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Using Outputs of NASA-TLX for Building a Mental Workload Expert System

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ABSTRACT

In this study, we evaluate the effect of demographic factors such as age, gender, marital status, and education level on mental workload of TEYDEB's (Technology & Innovation Grant Programs Directorate) experts working in basic stages of R&D projects evaluation activities. One of the workload measurement techniques, NASA-TLX is chosen since it is the most convenient measurement technique for the experiment groups used in this study. We make statistical analyses to measure the effectiveness of 6 scales used in NASA-TLX for evaluating the subjective mental workload of TEYDEB's experts. In the second phase of the study, output of NASA-TLX is used by AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) methods to construct an expert system for choosing an executive expert from TEYDEB's expert pool.

Keywords: Mental workload**,** NASA-TLX, AHP, TOPSIS

1. INTRODUCTION

Mental workload is an important measure to understand human-machine interaction in a work environment and a growing number of studies in the literature on the measurement of mental workload are noticed. In an interactive office with lots of computer-based work, mental workload and its effect on learning and application are important issues to be researched on. As work nature shifts from physical labor work to human-computer interactive work requiring mental workload, number of studies that focus on the optimization of mental workload by creating appropriate designs and interfaces increases [Hertzum & Holmegaard, 2013; George et al., 2012]. Since computers have become one of the critical components used in learning and implementation activities in office work, information flow and mental workload management issues have gained more importance. Starting with the submission of project applications and including project evaluation, document monitoring and staff management, all activities in TEYDEB are processed electronically and this makes TEYDEB an ideal working environment for measuring the mental workload based on human-computer interface. Especially financial and technical experts as the most important components of R&D support mechanism, spend quite intense mental effort during the project development, evaluation and funding activities.

Evaluation of R&D projects is mostly carried out under time pressure because of changing and developing technology. In addition to the time pressure, mental requirements and stress level during the activities of TEYDEB are considered as important factors affecting the mental workload of financial and technical experts. The purpose of this study is to measure the mental workload of experts working in TEYDEB's three basic stage of evaluation activities in R&D projects which are 1) AGY100 Pre-evaluation, 2) Preparation of Project Information Form, and 3) AGY300 Project Monitoring. Since financial experts evaluate the expenses of projects, they are only responsible for AGY300 Project Monitoring stage. By using different applications of AHP and TOPSIS, multi-criteria decision-making techniques, outputs of this study are used to build an

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expert system that can help to assign administrative staff among the experts of TEYDEB.

1.1 Methods for Measurement of Mental Workload

Generally, methods used in measuring mental workload can be classified into 3 groups. Subjective rating methods usually use measurement scales and questionnaires. [Byrne et al., 2014; Maior et al., 2014] These methods work best between tasks or after the completion of tasks. Performance rating methods evaluate synchronized data collected during primary tasks and secondary tasks in designed modules. In both methods, speed and error rates showing the performance rate of users, are evaluated for primary and secondary tasks. Physiological rating method can be used as an indirect measurement system since observed physiological changes such as heartbeat, nasal tip temperature, blink rate, body temperature and face temperature are evaluated in this method [Shu, 2012; Kajiwara, 2014]. Among these methods, performance rating method and physiological rating method are less effective methods in terms of application requirements and user interaction. Subjective rating methods are used frequently since - thanks to the users' auto-control - they are able to measure a wider range of the mental workload and require less money and effort. In subjective rating methods, users' rating scales are prepared assuming that any user has the ability to report his/her mental effort during the task. Since subjective rating methods use retrospective experiences and information, many studies in the literature question the ability of providing simultaneous information for subjective rating methods, however in most experiments, it has been observed that users can transfer information to the system in a consistent manner [Ericsson & Simon, 1980; Nisbett & Wilson, 1977].

Among mental workload measurement techniques based on self-reports, Subjective Workload Assessment Technique and NASA-TLX method are used most commonly [Miller, 2001 and Rubio et al., 2004]. Other than these methods, Multiple Choice Resource Survey (MRQ) and Workload Profile methods have been introduced by recent studies. These methods are often used in different fields such as transportation, industry, and control areas consequently they provide multi perspective definitions for mental workload. [Finomore, et al., 2013; Rubio et al., 2004] Among techniques based on self-reports, NASA-TLX has more capability of representing the mental workload comparing to the other two techniques (Hill et al., 1992) NASA-TLX has 6 sub-scales: Mental requirements, physical requirements, time requirement, performance, effort and stress level. In this method, each sub-scale takes a value between 0-100 and at the end of the measurement 15 questions for the binary comparison of these subscales are asked to the participants. A weighted calculation method is then used to extract the total workload. Having sub-scales affecting the total workload provides a multidimensional nature for NASA-TLX method and this is also one of the reasons that NASA-TLX method is frequently used in experimental studies. As a multi-dimensional rating method, NASA-TLX identifies the sources contributing to mental workload and it is considered as a global mental workload rating tool NASA-TLX also eliminates unnecessary sources of workload experimentally and concentrates on the sources that contribute significantly to the mental workload. [Hart, 2006].

