Original Article

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Modeling an Integrated Health, Safety and Ergonomics Management System: Application to Power Plants

* ***Mohammad Fam I. PhD*** **, ***Azadeh A.,*** *** ***Azam Azadeh M. PhD***

**Dept. of Occupational Health and Safety, Faculty of Health, University of Hamadan Medical Science, Hamadan, Iran*
***Dept. of Industrial Engineering and Department of Engineering Optimization Research, Faculty of Engineering, University of Tehran, Iran*
****Dept. of Social Science, Al Zahra University, Tehran, Iran*

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Abstract

Background: This study presents a framework for development of integrated health, safety and ergonomic (HSE) in complex critical systems. Total ergonomics model considers conventional ergonomics factors as well as management and organizational factors.
Methods: Control room operation and maintenance department of a thermal power plant was chosen as the case of our study. To achieve the above objectives, an integrated approach based on total ergonomics factors was developed. Second, it was applied to the thermal power plant and the advantages of total ergonomics approach were discussed. Third, the impacts of total ergonomics factors on local factors were examined through non-parametric statistical analysis. Moreover, the importance and impacts of total ergonomics factors were shown through statistical tests.
Results: It is shown that total ergonomics model is much more beneficial than conventional approach. It should be noted that the traditional ergonomics methodology is not capable of locating the findings of total ergonomics model.
Conclusion: The distinguished aspect of this study is the employment of a total system approach based on integration of the conventional ergonomics factors with HSE factors.

Keywords: *Health, Safety, Environment, power plant*

Introduction

Conventional ergonomics approach is concerned with improving the interface design between human operator and machine (1). However, in complex manufacturing systems, without its upward integration with job of operators and organizational design of such systems, at best, it leads only to sub-optimization and, therefore, results in an inherent error- and failure-prone total system (2). Such a system, eventually, when faced with concatenation of certain events, would suffer from this `resident pathogen' (3). In fact, operators' error should be seen as the result of human variability, which is an integral element in human learning and adaptation (4). Thus, human error occurrences are defined by the behavior of total human-task-organizational system (5).

Finding the mechanisms that optimize the teamwork between operator and machine is one of the great technological challenges of the twenty first century (6). The technological challenge is to create an intellectual interface between human operators, machine and organizational structures (human error

Corresponding author: Azadeh A, E-mail: aazadeh @ut.ac.ir

control). In fact, organizational errors are often the root causes of human errors and man-machine failures (7). Therefore, the interface systems must be matched with operators' capabilities (8, 9). In addition, there is a need for an integrated design between operators, machines, management and organization (10, 11).

A total ergonomics program requires teamwork between operators and managers at all levels. Work group or teamwork ideas have been shown to enhance productivity and reliability of manufacturing systems. Several studies show how teamwork could eliminate the potential for confusion and enhance the productivity (12). The operators and supervisors should give each other necessary feedbacks. In fact, feedback is seen as a contingency leading to effective and cognitive outcomes, including level of attraction to the group, pride in the group, defensive feelings, and acceptance of the group problems (13). The supervisors should allow operators' opinion or questions. This can be developed during simulator or training exercises. This means that the supervisors must always participate with the operators in team skill training and feedback sessions following simulator or training exercises.

We need to adopt a more holistic approach to human factors problems of manufacturing systems. We must consider the whole and avoid the trap of dealing with specialties with which we feel comfortable. The total ergonomics approach optimizes interface between operators, machines and organization by using teamwork, on-the-job training, reliable safety programs, well-defined procedures and effective management. One of the first practical studies to examine total ergonomics components in a manufacturing system is presented in this study. In the next sections, the structure of the total ergonomics model is discussed. In summary, a total ergonomics model considers all of the conventional ergonomics design features and thus insures optimal ergonomics compatibility of the system components with the system's overall structure. In socio-technical terms, this approach enables joint optimization of the technical and personnel sub-systems and results in higher productivity and safety.

