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The Impacts of Macroergonomics on Environmental Protection and Human Performance in Power Plants

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ABSTRACT

Human and his performance is a vital factor in protection of asset including environmental properties. The objective of this study was to evaluate the impact of total system design factors (TSD) on human performance in a power plant. The TSD factors are defined as design factors, which have impact on overall performance of the power plants in context of total human engineering or macroergonomics. The systems being studied are the control rooms and maintenance departments of a 2000 MW thermal power plant. To achieve the above objective, the TSD factors were addressed and assessed through a detailed questionnaire. The relationships between TSD factors and human performance were then examined through non-parametric correlation analysis (Kramer's Phi) and Kruskal-Wallis test of means. The results of this study show that the macroergonomic factors such as organizational and safety procedures, teamwork, self-organization, job design and information exchange, influence human performance in the power plant. The findings also suggest that the selected macroergonomic factors are correlated to human performance and must be considered, designed and tested concurrently with the engineering factors at the design phase of the system developmental cycle. Consequently, total system's faults and organizational errors are reduced to an acceptable level and human performance is significantly increased. The main goal in such program is customer's satisfaction (Internal customers). However, more elaboration on the scientific tools for implementation of TDS factors in context of human performance is also under investigation.

Keywords: *Total system design, Environmental protection, Power plants, Human performance, Ergonomic, Macroergonomics*

INTRODUCTION

The utilization of modern technology has developed industries that are more complex in the last decade. In the recent years, technological development has created major crisis accidents such this modern technology has been extensively questioned by scientists. One of the severe impacts of this crisis is the environmental property. For example, Chernobyl nuclear accident in 1986 has cost between 7000 to 10,000 lives (Shivastava, 1988). It cost about 26 billions for housing of 200,000 people who were affected by radiation. In addition, the total cost of this accident was estimated around b$ 400,000,000 and minimum time to eliminate

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the impact of radiation pollutant region was estimated around 200 years (Meshkati, 2002).
In complex systems such as process plants, petrochemical and chemical industries, human operator plays an important and critical role. The impact of human error can be sever and lead to catastrophic accidents in such systems. Analysis of these environmental disasters have shown in Table 1 (Azdeh et al., 2000).

Macroergonomics is an integrated developmental process, which is based on a series of well-defined phases. Macroergonomics requires equal consideration to all major components of the system such as human, hardware, software and organizational structures. Indeed, it is quite important to pay serious attention to human and organizational aspects of the macroergonomics process from early design phase.

Table 1: The causes of some major environmental disasters (Azadeh et al., 2000)

Name of accident	**Causes of accident/ Failure**				
	Managerial error	**Human factor**	**Inadequate interface design**	**Safety issues**	**Inadequate system design**
Chernobyl nuclear power plant accident (1986)	*	*	*	*	*
TMI nuclear power plant accident (1979)	*	*	*	*	*
Bhopal chemical processing plant accident (1983)	*	*	*	*	*
Aloha airlines accident (1988)		*			*
U.S. telephone network accident in Chicago suburb(1988)			*		*
Thirty major accidents in chemical plants (1985-1989)	*	*			
NASA's space shuttle explosion (1986)	*				*
Proctor& Camble Tylenol (1982)	*	*			*
U.S. public phone network outage (1991)	*	*	*		*
British Piper Alpha explosion (1988)	*				*

Total system design factors in context of human performance are referred to as socio-technical factors in context of system design. It should be noted that the engineering design process is often perceived as mainly technical activity, yet within engineering design organization it really only coheres as a social activity. This paper introduces the socio-technical factors as essential and vital part of the design process and prevention of accidents (and environmental protection) in power plants and because they are related to overall management and organization structures, referred to as TSD factors in context of human performance (Clegg, 2000; Lloyd, 2000; Sutcliffe, 2000).
TSD factors in context of human performance define the macroergonomics features of the system design and human performance engineering, whereas, the conventional system design factors in context of human performance define the ergonomics features of the system design and human performance engineering.

Ergonomy attempts to optimize the interaction between human operator and machine. It considers those factors of machine, design and work posture that affect the user interface and working conditions related to the job or task deign. In a macroergonomics study, the ergonomics factors are considered in parallel to organizational and managerial aspects of working conditions in context of a total system design. Moreover, it attempts to create equilibrium between, organization, operators and machines. It focuses on total "people-technology" systems and is concerned with the impacts of technological systems on organizational, managerial and personnel subsystems (Azadeh and Hooshiar, 1998; Hendrick, 1995).