In literature, there are some studies considering the comparison of NASA-TLX method and Saaty's AHP method for the estimation of subjective mental workload [Vidulich, et all 1997; Tian et all., 2012]. However designing an integrated structure of NASA-TLX and AHP methods and considering the interaction between the results of NASA-TLX and AHP is a novel study in this research area.

In this study mental workload is defined as the effort required to reach the usual performance of user for any task. Therefore mental workload is analyzed in human-oriented manner rather than task-oriented manner. Any user's mental workload is affected by various external factors in addition to task related factors, which means mental workload does not give us a constant value even for the same tasks and users and mental workload rates change for different time periods and environmental conditions. In addition to the requirements of the work to be done, environmental conditions, user's ability, behavior pattern and viewpoint, system and operator errors are the factors affecting the mental workload. Therefore mental workloads of different tasks or different users vary continuously. The structure, timing, and targets of tasks and resources of users are the main components of mental workload [Hart & Staveland, 1988].

After their statistical analysis, [Hart & Staveland, 1988] define classifications and subsets obtained in previous studies for 10 components of the mental workload as three subscales, which are: 1) Task-oriented scales; the difficulty of task, time pressure, activity type. They find out that only the difficulty of task and time pressure can provide meaningful information about mental workload. They divide task difficulty into two groups as physical and mental task difficulty. 2) Behavior-oriented scales; physical effort, mental effort, and user's own performance. In this group since there is a high correlation between mental and physical effort a new factor called "effort" is created by combining mental and physical effort and this is considered to be more adequate for evaluation. 3) Psychology-oriented scales; performance, stress and fatigue level. In Hart and Staveland's study, after some experimental and statistical analysis, it is observed that fatigue level did not contribute significantly to the overall mental workload and is excluded from the measurement scale.

These subscales are then consolidated and mental requirement, time pressure, effort, stress level, performance and physical requirement factors are accepted as the subscales of NASA-TLX rating method. Each of these 6 subscales is determined as the primary source of mental workload at least for one experimental case.

For NASA-TLX weighted rating system to obtain results for different tasks can be completed in less than 2 minutes. This shows that as a multi-dimensional rating method, NASA-TLX can be used more effectively comparing to 9-factor scale for operational areas. Furthermore for many fields, NASA-TLX is easier to apply compared to the 27-factor SWAT method. Also by observing the weighted average of each scale's rating, it is more likely to find out the primary source of mental workload in NASA-TLX compared to other rating methods [Hart & Staveland, 1988].

2. METHOD

2.1 Subjects

With the attendance of TEYDEB's technical and financial experts, an experiment group including 56 personnel is composed for this study. All of the employees in the group have at least a bachelor degree. Experts in the experiment group have diversity in education, gender, age, profession and marital status.

2.2 Tasks

Technical experts in TEYDEB have 3 different routine tasks and these tasks are considered as experimental cases for this study. Financial expert's routine tasks are significantly different than technical experts' tasks and for this study only "monitoring R&D projects" task is used as an experimental case for financial experts of TEYDEB. Our goal is to identify the effect of demographic factors such as education level, age, marital status, gender etc. on the mental workload of technical and financial experts responsible for the evaluation phases of R&D projects. For this study main phases of project evaluation were divided into 3 steps, which are: AGY100 Pre-evaluation, Preparation of Project Information Form and AGY300 Monitoring.

2.3 Workload Measures and Results

NASA-TLX questionnaire used in this study, consists of two different question groups. 6 mental workload scales, definitions of these scales and expected work from the experts within the scope of each task are included in the first part of the questionnaire. In the second part of questionnaire, binary comparison of these 6 scales is requested from the experts to calculate the weight of each scale. Sample scale comparison for AGY100 Pre-evaluation phase is shown in Table 1. In Table 1 for each task, according to the selection made by the user, if mental requirement creates a higher mental workload than time pressure, mental requirement's scoreboard value is incremented by 1. Likewise if time pressure creates a higher mental workload than performance, time pressure's scoreboard value is incremented by 1. Since there are 3 tasks for the experiment, all these procedures were repeated for 2 more tasks (Preparation of Project Information Form and AGY300 Project Monitoring).