The objective of this paper is three fold. First, a general framework for development of the total ergonomics model is introduced. Second, it is described how total ergonomics model may be applied in practice to intensify the productivity and working conditions of manufacturing systems. Third, it is shown whether the total ergonomics model is superior to the conventional ergonomics approach. This study is among the first to examine the total ergonomics and conventional ergonomics factors in a manufacturing system. A 2000 MW thermal power plant was chosen as the case of our study. By a non-parametric statistical methodology the correlation of total ergonomics factors are examined against conventional (local) ergonomics factors. Also, the differences between mean ratings of operators in respect to particular total factors are examined through non-parametric analysis. Furthermore, the influence or impacts of total ergonomics factors on local factors are examined through non-parametric Cramer's Phi coefficient and Kruskal-Wallis tests.

Total Ergonomics Model

Total ergonomics model is the integration of conventional ergonomics factors and management and organizational factors. Furthermore, the total model requires the assessment of management factors, information flow (between departments, personnel and management) in addition to conventional ergonomics analysis. The general procedure of the total ergonomics model is shown in Fig. 1.

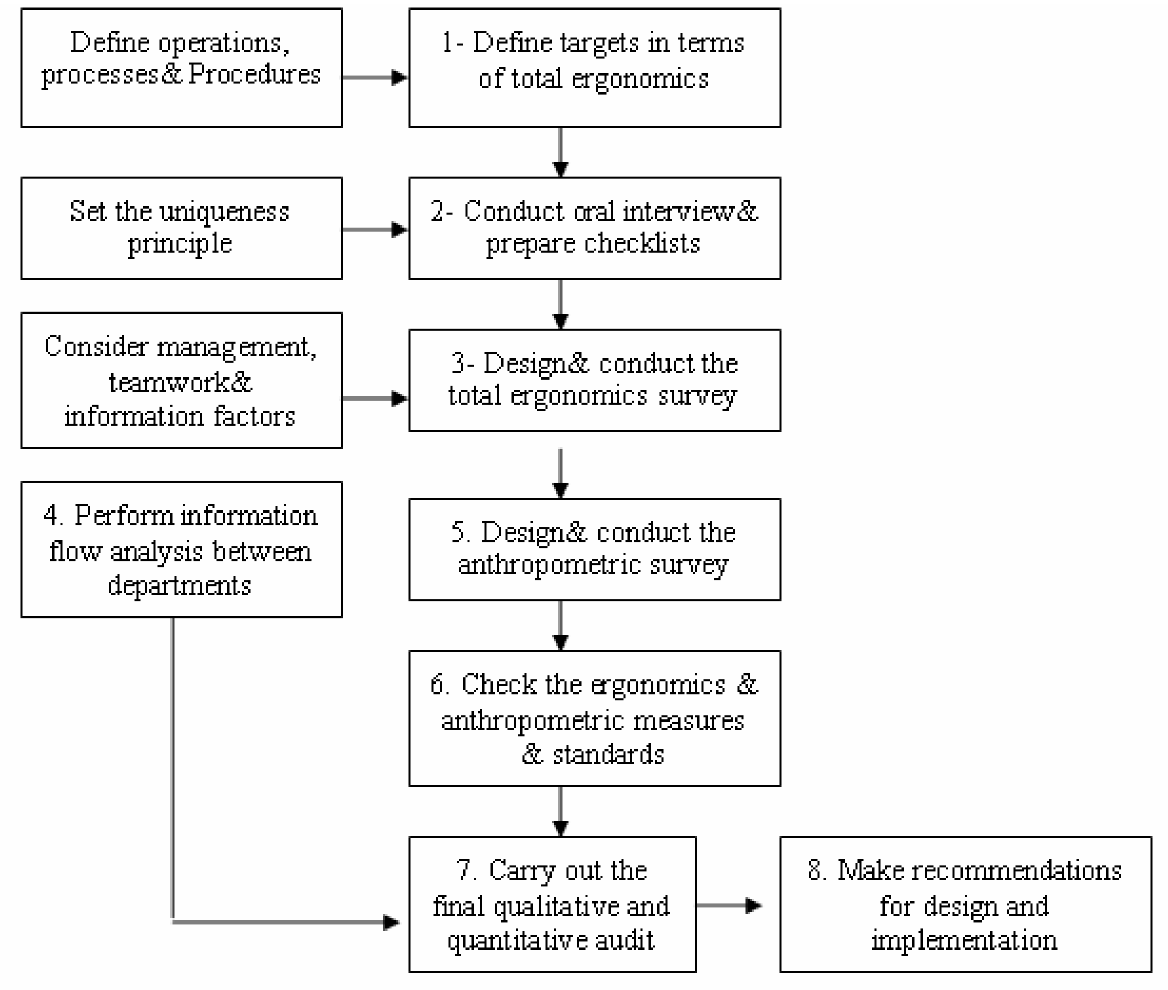

Fig. 1: The general steps required to achieve a total ergonomics model.

The two distinct features of the total model are shown in outboxes number 3 and 4. Other activities (boxes 1, 2, 5 and 6) are performed by a conventional approach.
As seen and like conventional approach, all procedures, processes and operations of the system under study must be defined. Second, managers and operators are interviewed to exhibit their opinion about the working conditions and ergonomics considerations. Third, a detailed questionnaire containing valuable information related to human factors, safety, management, teamwork and training are developed and presented to operators and managers to reveal the drawbacks and to identify the cause-and-effect relationships. Fourth, an integrated information flow analysis between departments (in our study between maintenance and control room departments) is performed to identify weaknesses and strengths about information flow. Fifth, a detailed ergonomics questionnaire concerning working postures, body movements and environmental issues is designed and conducted.
Also in each station, anthropometric and ergonomics measures was checked against standards. Finally, a final audit and a complete qualitative and quantitative (if applicable) analysis are performed to uncover hidden points (14). This approach would develop a