MATERIALS AND METHODS

Macroergonomic factors in context of human performance are defined as factors influencing total system's performance, such as rules and procedures and information exchange between personnel/ departments. To measure the impacts of macroergonomic factors on human performance, a quesionnair was designed and handed out to all control room and maintenance operators. It was designed based on total system design (TSD) aspects of human performance in power plants. Moreover, key macroergonomics factors were included to evaluate human performance. The selected TSD factors are related to procedures, work assessment, teamwork, self -organization, information exchange and communication. They were inputted to the questionnaire and their statistical relationships to the human performance were examined through two non-parametric statistical (namely,Cramer's Phi and Kruskasl-Wallis) approach. The selected TSD factors in context of human performance were tested in the following format:

-Degree of familiarity with rules and procedures
-Supervisors' monitoring and assessment at work
-Reward for teamwork by supervisors
-Ease of contact with supervisors
-Problems with co-workers due to inter-organizational relationship
-Quality of perceived information from supervisors
-Quality of perceived information from co-workers
-Usefulness of informal information exchange
-Freedom for self-organized and individual decision-making

As mentioned, a set of non-parametric test of hypothesis was conducted to foresee if human performance was independent of the selected TSD factors. Furthermore, job pressures were selected as the factor representing human performance since it was identified as one of the most important human shaping factors (Wiens, 1996). The sources of job pressures in the power plants were classified as 1) workload, 2) stress and 3) time considerations (Bahr, 1997). Because workload was identified as the most influential source of job pressures, it was selected as the measure of human performance in this study. It was tested whether job pressures due to workload is influenced by the TSD factors. In addition, the difference between mean ratings of operators with respect to selected TSD factors were examined through Kruskal-Wallis test. All operators and supervisors of control rooms and maintenance departments participated in this study. Furthermore the study was based on entire populations in both department rather than sampling.

RESULTS

The Cramer's Phi statistic tests the null hypothesis (H0) of no correlation between the two variables against alternative hypothesis (H_1) of correlation between the two variables (Hinton, 1996). The results of the non-parametric Cramer's Phi correlation between human performance (job pressures) and the nine TSD factors are presented in Table 2.

As shown, there is strong evidence that the nine-macroergonomic factors are correlated with the job pressures at work. Furthermore, the job pressures at work are influenced by familiarity with organizational rules and procedures and information flows between co-workers as well as co-workers and supervisors. In addition, job pressures are positively correlated with teamwork. Operators who are rewarded for teamwork report lower level of job pressures and consequently produce higher performance. The freedom for self-organization is positively correlated with human performance. In summary, these findings suggest the positive impacts of macroergonomic factors on human performance.

Table 2: Test of correlation between human performances (job pressures) and the selected TSD factors

TSD factor	Cramer's Phi	*P*- value (α)
1. Degree of familiarity with rules and procedures	0.67	0.00000
2. Supervisors' monitoring and assessment at work	0.40	0.00900
3. Reward for teamwork by supervisors	0.55	0.00002
4. Ease of contact with supervisors	0.50	0.00002
5. Problems with co-workers due to inter-organizational issues	0.61	0.00000
6. Suitability of perceived information from supervisors	0.56	0.00000
7. Suitability of perceived information from co-workers	0.45	0.00008
8. Usefulness of informal information exchange	0.43	.00017
9. Freedom for self-organized and individual decision-making	0.50	.00002

To further our investigation, by using Kruskasl-Wallis test, series of comparative studies were performed between various groups of operators in the next section. It was examined if macroergonomic factors influence the human performance in particular and the system in general. To achieve this objective, two groups of operators are examined on the selected response variables. The selected response variables were the quality of information perceived from supervisors and co-workers and job pressures (human performance). The summary of the results are listed below:

Operators who received no on-the-job training report higher level of job pressures.

The quality of perceived information from supervisors is higher for the operators who receive on-the-job training.

Operators who do not receive safety training report higher level of job pressure. This with the above findings requires consideration of on-the-job and safety training as two TSD features at the design phase. For the power plant of this study in particular and other power plants with similar deficiencies in general, it requires the re-designing of the training system, such that it is spread to all sensitive areas of the plant.

Operators who are capable of locating emergencies report higher quality of perceived information from co-workers.

Operators who do not have any problem with organizational procedures report lower level of job pressures.

Operators who violate safety procedures due to job pressures report higher level of job pressures during routine situations.

Operators who do not have any problem with organizational procedures report higher quality of perceived information from supervisors.

Operators who do not have any problem using organizational procedures report higher quality of perceived information from co-workers.

Operators who do not violate safety procedures due to job pressures report higher quality of perceived information from co-workers. This and the last five findings highlight the importance of organizational and safety procedures as two vital elements of TSD in context of human performance. The standardization of organizational and safety procedures may be a good start for re-design of the existing procedural system. This may be achieved by implementation of ISO 9000 and 14000 and OHSAS 18000 which are international standards for documentation of organizational, environmental and hygiene and safety procedures, respectively.

Operators who have freedom to make decisions without continuous contact with others report higher quality of perceived information from supervisors.

Operators who cannot easily communicate with supervisors report higher level of job pressures.

Operators who can easily communicate with supervisors report higher quality of perceived information from supervisors.