Table 1. Pairwise comparison of mental workload scales for AGY100 Pre-evaluation task

AGY100 Pre-evaluation

Scale-1	Selection	Scale-2	Selection
Mental requirement	x	Time pressure	
Time pressure		Performance	x
Mental requirement	x	Stress level	
Effort		Performance	x
Mental requirement	x	Physical requirement	
......		.....	

Same procedures are applied for all 15 scale's pairwise comparison and total scoreboard value was calculated for each mental workload scale. (Table 2)

Table 2. Scores of mental workload scales for AGY100 Pre-evaluation task

Mental Workload Scales	**Scoreboard values**
Mental requirement	6
Physical requirement	1
Time pressure	2
Effort	2
Performance	3
Stress level	1

For the third part of questionnaire, scoring for each scale's effect on mental workload is requested from the experts. Experts can use the range of 0-20 points for their evaluation. (Table 3)

Table 3. Scale Rating for AGY100 Pre-evaluation task

Scale	**Points**
Mental requirement	16
Physical requirement	3
Time pressure	10
Effort	10
Performance	2
Stress level	5

To calculate total mental workload, points given by experts for each scale and scoreboard values of each scale from binary comparison table are multiplied and the values for all scales were added together. The value obtained is divided by 15 which is the 2 choose 6 scales

$\binom{6}{2}$.

$$\sum_{i=1}^{6}(ÇD(i) * SP(i)) \;/\; 15 \qquad (1)$$

ÇD(i)	Mental Workload Scales' scoreboard values
SP(i)	Scale rating

In the last part of the questionnaire, encoding of their demographic characteristics is requested from the experts.

As a result of the above process, relative importance degrees of NASA-TLX's 6 scales are obtained. In this study, choosing any scale in preference to another means that the scale is given more weight for the calculation of total mental workload. Identifying the rankings of each expert's mental workload scales, measuring the impact of selected scales on the overall mental workload, and calculating a total mental workload score by using weighted scale scores depending on the declaration of experts are some of our targets.

The assumptions used during calculation of mental workload scores are: 1. The effect of scales used for calculation of total mental workload varies from one user to another. 2. Users are capable of evaluating the weight and effect of all the scales on total mental workload. 3. Data obtained from experts' evaluations are unregulated data 4. Combination of all rating scores provides an average mental workload score and this score shows less variability. 5. Combination rules are linear. 6. Weighted average scores reflect each scale's overall importance and impact for each task.

Another result of this study obtained with ANOVA (Analysis of Variance) shows that stress, performance, mental requirement, and effort scales have statistically significant effect on mental workload of TEYDEB's experts. However, we could not prove that physical requirement scale has statistically significant effect on mental workload of TEYDEB's experts. The reason for that can be explained by the fact that TEYDEB's experts are not subjected to physical strain during their routine work. In Table 4 p-value values obtained from ANOVA method are given. Data obtained from experts are evaluated by using ANOVA method and LSD (Least Significant Difference) test and the level of significance was set at 0.05.

Table 4. Scale Rating

ANOVA

	Stress	**Effort**	**Performance**	**Physical Requirement**	**Mental Requirement**	**Time Pressure**
F	6,49	5,7	29,95	1,72	10,92	7,85
P-Value	0,028	0,026	0,003	**0,248**	0,036	0,031

If p-value value for a scale is smaller than 0.05, that scale have statistically significant effect on mental workload. Therefore in this study in Table 4, it has been shown that stress, effort, performance, mental requirement, and time pressure scales have statistically significant effect on mental workload of TEYDEB's experts. However, it could not be shown that physical requirement has statistically significant effect on mental workload since the p-value value is 0.248 which is greater than 0.05. Therefore in the next step of this study for calculating mental workload "physical requirement" scale is excluded and for the questionnaire, a new rating scale is created with 5 scales (Stress, effort, performance, mental requirement and time pressure)

2.4 Evaluation of Mental Workload Measurement Results

Total mental workload scores obtained by using NASA-TLX method can only be used for comparison of experiment groups. Therefore boxplot graphics are created for each demographic factor and these boxplots are evaluated. Results were evaluated in SPSS package and generated plots are given in Figures 1, 2, 3, 4, 5 and 6.