total rather than local ergonomics modeling. It must be noted that the total ergonomics model must be cautiously tailored and applied to the system under study. The two distinct features of the total ergonomics model are discusses in the next sections.

Total Ergonomics Survey

An effective and practical total ergonomics model should be designed for the real people in the loop, namely, operators and supervisors. Therefore before designing and implementing the total ergonomics survey, managers and operators of the system being studied are required to be interviewed to exhibit their opinion about the working conditions and ergonomics considerations. The results of interviewing method should enable us develop total ergonomics and anthropometric questionnaires with reference to existing standards in the field. Interview techniques should cover the issues related to safety and hygiene factors, teamwork, anthropometric measures, management and organizational factors, training and job satisfactions After the interviewing process, a detailed questionnaire must be designed by referring to the findings of the interview method and use of ergonomics, safety and organizational standards (15). The inquisition process must contain valuable and practical information related to human, safety, management and organizational factors. In addition, several questions concerning teamwork and training must be developed. The results of survey may be analyzed by statistical techniques such as pie chart, bar chart, non-parametric tests and correlation analysis. The findings of this study must stress weak and strong points regarding the above factors.

Information Flow Analysis

This part of study examines the flow of information between departments. Also, interpersonal communication problem between operators and operators and supervisors must be studied. This requires organizational and information structures including existing software, hardware, information systems, level of hierarchy, procedures and documentation be examined. The objective is to use all the formal means to uncover deficiencies in the flow of information within and between departments. To achieve the above objective, it is suggested that data flow diagrams (DFD) representing the information flow between and within departments be prepared. Second, documentation relating to work requests, work permits and quality of communications are studied and analyzed. The results of this technique together with findings of the total ergonomics survey should enable us locate major deficiencies in regard to the flow of information between and within departments.

