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# A Total Ergonomic Design Approach to Enhance the Productivity in a Complicated Control System

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**Abstract:** The presented study described a total ergonomic design approach, which would enable designer to increase the productivity of a complicated control or a continuous process system by optimizing the human factors at work. This study is among the first to examine traditional ergonomics and macroergonomics integrally for designing more efficient work conditions. Control room and maintenance departments of the large and complex thermal power plants in Iran were chosen as the case of this study. To achieve the above objective, first the existing system was identified by applying various methods for data gathering. All system components, observed in accordance to the prepared checklists. Then managers, supervisors and operators, were selected and interviewed and major problems in relation to human factors engineering were discussed and identified. Based on interview feedback and our thorough comprehension of the process, operations and information system, five questionnaires were designed. The surveys contain valuable information related to ergonomics, anthropometry and macroergonomics concepts, such as interface design, training, safety, equipment, teamwork, managerial and organizational factors. In addition, anthropometric factors were measured in each unit and the results were examined against the exist standards. Finally, a comprehensive qualitative analysis and a final audit were performed to identify hidden points. The results of this integrated model revealed several problems, in regard to microergonomics and macroergonomics. The distinguished aspect of this study is the employment of a total system approach base on integration of the traditional human factors engineering (ergonomics) techniques as well as macroergonomics techniques.

**Key words:** Productivity, ergonomic, macroergonomic, safety

## INTRODUCTION

Human engineering techniques concerned with improving the interface design between human operator, machine and system. However in complex 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 inherently error and failure-prone total system. Such a system eventually, when faced with concatenation of certain events, would suffer from this resident pathogen (Reason, 1992; Perrow, 1986; Meshkati, 1991). In fact, operators' error should be seen as the result of human variability, which is an integral element in human learning and adaptation (Rasmussen, 1991; Rasmussen and Batstone, 1989; Rasmussen, 1990; Meshkati, 1988). Thus human error occurrences are defined by the behavior of total human-task-organizational system.

Finding the mechanisms, which optimize the teamwork between operators and machine, is one of the great technological challenges of the twenty first-century (Browning, 1990). The technological challenge is to create an intellectual interface between human operators, machine and organizational structures. In fact, organizational errors are often the root causes of human errors and man-machine failures (Pate-Cornell, 1990; Perrow, 1983; Kawowski, 1991). Therefore, the interface systems must be matched with operators' capabilities. In addition, there is a need for an integrated design between operators, machines, management and organization.

Microergonomic strives to optimize the interaction between human operator and machine. It considers those factors of machine, design and work posture which affect the user interface and working conditions related to the job or task design. In a total ergonomic study the

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ergonomics factors in parallel to the organizational and managerial aspects of working conditions in a context of a total system approach are considered. Moreover, it attempts to create equilibrium between, organization, operators and machines. It focuses on overall people-technology systems and is concerned with the impacts of technological systems on organizational, managerial and personnel sub systems (Hendrick, 1987a,b; Azadeh, 1996). In fact we can define the total ergonomics studies as an approach, applying both micro and macro ergonomics in order to optimize the human power performance in his workplace and his organization as well.

A well-defined macroergonomics program requires teamwork between operators and managers at all level. Work group or teamwork concepts have been shown to enhance productivity (Sundstorm *et al*., 1989; Turner, 1989; Hart *et al*., 1990). The operators and supervisors should give each other necessary feedback. 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 (Brehmer, 1988; Raudsepp, 1983; Harmon and Rohrbaugh, 1990). The managers and supervisors should permit operators' input or questions. This can be developed during simulator or training exercises.

Considering the optimal decision styles of the crew of operators working together could optimize teamwork. Decision style model is an ideal tool for assessing coordination and creating teamwork between operators and machines (Driver, 1983; Driver *et al*., 1990). This model suggests that environmental load systematically affect the complexity of information processing in persons in an inverted-u shape function. So increasing the environmental pressure will decrease the ability of thinking and performing.

We need to adopt a more holistic approach to human factors problems of manufacturing systems, specially when we are dealing with complicated and complex systems in which any tiny neglecting can result in bad events that could not be compensate easily. We must consider the whole and avoid the trap of dealing with specialties with which we feel comfortable. An holistic human factors program ( total ergonomic design ) optimize interface between operators, machines and organization by utilizing teamwork, on-the-job training, reliable safety and ergonomics program, well defined procedures and effective management. This study presents one of the first practical studies to examine macroergonomics components as well as traditional ergonomics factors in a thermal power plant system.

The objective of this paper is to present a holistic model for analyzing and designing the efficient integrated man-machine systems, which we called "Total Ergonomic Design Approach". This model is based on some special methodologies that will be explained in this paper. Respecting to these methodologies we prepare an algorithm for indicating the necessary stages that must have been passed in order to developing this model. This algorithm can be applied for analyzing many systems such as that power plant which we use as our case study. The results of our study declares that using the aspects of macroergonomics, leads us to a more efficient design for the working environments, interfaces and work stations. In fact total ergonomic design approach must be considered by any designer for gaining the global optimization.