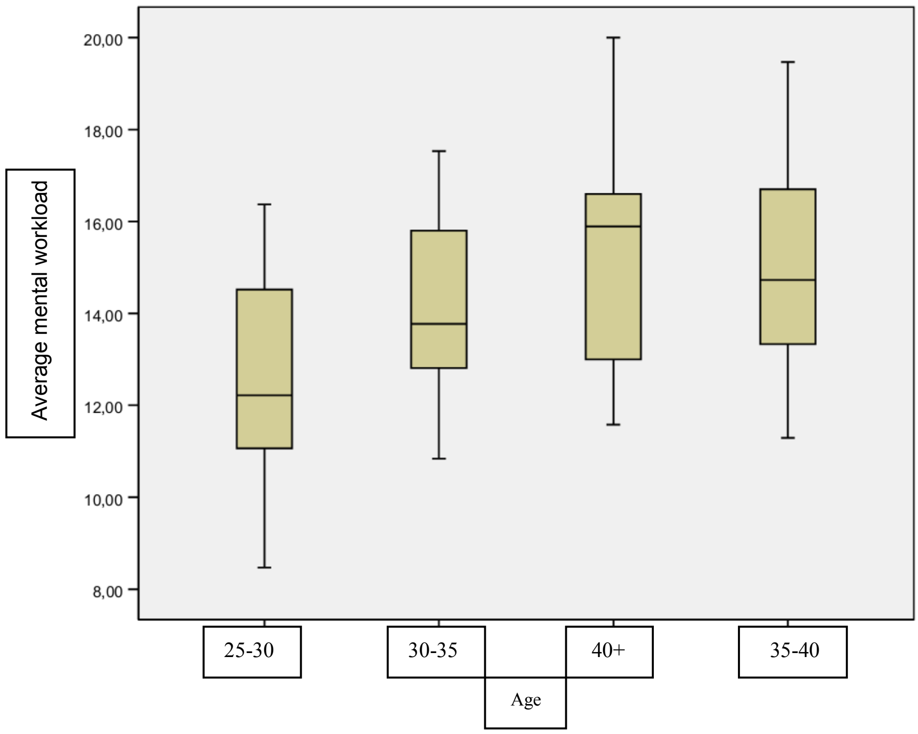

Figure 1**.** Comparison of mental workload by age

As shown in Figure 1, as the age increases, average mental workload increases.

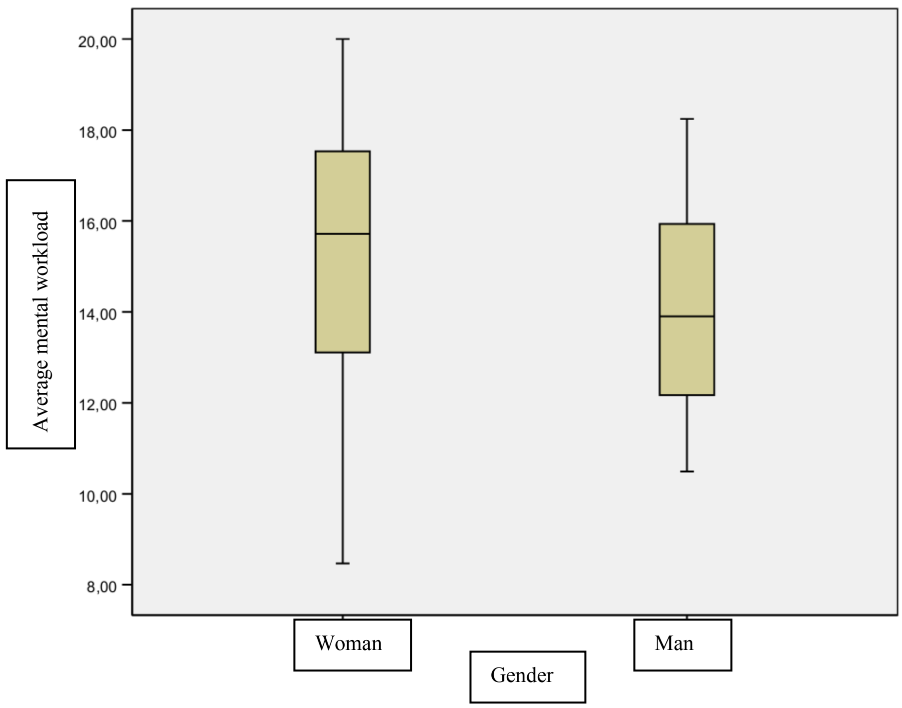

Figure 2**.** Comparison of mental workload by gender

In Figure 2, comparison of mental workload and gender indicates that women have higher average mental workload than men. In Figure 3, comparison of mental workload and education level indicates that experts with master degree have lowest average mental workload value while experts with bachelor degree have highest average mental workload value.

