the OWL model. One of the major purposes of validation of the OWL are to determine how well the OWL model predicts the existence and intensity of workload. The results could be used as an injury and illness prediction and a guidance when correcting problem areas. Another purpose is to classify the "meaning" of the index value of the OWL as an indication of workload such as "very low," "low," "moderate," "high," and "very high."

The physiological effects of the various jobs were studied by measuring Heart Rate(HR). Grandjean[9] and Green et al.[10] stated that the rise in heart rate reflects both increasing mental and physical workload. Another finding by Kalsbeek[14] mentioned that an increasing HR is a sign of mental stress. For these reasons, HR has been increasingly used in recent years as an index of both physical and mental workload. So, if HR and OWL have a very close linear relationship, then the OWL model is a good tool to predict both physical and mental stress since the OWL accounts for both of these workload stresses. Thus, HR can be chosen as the most convenient and reliable index for determining the assessment of workload from among the available physiological measures.

To test the validity of the OWL, the physiological effects of the various jobs in the machine processing industry were studied by measuring HR. This industry processes metal parts, assembles sub-parts, and sells these parts to auto industries. Heart rate is generally less useful in low-workload situations and non-operational environments[12]. Thus, the machine processing industry is selected for the validation procedure, because there appears to be more physical work involved in this type of operation.

28 workers participated in this validation procedure. The Heart Speedometer Model 8719 made by Computer Instruments Corporation was used to measure the

heart rate. The pulse sensor is clipped to the subject's earlobe for pulse detection. After a certain period of time, the 7-LCD pulse and time indicator displays the pulse beat. Table 2 shows the average OWL, and the average work pulse(WP) for each department in this company.

Table 2. The OWL and Average WP for the Selected Jobs

| Department | No. of Subjects | Average OWL | Average WP |
|---|---|---|---|
| Lathing | 4 | 0.63 | 17 |
| Shaping | 3 | 0.56 | 8 |
| Milling | 3 | 0.63 | 16 |
| Drilling | 3 | 0.57 | 14 |
| Machining Center | 2 | 0.63 | 14 |
| CNC Lathing | 2 | 0.57 | 12 |
| Welding | 3 | 0.46 | 6 |
| Assembling | 5 | 0.37 | 2 |
| Receiving, Shipping, Stocking | 3 | 0.66 | 17 |
| Total | 28 | - | - |

The measurement was taken twice for each of the intervals before, during, and after the task. Values were derived for the WP by computing the difference between baseline HR(Resting Pulse) before the task and HR during the task. The Relative Work Pulse(RWP) was derived as,

$$\text{Relative Work Pulse(RWP, \%)} = \frac{\text{Working HR} - \text{Baseline HR}}{\text{Baseline HR}}.$$

The statistical analysis between the OWL and WP and between the OWL and RWP was conducted to find the relationship of these two measurements. Table 3 shows the statistical results of the correlations between the OWL and age and two physiological measurements. The higher R^2 and R values indicate that there is a close linear relationship between the physiological measurements and OWL. Another finding from this analysis reveals that there is no significant relationship between OWL and age.

Table 3. The Statistical Results Between the OWL(Dependent Variable) and Age and Physiological Measurements(Independent Variables)

| Independent Variable | Mean(SD) | R^2 | R | S.E. | Signicance F |
|---|---|---|---|---|---|
| Age | 27(6.8) | 0.001 | -0.029 | 0.141 | not significant |
| WP(pulses/min) | 15(10.0) | 0.715 | 0.845 | 0.075 | $p<0.001$ |
| RWP(%) | 0.22(0.16) | 0.676 | 0.822 | 0.080 | $p<0.001$ |

The interpretation of the "meaning" of the OWL is an essential procedure in determining usefulness to the end users. HR is used to classify the meaning of workload stress because the HR measure has undoubtedly been proven to be the most versatile measure of workload stress[9].

It is assumed from the reaction measured at various work loads by Grandjean[9] 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 is conducted between the value of OWL and the value of work pulse as an indication of workload. From the regression analysis between the value of OWL as dependent variable and work pulse as independent variable, the linear regression equation forms as $y = 0.43156+1.1728e{-2}x$ with $R^2 = 0.743$.

Using this regression equation, the unnormalized OWL is calculated corresponding to the work pulse and normalized based on the highest OWL, 1.78. The classification of OWL is set and presented in Table 4.

In summation of the results according to the classification of OWL as an indication of workload, the workload at this machine processing industry was generally not too excessive. The least workload occurred for the assembling department and the greatest for the receiving, shipping, and stocking department. The environmental workload was high at all departments. This was primarily the result of both high level of noise and dust.

Table 4. Classification of OWL as an Indication of Workload

| Assessment of Workload | Heart Rate (Pulses/min) | Work Pulse(WP) | Unnormalized OWL | OWL |
|---|---|---|---|---|
| Very Low(resting) | 60 - 70 | 0 - 10 | 0.00 - 0.55 | 0.00 - 0.31 |
| Low | 70 - 100 | 10 - 40 | 0.55 - 0.90 | 0.31 - 0.51 |
| Moderate | 100 - 125 | 40 - 65 | 0.90 - 1.19 | 0.51 - 0.67 |
| High | 125 - 150 | 65 - 90 | 1.19 - 1.49 | 0.67 - 0.84 |
| Very High | 150 - 175 | 90 - 115 | 1.49 - 1.78 | 0.84 - 1.00 |
| Extremely High | 175< | 115< | - | - |

High workload, in this approach, 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 accident and illness rate. Conversely, it can be argued that a low workload is not stressful(at least in the sense meant here, in which workload 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.

# 5. Conclusion

Workload is an important and integrative concept that determines the abilities of human operators of complex systems to accomplish mission requirements, given the equipment and training that are provided and the organizational and environmental constraints that are placed on them. Workload can be measured with reasonable accuracy. However, there are considerable problems in separating job-related workload from other sources of workload. There are also problems associated with particular task events as a source of acute workload.

A variety of subjective rating scales, measures of primary and secondary task performance, and physiological indicators have been developed, tested, and used to aid designers, manufacturers, and users in measuring the effects of task requirements on the operators. Because each measure is especially sensitive to different workload causes and consequences, the results obtained with different measures may not covary. However, recent research in the field has focused on clarifying the underlying causes of such dissociations and on formulating a model of workload/performance trade-offs. This model should aid in interpreting the results of workload analysis, identifying workload criteria, and improving the accuracy of workload prediction.

After further practical applications are administered as the method performed by Chen et al.[4] and other objective workload assessment methods(e.g., oxygen consumption), the technique developed here needs to be modified, expanded, and validated whenever necessary so that more reliable problem identification and recommendations can be provided such as work-related accident and illness and the physiological health of employees.

Furthermore, in future development and modification of the OWL, it is recommended that the future workload prediction model should take into account the effects of the following:

1. the inclusion of the characteristics of a worker's personality (i.e., psychosocial aspect), which may increase susceptibility to the workload; such characteristics include job satisfaction, occupational self-esteem, role conflict, and responsibility pressure.
2. the need for future longitudinal studies with more medical data on health status;

the need for further assessment of genetic factors that may interact with occupational workload in determining worker's health.

3. the consideration of nonjob-related stress.

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## 저자소개

정화식 단국대학교 건축공학과를 졸업하고 미국 Murray State University 산업공학 석사, University of Houston 산업공학 박사학위를 취득하였다. 주요 관심분야는 인간공학, 데이터베이스, 전문가시스템 등이다