American Journal of Applied Sciences 2 (9): 1301-1304, 2005
ISSN 1546-9239

The Impacts of Total System Design Factors on Human Performance in Power Plants

[1]A. Azadeh, [2]J. Nouri and [3,1]I. Mohammad Fam
[1]Research Institute of Energy Management and Planning and Department of Industrial Engineering Faculty of Engineering, University of Tehran, Tehran, Iran
[2]Department of Environmental Health Engineering, School of Public Health Tehran University of Medical Sciences, Tehran, Iran
[3]Department of Environmental Management, Graduate College of the Environment Science and Research Groups Islamic Azad University, Department of Occupational Health, Faculty of Health University of Hamadan Medical Science, Tehran, Iran

Abstract: The objective of this study is 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 an impact on the overall performance of the power plants in the context of total human engineering or macroergonomy. 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 selected TSD factors are related to procedures, work assessment, teamwork, self-organization, information exchange and communication. The results of this study show that the TSD 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 TSD factors correlate to human performance and must be considered, designed and tested concurrently with the engineering factors at the design phase of the system development cycle. Consequently, total system's faults and organizational errors are reduced to an acceptable level and human performance is significantly increased. This is a challenging task for designers of power plants but is required if we are facing unforeseen and complex issues of such systems in twenty-first century. The methodology discussed here may be easily extended to all types of power plants.

Key words: Ergonomic, human performance, macroergonomic, power plants, total system design

INTRODUCTION

Total System Design (TSD) is an integrated developmental process, which is based on a series of well-defined phases. Frequently in the past, designers used other approaches without giving much attention to human performance. TSD 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 TSD process from the early design phase.

Total system design factors in the context of human performance are referred to as socio-technical factors in the context of system design. It should be noted that the engineering design process is often perceived as mainly technical activity, yet within an engineering design organization it really only coheres as a social activity. This study introduces the social-technical factors as essential and vital part of the design process in power plants and because they are related to overall management and organization structures, they are referred to as total system design (TSD) factors in the context of human performance[1-3].

TSD factors in the context of human performance define the macroergonomics features of the system design and human performance engineering, whereas, the conventional system design factors in the context of human performance define the ergonomic features of the system design and human performance engineering. Macroergonomic and the concept of total human factors were developed by Hendrick and Meshkati and have been elaborated by other researchers[4-10].

Ergonomic attempts to optimize the interaction between human operators 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 ergonomic 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,

Corresponding Address: A. Azadeh, Research Institute of Energy Management and Planning and Department of Industrial Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran, Tel: 00989121221103 Fax: 00982166461680

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[11-13].

Macroergonomic adopts a more holistic approach to human factors' problems of manufacturing systems. It considers the whole and avoids the trap of dealing with specialties with which we feel comfortable. A macroergonomics program optimizes interface between operators, machines and organization by using teamwork, on-the-job training, well defined procedures and total management.

MATERIALS AND METHODS

TSD factors in the 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 TSD factors on human performance, a questionnaire was designed and handed out to all control room and maintenance operators. It was designed based on total system design 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 imputed to the questionnaire and their statistical relationships to the human performance were examined through two non-parametric statistics (namely, Cramer's Phi and Kruskasl-Wallis) approach. The selected TSD factors in the context of human performance were tested in the following format:

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

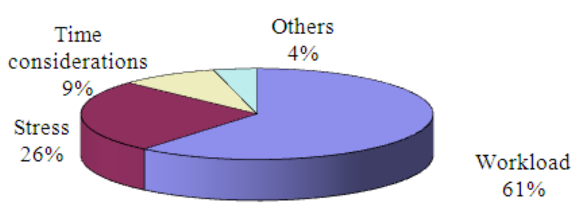

Fig. 1: Sources of job pressure in the power plant during emergencies

As mentioned, a set of non-parametric test of a hypothesis is conducted to foresee if human performance is independent of the selected TSD factors. Furthermore, job pressure is selected as the factor representing human performance since it is identified as one of the most important human shaping factors. The sources of job pressure in the power plants are classified as 1) workload, 2) stress and 3) time considerations. Because the workload is identified as the most influential source of job pressure, it is selected as the measure of human performance in this study (Fig. 1). It is tested whether job pressure due to workload is influenced by the TSD factors. Also, the difference between mean ratings of operators in respect to selected TSD factors are examined through Kruskal-Wallis test. For example, the operators who can easily communicate with supervisors compare with the ones who can't easily communicate with supervisors in respect to the level of job pressure.

RESULTS

The Cramer's Phi statistic tests the null hypothesis (H_0) of no correlation between the two variables against the alternative hypothesis (H_1) of correlation between the two variables [14]. The results of the non-parametric Cramer's Phi correlation between human performance (job pressure) and the nine TSD factors are presented in the Table 1. The test of the hypothesis is in the following general format:

H_0: The TSD factors are not correlated with job pressure due to workload

H_1: Otherwise

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

To further our investigation, a series of comparative studies are performed between various groups of operators in the next section. It is examined if TSD 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 are the quality of information perceived from supervisors and co-workers and job pressure. The Kruskasl-Wallis test performs an analysis that is very similar to an analysis of variance (ANOVA) on the ranks.