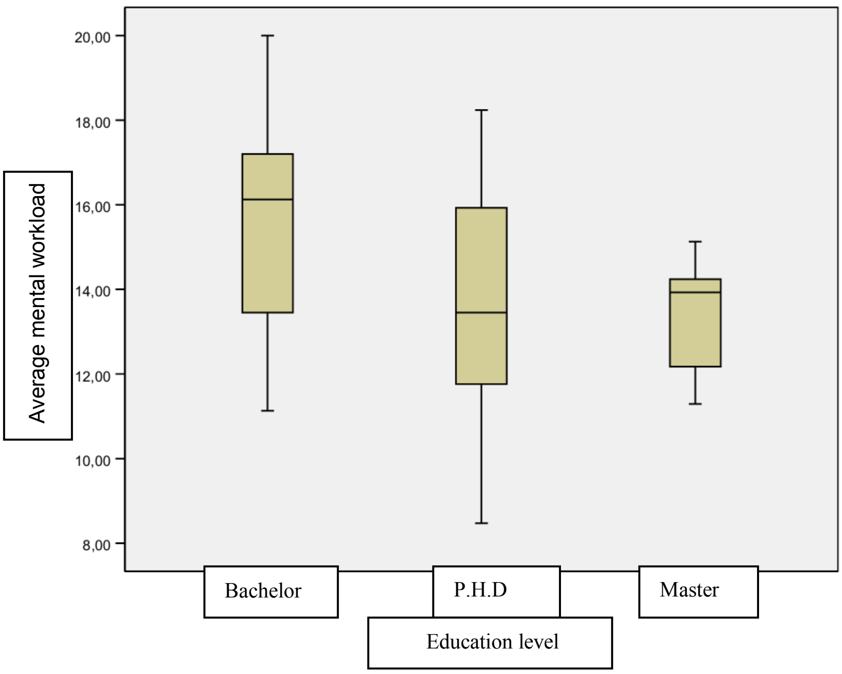

Figure 3**.** Comparison of mental workload by education level

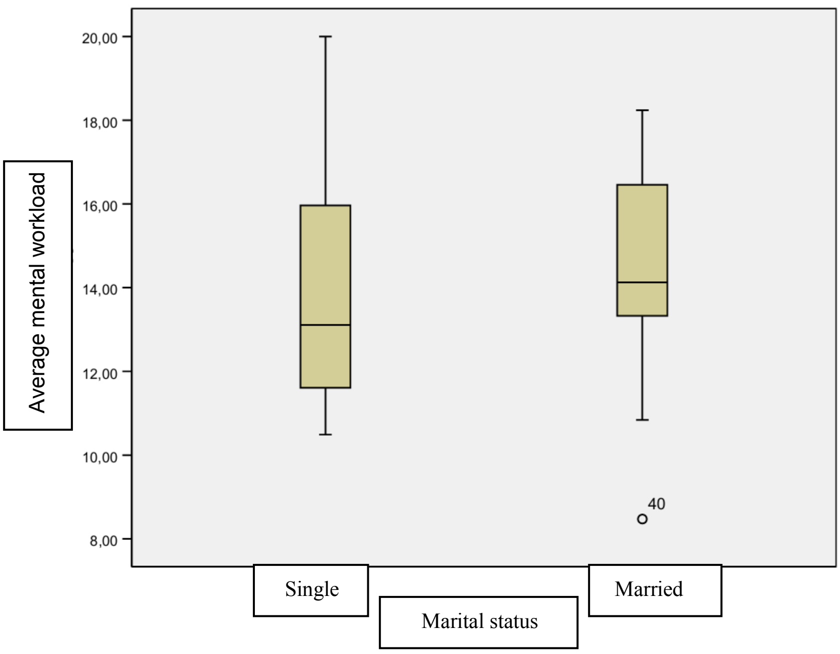

Figure 4. Comparison of mental workload by marital status

In Figure 4, comparison of mental workload and marital status indicates that married experts have higher average mental workload than single experts. One of the sample data belonging to an expert was considered as an outlier data and excluded from the evaluation