After all the 7 steps are carried out, a final audit is conducted to uncover hidden points in relation to safety and ergonomics issues. This phase acts as a final check against total ergonomics factors discussed in the previous sections.

Materials and Methods

A 2000 MW thermal power plant composed of large control rooms and maintenance department was considered as the case of our study. The power plant is composed of four units and each two units are controlled by one control room. Maintenance department is composed of several machine shops, technicians and engineers. The objectives of the total ergonomics model were defined as:

- Improvement of working conditions.
- Reduction of lost workdays as the result of injuries.
- Use of proper operating procedures for operators.
- Identifying organizational deficiencies which degrade human performance
- Enhancing the availability of the power plant through design of total ergonomics model.

Note that the last two objectives (four and five) are strictly related to total ergonomics approach and could not be achieved through the conventional approach. All operators and supervisors of the control rooms and maintenance department were involved in our study. The total approach discussed in this paper was applied to the power plant. For the accomplishment of total ergonomics program, the rules and procedures, operations and processes of the shop was carefully studied. To help the ease of comprehension, a detailed flowchart and a schematic diagram were prepared.

Results

The most important findings of the interview methods with operators and managers are as follows:

- Moderate to high workload level in several workstations.
- Safety procedures are violated.
- Protective and safety equipment are not used.
- Operators complaining of back pains.
- High level of stress in the control rooms.
- Lack of teamwork between operators and supervisors in both maintenance and operation departments a total ergonomics survey was developed and presented to operators and supervisors. Some questions are presented in Table 1 which suggests workstation and organizational design issues. In fact, question number 5, 6 and 8 are related to the total ergonomics approach discussed in this paper. They are not considered in a conventional ergonomics approach. In addition, certain pressures that push operators override safety precautions are summarized in Figure 2 that suggests poor job design and imbalance of operators' workload level during emergencies. Furthermore, a high workload level is due management and organizational issues not considered in a typical conventional approach.

Table 1: Selected questions from total ergonomics survey

Question	Percent Responded		
	Yes	No	Uncertain
1. Is there formal on-the-job training at work?	76.8	23.2	0
2. Is there training about safety procedures & precautions?	91.9	8.1	0
3. Do you need to memorize rules & procedures?	83.7	9.3	7
4. Are you able to figure out what causes an accident?	93	2.3	4.7
5. Are you familiar with organizational rules & procedures?	33.7	10.5	54
6. Is there any financial reward for as a team?	44.2	24.4	31.4
7. Do you have difficulty with procedures during emergency or increased demand?	27.9	40.7	31.4
8. Are there pressures that could push you override safety precautions?	57	30.2	12.8
9. Should there be a better workstation design?	73.3	3.5	23.2

A complete ergonomics and anthropometric study was conducted throughout the control rooms and maintenance department. The results of this study shows:

- Poor workstations design
- Improper utilization of equipment and instruments.
- Inappropriate labeling and coding procedures.
- Anthropometric and ergonomics measures were checked and measured against acceptable standards. Some of the most important findings of this study are as follows:

- There needs to be a balance between maintenance department's temperature and humidity.
- Incompatibility between panel dimensions and operators' natural dimension in the control rooms.
- Noise level in control rooms needs to be reduced to the standard level.
- There is insufficient lighting in the maintenance workshops.