Operators who do not have problem with co-workers due to inter-organizational issues report higher quality of perceived information from supervisors.

Operators who have problems with co-workers due to inter-organizational issues report higher level of job pressures.

Operators who are rewarded for teamwork report higher quality of perceived information from co-workers.

Operators who are rewarded for teamwork report lower level of job pressures. Clearly, teamwork is a key ingredient of the TSD in context of human performance (also see the last six bullets). Teamwork or groupthink must be spread from top to bottom in order to become most effective. This may be achieved through the deployment of re-engineering concept for the existing power plants (including the case of our study) and information exchange technology in context of information technology.

Operators who believed that there could be a better job design reported higher level of job pressures. This is an important finding, which reveal the current system of job design is partially rather than totally optimized. This is due to lack of considerations of the TSD factors of when the current system of job design was designed and implemented. This means the existing system of job design must be re-engineered.

The significant levels of the tests (α) on the quality of perceived information from supervisors (macroergonomic factors) and human performance (job pressures) are summarized in Tables 3 and 4, respectively. The last column in Tables 3 and 4 define the relative advantage of group 1 over group 2 in relation to the quality of information perceived from supervisors and co-workers, respectively. Furthermore, the relative statistical advantage of group 1 over group 2 is tabulated by the percent increase in quality of information perceived from supervisors and co-workers, respectively. The last column in Table 3 defines the relative advantage of group 1 over group 2 in relation to the job pressures. The significant difference between the groups of operators who are utilizing the macroergonomic factors and the groups who are not with respect to the response variables reveal that macroergonomic factors extensively influence the human performance in particular and the system in general.

Table 3: The significant level of test of comparison on the quality of information perceived from supervisors

Parameters	Difference in mean ranking		*P*- Value (α)	Relative Advantage (%)
	Group* 1	Group 2		
On-the-job training	65	21	0.0856	30
Problem with organizational procedures	46	13	0.0030	60
Rewarded for teamwork	38	29	0.0041	40
Individual decision-making capability	41	21	0.0454	30
Communicate with supervisors	43	19	0.0164	40
Problem with co-workers due to inter-Organizational issues	8	54	0.0123	32

Group*: Two compared groups, for example with and without “on-the-job training”

Table 4: The significant level of test of comparison on the job pressures (human performance)

Parameters	Difference in mean ranking		*P*- Value (α)	Relative Advantage (%)
	Group 1	Group 2		
Safety training	62	16	0.0924	30
Problems with organizational procedures	57	8	0.0100	40
Rewarded for teamwork	48	19	0.0009	50
Violate safety procedures	35	29	0.0030	70
Communicate with supervisors	34	11	0.0054	45
Problems with co-workers due to inter-organizational issues	54	8	0.0073	58
Believing a better job design is required	57	7	0.0139	45

The Kruskal-Wallis test of comparison between the two groups verifies and validates the previous results obtained from the test of correlation between TSD factors and job pressures. It can be concluded that TSD factors significantly influence human performance and therefore they must be considered and designed concurrently with other conventional hardware and software factors in order to optimize human performance in particular and the system in general.

DISCUSSION

The conventional design approach in power plants considers the engineering design parameters and ergonomics factors (in some cases). However, TSD approach of this study in context of human performance considers the engineering design parameters and macroergonomics factors. The impacts of macroergonomic factors on human performance and environmental protection aspects are shown in this paper. This is shown through design and evaluation of a detailed survey containing information about macroergonomic factors and human performance. It has been shown that a macroergonomic approach in context of human performance is much more efficient than a conventional design approach. This is shown through introduction of the macroergonomic model, applying the model in a power plant and showing its advantage through statistical analysis.

Non-parametric statistical analyses are used to show positive correlation between human performance and macroergonomic factors and to highlight the impact of macroergonomic factors on human performance. Furthermore, it is noted that by designing and implementing a macroergonomic approach, the system and its human element are totally rather than locally optimized in context of human performance.

It should be noted that the conventional design approach in context of human factors is only capable of identifying local or stationary human performance issues. This study shows that the employment of a macroergonomic approach is superior to conventional design approach.

The findings of this study have several design implications. Rules and procedures, information exchange between personnel (operators and supervisors) teamwork and self-organization may be designed and accommodated through standardization of the documentation process and automated tracking systems. This may be achieved through:

Implementation of ISO 9000 series of standards to promote standardization of documentation (rules, procedures, guidelines and communications) process.

Implementation of ISO 14000 to develop standardization of documentation process for environmental management systems.

Implementation of OHSAS 18000 to develop standardization of documentation process for safety management and occupational hygiene systems.

Design and implementation of automated information exchange in context of information technology. This would facilitate and enhances the existing information structure.

Design and implementation of the re-engineering concept may enhance organizational relationships and surveillance. Re-engineering is the collection of activities and mechanisms required changing from hierarchical to horizontal, flat and cross-functional structures based on teamwork within an organization.

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