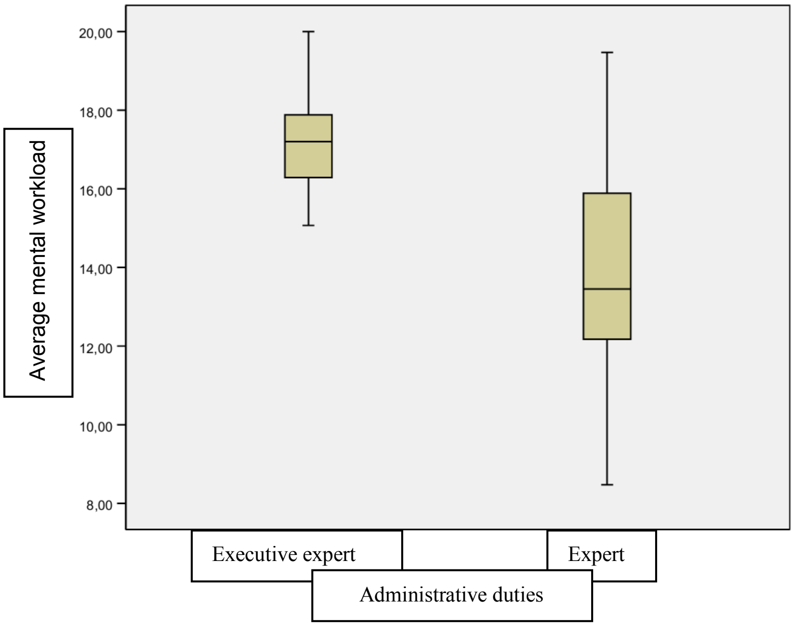

Figure 5. Comparison of mental workload by administrative duties

In Figure 5, comparison of mental workload and administrative duties indicates that executive experts have higher average mental workload than experts.

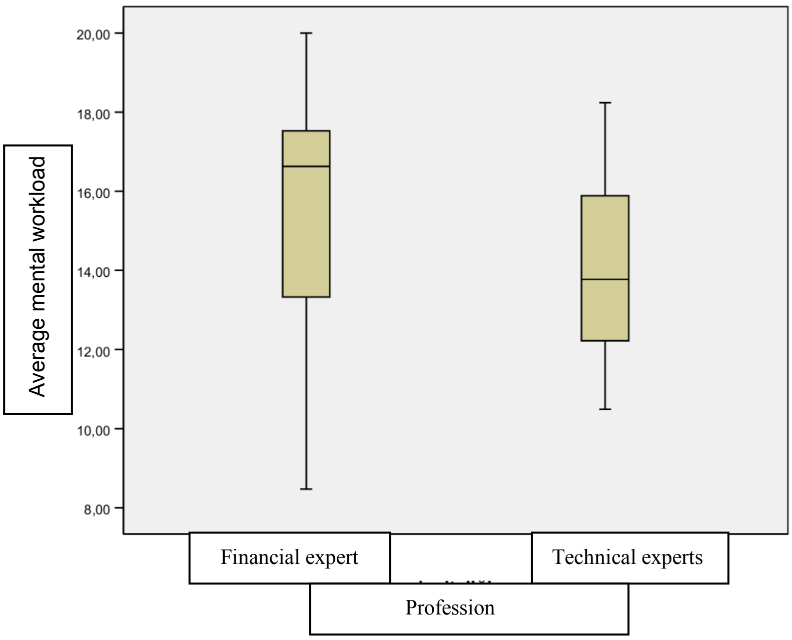

Figure 6. Comparison of mental workload by profession

In Figure 6, comparison of mental workload and profession indicates that financial experts have higher average mental workload than technical experts. Also with this study it has been determined that administrative tasks have statistically significant effect on mental workload.

3. APPLICATION

3.1 An Application for Integration of Mental Workload Measurement Results and Decision Support Systems

Data obtained from experts by using NASA-TLX method are statistically evaluated and the result shows that administrative duties have statistically significant effect on mental workload and executive experts have higher mental workload value than experts. This finding combined with the results of previous studies indicating that the subjects' performance is declining in series with the increase of mental workload [Zeng et al., 2007; Salvucci & Bogunovich, 2010] helps us to determine the strategy for assigning experts to administrative positions. Science administrative duties has a significant impact on mental workload, candidate experts having less total mental workload should be chosen for administrative tasks. Based on this concept, an expert system that assigns administrative positions to experts with the objective of minimizing mental workload, is created. Characteristics of experts such as experience, social relations, and personality are not considered within the scope of this study. The outputs obtained from the questionnaire are used by different applications of AHP (Analytic Hierarchy Process) [Saaty, 2008] and TOPSIS (Technique for Order Preference by Similarity to İdeal Solutions) [Hwang, Lai, & Liu, 1993], two commonly used multi criteria decision making methods, to create a mental workload expert system. The AHP is used in this study since it is most useful where teams of people are working on complex problems, especially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions [Bhushan & Rai, 2004].