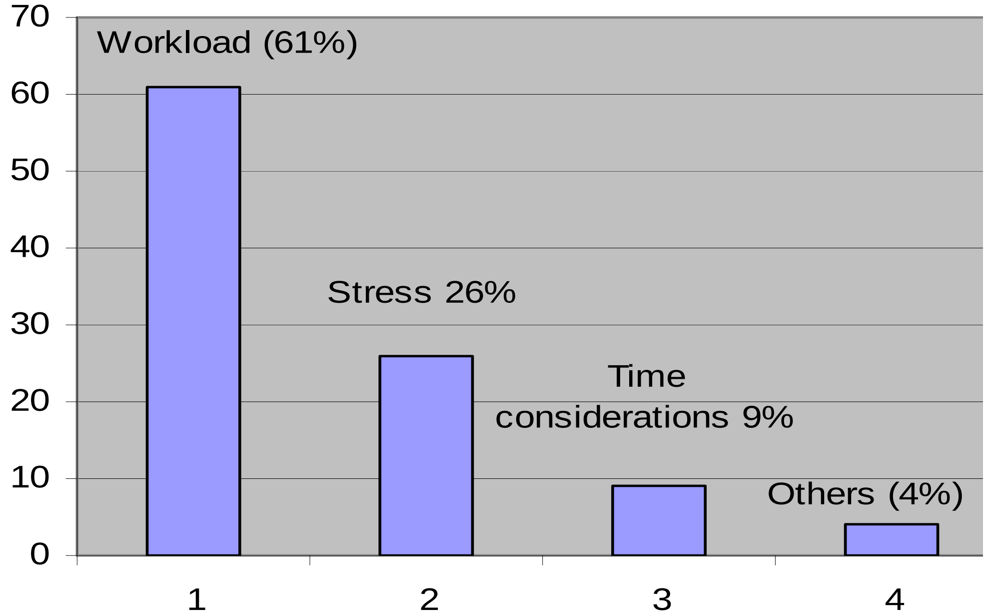

Fig. 2: Certain job pressures during emergencies in the control rooms

Information flow between control rooms and maintenance departments is analyzed through historical data, order forms and other forms exchanged between the two departments. Also, certain complementary questions are included in the total ergonomics survey which together with information flow assessment revealed certain shortcomings with the flow of information between the two departments. Finally, a final audit was conducted as a complementary technique to unveil forgotten and unseen issues in the control rooms and maintenance workshops. The results show several problems concerning local and total ergonomics factors. For instance, proper protective equipment was not worn (local) and safety procedures were violated by operators of a welding workstation (total factor).

The most important findings of the total ergonomics approach are listed as follows:

1. Spread teamwork and group think
2. Re-design of information flow between maintenance and control rooms.
3. Prepare sufficient organizational support for control room operators.
4. Develop a set of well-defined procedures for control room operations.
5. Optimize workload level of operators.
6. Some workstations of the maintenance department must be redesigned.
7. Utilization of safe and conventional protective equipment.
8. Modifications of coding and labeling in control rooms.

It should be noted that a conventional ergonomics approach could only locate the local issues addressed in the last four bullets (and probably some portion of bullet number 4). This is why designing and implementing the conventional ergonomics approach would result in local rather than total optimization of human performance. The company is at stage of carrying out the findings of our study and consequently improving productivity and reliability of control rooms and maintenance operations of the power plant.

In this section a set of test of hypothesis is conducted to foresee if local factors are independent of total ergonomics factors. Also, the differences between mean ratings of operators in respect to particular total factors are examined through Kruskal-Wallis test. For example, the operators who can easily communicate with supervisors are compared with the ones who can't easily communicate with supervisors in respect to the level of job pressures. Local factors are defined as factors affecting ergonomics conditions stationery such as job pressures or evaluation techniques. Total factors are defined as factors influencing total system's performance such as rules and procedures, information exchange between personnel/departments. To show if the total ergonomics approach is superior to conventional ergonomics approach, we need to show the total factors are influencing conventional (local) factors. A set of total factors are identified from one of the questionnaire and their statistical relationships to the local factors are examined through a non- parametric (namely, Cramer's Phi) approach. The total factors chosen are as follows:

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

The results of the non-parametric Cramer's Phi Coefficient between the local ergonomics variable and the nine total ergonomics variables and the results of the Kruskal-Wallis tests are summarized in the Table 2 and 3, respectively.