Table 1: Test of correlation between human performances (job pressure) 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	0.00017
9.	Freedom for self-organized and individual decision-making	0.50	0.00002

Table 2: The significant level of test of comparison of the quality of information perceived from supervisors

Difference in mean ranking Group 1	Group 2	P- Value (α)	Relative advantage (%)
With on-the–job training	Without on-the-job training	0.0856	30
No problem with organizational procedures	Having problems with organizational procedures	0.0030	60
Rewarded for teamwork	Not rewarded for teamwork	0.0041	40
With individual decision-making capability	Without individual decision-making capability	0.0454	30
Can easily communicate with supervisors	Can’t easily communicate with supervisors	0.0164	40
No problem with co-workers due to inter-organizational issues	Having problems with co-workers due to inter-organizational issues	0.0123	32

Table 3: The significant level of test of comparison of the job pressure

Difference in mean ranking Group 1	Group 2	Significant level (α)	Relative disadvantage (%)
Can easily communicate with supervisors	Can't easily communicate with supervisors	0.0073	58
Believing a better job design is required	Believing current system is ok	0.0010	300

The test is conducted when the assumptions for the parametric ANOVA cannot be made[15]. Furthermore, it assumes independence between subjects in conditions. This test also acts as verification and validation process of the previous test and almost the same types of results are reported in different formats. The general format for the test is as follows:

Ho: The two groups of operators have the same performance with respect to the response variable, where the response variables are the quality of perceived information from supervisors and co-workers and job pressure.

H_1: Otherwise

Operators who can't easily communicate with supervisors report higher levels of job pressure. Operators who can easily communicate with supervisors report higher quality of perceived information from supervisors. Operators who believe that there could be a better job design reported the highest level of job pressure.

This is an important finding which reveals 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 (P- Value) on the quality of perceived information from supervisors and co-workers (TSD factors) and human performance (job pressure) are summarized in Table 2 and 3, respectively. The last column in Tables 2 and 3 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 the 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 pressure. The significant difference between the groups of operators who are utilizing the TSD factors and the groups who are not with respect to the response variables reveal that TSD factors extensively influence the human performance in particular and the system in general.

The Kruskal-Wallis test of comparison between the two group verifies and validates the previous results obtained from the test of correlation between TSD factors and job pressure. 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, the total system design (TSD) approach of this study in context of human performance considers the engineering design parameters and macroergonomics factors. The impacts of TSD factors on human performance are shown in this paper. This is shown through the design and evaluation of a detailed survey containing information about TSD factors and human performance. It has been shown that a total system design approach in the context of human performance is much more efficient than a conventional design approach. This is shown through the introduction of the TSD 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 TSD factors and also to highlight the impact of TSD factors on human performance. Furthermore, it is noted that by designing and implementing a TSD approach, the system and its human element are totally rather than locally optimized in the context of human performance.

It should be noted that the conventional design approach in the context of human factors is only capable of identifying local or stationary human performance issues. This study shows that the employment of a TSD 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 series of standards to promote 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. The main goal in such program is customer's satisfaction. More elaboration on the scientific tools for implementation of TSD factors in the context of human performance is left for a full research paper in the future[16,17].

REFERENCES

1. Clegg, C.W., 2000. Sociotechnical principles for system design. Appl. Ergonom., 31: 463-477.
2. Lloyd, P., 2000. Storytelling and development of discourse in the engineering design process. Design Studies, 21: 357-373.
3. Sutcliffe, A.G., 2000. Requirement analysis for socio-technical system design. Information Systems, 25: 213-233.
4. Hendrick, H.W., 1995. Future directions in macroergonomics. Ergonomics, 38: 1617-1624.
5. Hendrick, H.W., 1987. Macro ergonomics: A concept whose time has come. Bull. Human Factors Soc., 30: 1-2.
6. Meshkati, N., 1991. Integration of workstation, job and team structure design in complex human-machine systems: A framework. Intl. J. Indust. Ergonom., 7: 111-122.
7. Meshkati, N., 1998. An integrative model for designing reliable technological organizations: The role of cultural variables. Position Statement for the World Bank Workshop on Safety Control and Risk Management (in Large-Scale Technological Operations), Washington, D.C., Oct. 18-20.
8. Kleiner, B.M., 1998. Macroergonomic analysis of formalization in a dynamic work system. Appl. Ergonom., 29: 255-259.
9. Kleiner, B.M. and C.G. Drury, 1999. Large-scale regional economic development: Macroergonomics in theory and practice. Human Factors and Ergonomics in Manufacturing, 9: 151-163.
10. Azadeh, M.A., A. Keramati and B. Jamshidnezhad, 2000. Enhancing the availability and reliability of power plants through macroergonomics approach. Energy 2000: Proceedings of the 8th Intl. Energy Forum, Las Vegas, Jul., 23-28.
11. Azadeh, M.A. and M. Hooshiar, 1998. An integrated macroergonomics model to enhance the productivity and working conditions of an assembly shop. CSME Forum SCGM, Ryerson University of Technology, Toronto, Canada, May., 19-22.
12. Hendrick, H.W., 1987. Organizational design. In G. Salvendy (Ed.) Handbook of Human Factors, New York: John Wiley and Sons.
13. Hendrick, H.W., 1995. Harmonizing re-engineering for true organizational effectiveness: A macroergonomics approach. Proc. Human Factors and Ergonomics Soc., 2: 761-765.
14. Hinton, P.R., 1996. Statistics Explained. New York, Routledge.
15. Hooman, H.A., 1994. Statistical Inference in Behavioral Research. Tehran, Parsa Press.
16. Azadeh, M.A., 2002. Design of intelligent integrated human engineering environment. 1st Intl. NAISO Cong. Autonomous Intelligent Systems, Feb., 12-15.
17. Azadeh, M.A. and N. Meshkati, Design and verification of an intelligent integrated environment for complex manufacturing systems. To be published.