In the first step of TOPSIS method, a decision matrix is created to assign an executive expert for an available position among the candidates having different demographic features. In Table 5 decision matrix and related criteria are shown. Decision matrix is formed by executive expert candidates shown by A-F were located in the row and age, gender, profession, education level, and marital status criteria are located in the column. For marital status, "1" represents single and "2" represents married experts. By using statistical analysis and graphics from previous steps of this study, it has been determined that if values for "marital status" criteria increases, average mental workload increases, too. For education level, "1" represents experts with bachelor degree, "2" represents experts with master degree and "3" represents experts with P.H.D. For this criterion if the number increases, average mental workload decreases. For profession "1" represents financial experts and "2" represents technical experts. For this criterion if the number increases, average mental workload decreases. For gender criterion "1" represents women and "2" represents men and as the number increases, average mental workload decreases.

Table 5. Decision matrix for Executive expert selection

DECISION MATRIX

	AGE	GENDER	PROFESSION	EDUCATION LEVEL	MARITAL STATUS
A	25	1	2	2	1
B	30	2	2	1	2
C	30	2	1	3	1
D	35	2	2	2	1
E	40	1	1	2	2
F	45	2	2	1	2

After data obtained from NASA-TLX method are evaluated statistically by using ANOVA and correlation analysis, in the second step of TOPSIS "Bilateral comparison matrix of main criteria" is created by using the correlation of each demographic factor with total mental workload. In this step, for 3 different task categories, correlation values between demographic factors and total mental workload are calculated and then average value is taken. For AGY100 Pre-evaluation task category, correlations shown in Table 6 are calculated and then "Bilateral comparison matrix of main criteria" is created as shown in Table 7.

Table 6. Correlations between demographic factors and total mental workload for AGY100 Pre-evaluation task

Correlations between demographic factors and total mental workload

	PROFESSION	AGE	GENDER	EDUCATION LEVEL	MARITAL STATUS
Total workload	0,81	0,5	0,38	0,7	0,088

Table 7. Bilateral comparison matrix of main criteria

	AGE	GENDER	PROFESSION	EDUCATION LEVEL	MARITAL STATUS	Weight vector
AGE	1	1,32	0,625	0,72	5,65	
GENDER	0,76	1	0,47	0,54	4,26	
PROFESSION	1,6	2,13	1	1,16	9,07	
EDUCATION LEVEL	1,4	1,85	0,87	1	7,9	
MARITAL STATUS	0,18	0,23	0,11	0,12	1	
	4,94	6,53	3,075	3,54	27,88	

In the AHP method, Saaty's consistency index is performed to ensure that the information provided by an individual is accurate [Yucheng Dong et al., 2013]. Therefore in this study to determine the consistency of bilateral comparison matrix of main criteria, consistency index (which according to Saaty is the maximum eigenvalue of the comparison matrix) is calculated. Consistency index of bilateral comparison matrix of main criteria is calculated using Equation 1 and 2 defined by Saaty [Saaty, 1990].

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \left\{ \frac{\sum_{j=1}^{n} a_{ij} \cdot w_j}{w_i} \right\} \quad (1)$$

$$CI = (\lambda_{maks} - n) / (n - 1) \quad (2)$$

λ_{max} The largest eigenvalue of the matrix
CI Consistency rate
w criterion weight
a_{ij} relative importance of the elements i and j.

Consistency rate is found 0,0018 using the formulations in Equation1 and 2 and since this number is smaller than 0.1, it is concluded that bilateral comparison matrix of main criteria is consistent. After this step, we normalize each matrix element by the sum of elements in each column and we calculate the sum for each row. After that by normalizing the sum of the rows, weight vectors for each criterion is calculated and shown in Table8.

Table 8. Criteria weight vectors

	AGE	GENDER	PROFESSION	EDUCATION LEVEL	MARITAL STATUS	Weight vector
AGE	0,2024	0,2021	0,2032	0,2033	0,2026	0,20279
GENDER	0,1538	0,1531	0,1528	0,1525	0,1527	0,1530
PROFESSION	0,3238	0,3261	0,3252	0,3276	0,3253	0,3256
EDUCATION LEVEL	0,2834	0,2833	0,2829	0,2824	0,2833	0,2830
MARITAL STATUS	0,0364	0,0352	0,0357	0,0338	0,0358	0,0354
	1	1	1	1	1	

From Weighted Decision Matrix shown in Table 9, Positive and Negative Ideal solutions are obtained in order to use in TOPSIS method. In this method, since Age and Marital status criteria are positively correlated with mental workload and the objective function of this problem is taken as the minimization of mental workload, they are considered as “cost criteria”. Since other criteria have negative correlation with mental workload, they are considered as “benefit” criteria.