It should be noted that the number 1 in the first column refers to the job pressures (local variable). As shown there is strong evidence that the nine total 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 and co- workers and supervisors. Also, job pressures are positively correlated with teamwork (work relationship with supervisors). In summary, these findings show the positive impacts of local on total ergonomics factors and to further our investigation, series of comparative studies are performed between various groups of operators in the next section. It is examined if total ergonomics factors influence the human performance in particular and the system in general.

Table 2: The Cramer's Phi between local and total factors in the maintenance department

Local Variable	Total Variable	Cramer's Phi	Significant Level (alpha)
1	2	.67	.00000
1	3	.40	.00900
1	4	.55	.00002
1	5	.50	.00002
1	6	.61	.00000
1	7	.56	.00000
1	8	.45	.00008
1	9	.43	.00017
1	10	.50	.00002

Table 3: The results of Kruskal-Wallis test on difference on ranks

Difference in mean ranking of 2 groups of operators		Response variable	Significant level
Group I	**Group II**		
Operators with on-the-job training	Operators with no on-the-job training	Job pressures	0.0924
Operators with on-the-job training	Operators with no on-the-job training	Quality of perceived information from supervisors	0.0856
Operators with safety and accident prevention training	Operators with no training	Job Pressures	0.0100
Operators capable of locating emergency situations	Operators not capable of locating emergency situations	Quality of perceived information from co-workers	0.0694
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Quality of perceived information from co-workers	0.0609
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Quality of perceived information from supervisors	0.0003
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Job Pressures	0.0009
Operators having problems using procedures during emergency	Operators having no problem using procedures during emergency	Quality of perceived information from supervisors	0.0011
Operators who are rewarded for teamwork	Operators who are not rewarded for teamwork	Job Pressures	0.0030
Operators who are rewarded for teamwork	Operators who are not rewarded for teamwork	Quality of perceived information from supervisors	0.0041
Operators who violate safety procedures	Operators who don't violate safety procedures	Job Pressures	0.0054
Operators who can easily communicate with supervisors	Operators who cant easily communicate with supervisors	Job Pressures	0.0073
Operators who can easily communicate with supervisors	Operators who cant easily communicate with supervisors	Quality of perceived information from supervisors	0.0164
Operators with problems with co-workers	Operators with no problem with co-workers	Job pressures	0.0139
Operators with problems with co-workers	Operators with no problem with co-workers	Quality of perceived information from supervisors	0.0123
Operators with individual decision making capability	Operators with no individual decision making capability	Quality of perceived information from supervisors	0.0454
Operators believing a better job design is required	Operators believing current system is Ok	Job pressures	0.0010

As seen we can conclude that total factors significantly influence human performance and therefore they must be considered and designed concurrently with the local factors in order to optimize human performance in particular and the system in general.

Discussion

The importance of a total rather than a local ergonomics approach is shown in this paper. It is noted that by designing and implementing a total ergonomics approach, the system and its human performance are totally rather than locally optimized. It should be noted that the conventional ergonomics approach is capable of identifying local or stationary ergonomics issues (16). The distinguished aspect of this study is the employment of a total system approach based on integration of the conventional ergonomics and management factors. To conduct a total ergonomics study, we must consider the whole and avoid the trap of dealing with specialties with which we feel comfortable. A well defined practical total ergonomics program requires teamwork between operators and supervisors at all levels. The total approach should be cautiously carried out to avoid local or short term improvements. This requires a team of experts specializing in human factors, organizational design and statistics (17). Moreover, the experts should be familiarized with the idea of total ergonomics. It should be noted that each system is unique and the problem solving approach of each system must be based on systems uniqueness philosophy.

The importance of a total rather than a local approach is said best by Peter Drucker (18). He states that the emerging theory of manufacturing will require that every manufacturing manager be responsible for integrating people, machines and time (18). The manufacturing managers need to adopt a more systemic approach understanding the complex interrelationship in the system. Systemic understanding is difficult to achieve, but is necessary if we are to face with increasing uncertainties and competitions of manufacturing systems in the twenty first century.

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