Table 9. Weighted Decision Matrix

	AGE	GENDER	PROFESSION	EDUCATION LEVEL	MARITAL STATUS
A	0,112652133	0,076517112	0,32565663	0,188730476	0,017719797
B	0,135182559	0,153034223	0,32565663	0,094365238	0,035439594
C	0,135182559	0,153034223	0,162828315	0,283095714	0,017719797
D	0,157712986	0,153034223	0,32565663	0,188730476	0,017719797
E	0,180243413	0,076517112	0,162828315	0,188730476	0,035439594
F	0,202773839	0,153034223	0,32565663	0,094365238	0,035439594

In weighted and normalized decision matrix, with best values for all criteria, positive ideal solution space is obtained. Similarly with worst values for all criteria, negative ideal solution space is obtained. Positive and Negative ideal solution spaces are obtained by using Equation 3 and 4.

Positive ideal solution:

$$A^{+} = \left\{ \left[\max_{j=1,i=1,m} v_{ij} \right], \left[\max_{j=2,i=1,m} v_{ij} \right], \ldots\ldots\ldots \ \ldots\ldots\ldots \left[\max_{j=n,i=1,m} v_{ij} \right] \right\} = \left\{ v_1^{+}, v_2^{+}, \ldots\ldots\ldots\ v_n^{+} \right\}$$

, i=1,2…….n^{th} row ; j= 1,2………m^{th} column maximum value for each column j (3)

Negative ideal solution:

$$A^{-} = \left\{ \left[\min_{j=1,i=1,m} v_{ij} \right], \left[\min_{j=2,=1,m} v_{ij} \right], \ldots\ldots\ldots \ \ldots\ldots\ldots \left[\min_{j=n,i=1,m} v_{ij} \right] \right\} = \left\{ v_1^{-}, v_2^{-}, \ldots\ldots\ldots\ v_n^{-} \right\}$$

i=1,2…….n^{th} row; j=1,2………m^{th} column minimum value for each column j (4)

Equation 5 and 6 were used to calculate the distances between alternatives and Positive and Negative Ideal solutions. (S_i^+ and S_i^-)

$$S_i^{+} = \left[\sum_{j=1}^{n} \left(v_{ij} - v_j^{+} \right)^2 \right]^{1/2} \tag{5}$$

$$S_i^{-} = \left[\sum_{j=1}^{n} \left(v_{ij} - v_j^{-} \right)^2 \right]^{1/2} \tag{6}$$

After obtaining distance values from Positive and Negative Ideal solution, to find rankings of alternatives and best candidate for an administrative position, Equation 7 was used and ranking scores (CC_i) were calculated.

$$CC_i = \frac{S_i^{-}}{\left(S_i^{-} + S_i^{+} \right)} \tag{7}$$

$0<CC_i<1$

After obtaining the Positive and Negative Ideal Solutions, Ranking Matrix in Table 10 was created by using related formula. According to the rankings in Table 10 expert "C" is the best candidate for an administrative position, if demographic factors considered as main criteria are taken into account for the position.

Table 10. Ranking Matrix

	Distance from positive ideal solution	Distance from negative ideal solution	Ranking score	Ranking
A	0,121489368	0,209412921	0,178857421	2
B	0,190894746	0,192188734	0,141787441	4
C	0,164379683	0,215305906	0,160263672	3
D	0,104571883	0,208847309	0,188324385	1
E	0,214837843	0,097017618	0,087922599	6
F	0,209893082	0,179910891	0,1304411	5

With this expert system created in this study, demographic features of each employee gain importance as well as their mental workload during office hours for their promotion. This expert system software can be used as a decision support system for both promotions and performance awards for public or private corporations.

4. CONCLUSIONS

In this study by using the outputs of NASA-TLX method, an experts system which can choose an executive expert among the experts having different demographic features is created. For this ranking problem, the objective function is taken as minimization of mental workload. In future studies different objective functions and criteria can be considered for the same ranking problem. This will change our Decision matrix and Bilateral comparison matrix of main criteria. By adding more criteria, our expert system can be improved to give more accurate and precise results for the ranking problem.

Another output of this study is the fact that all scales of NASA-TLX have statistically significant effect on mental workload of TEYDEB's expert, except physical requirement scale. Therefore, for future studies a new mental workload index for TEYDEB can be created to get other scales for mental workload evaluation questionnaire. Also outputs of the first phase of this study can be used to develop a project assignment software for the experts of TEYDEB which considers the degree of project's difficulty, budget and area of expertise.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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