## METHODS

To achieve the above objective a hierarchical approach based on several distinct techniques is employed. The prescribed algorithm is based on a set of well defined, hierarchical steps in order to develop a total ergonomic design model for a specific system being studied. These steps are accomplished in three discrete phases which are Identifying the system, Analyzing the results and Designing (Developing) a new system. In fact, any attempt for designing or optimizing a system, have to be started with identification. This step can be passed by data gathering techniques, successfully. Then after checking the validity of results, the designer must analyze the gathered information to find out the deficiencies of the under studying system and finally the suggested system must be prepared (Bailey, 1989; Eastman Kodak Co., 1983; 1986).

In identifying phase all procedures, processes, components and operations of the system under study must be fully comprehended. Some techniques are employed for this reason that we are trying to explain them in the following:

**Observation method:** For conducting this method, objectives of the investigation must be settled, first. In fact understanding the problem and the objectives of the survey is a really important matter. Respecting to the objectives, some notes will be pointed out and consequently some checklists will be developed for leading the directions of observation and also the other methods. These checklists will clear the total ergonomic concepts that must be observed during research and can be used as a guideline for investigating the total ergonomic factors.

**Interview method:** An effective and practical integrated ergonomic and macroergonomic model should be designed for the real people in the loop, namely, operators, supervisors and managers. Therefore, managers and operators are required to be interviewed to reflect their opinion about the working condition and ergonomics considerations. This technique should cover the issues related to: safety, teamwork, anthropometric measures, management factors, relationships, documentation, standards, training and etc. The results of interviewing method would enable us to develop a total human factors and anthropometric questionnaire discussed in the following as another method for data gathering.

**Task and method study:** This technique is to study all rules and procedures that construct work and information system relationships. For this reason all the components should carefully studied and the existing methods of working, required to be revised. In this method, all the sub systems must be surveyed according to documentation, existing rules and procedures and organizational responsibilities and information relationships. Task descriptions also, should be found out in this step. Our experiences reveal that flowcharts and relationship diagrams are ideal tools to apprehend the operations and processes of the studying system. Moreover, a detailed flowchart and a schematic diagram could help us locate weak points and critical areas.

**Questionnaires:** A detailed questionnaire must be designed and presented to operators by referring to the findings of the interview technique and utilization of human factors, safety and organizational standards. The inquisition process must contain valuable and practical information related to human, safety, management and organizational factors In addition; several questions in regard to teamwork and training must be developed.

**Anthropometric survey:** At this stage, a detailed anthropometric questionnaire is developed and presented to all operators. The questions must be designed by referring to the results of interview technique and employment of anthropometric and ergonomics standards. The survey may contain information about working postures, height, weight, seating position, standing position, noise, light, pollution and etc. In addition the anthropometrical factors must be measured carefully, by using the ergonomic measurement devices. The critical factors in relation to working condition must be introduced. For instance, a high percentage of the operators claiming moderate to high pain or tiredness in their hands could be indicative of improper height of workstations or unsuitable instruments and etc.

In evaluation phase, all the diverse data which have been gathered by foretelling techniques, categorized in special tables and diagrams and will be analyzed by researcher in order to prepare the diagnostic micro and macro ergonomic system. It must be noted that each system is atypical and the problem solving approach of each system must be based on systems uniqueness philosophy. This means each project is unique and requires an approach that dwells on its own contextual requirements. Thus the methodologies required to achieve an integrated ergonomics and macroergonomics program so a total ergonomic approach should be employed and an integrated concept must be considered.

The analysis techniques are more various than the identification' methods, but we divide them into two main categories: quantitative and qualitative methods. In fact all the mathematical based technique which use the statistical aspects and methods or measuring techniques for anthropometric design and layout development may be considered as quantitative methods. The results of much identification' surveys may be analyzed by quantitative methods such as statistical hypothesis tests, pie charts, bar charts, t-test, correlation analysis and analysis of variance. The results of this study must stress weak and strong points in regard to the above factors.

Moreover, anthropometric measures should be checked against standards in each single workstation. Measures are related to operators, workstations, instruments and work environment. They are categorized as: height, width, length, reach, noise, humidity, temperature, pollution, illumination, light and weight. An anthropometric measurement is a complementary analysis technique to anthropometrics survey explained in the pervious section. The results should help us locate stationary human factor deficiencies and safety and environmental issues.

Finally a complete qualitative analysis is conducted to uncover hidden points in relation to safety and ergonomics issues. This step acts as a final check against macroergonomics factors discussed before. The analysis of macroergonomics factors often needs qualitative analysis as well as some of complicated ergonomics factors. The lack of standards and have not any numeric method in most of macroergonomic aspects, causes this matter and approve the necessity of using qualitative analysis. In this method first, all pervious findings are reviewed to expose hidden macroergonomics issues such as managerial or training problems. Second, the studying system must be carefully visited to unveil hidden issues. Totally the results of discussed methodologies would

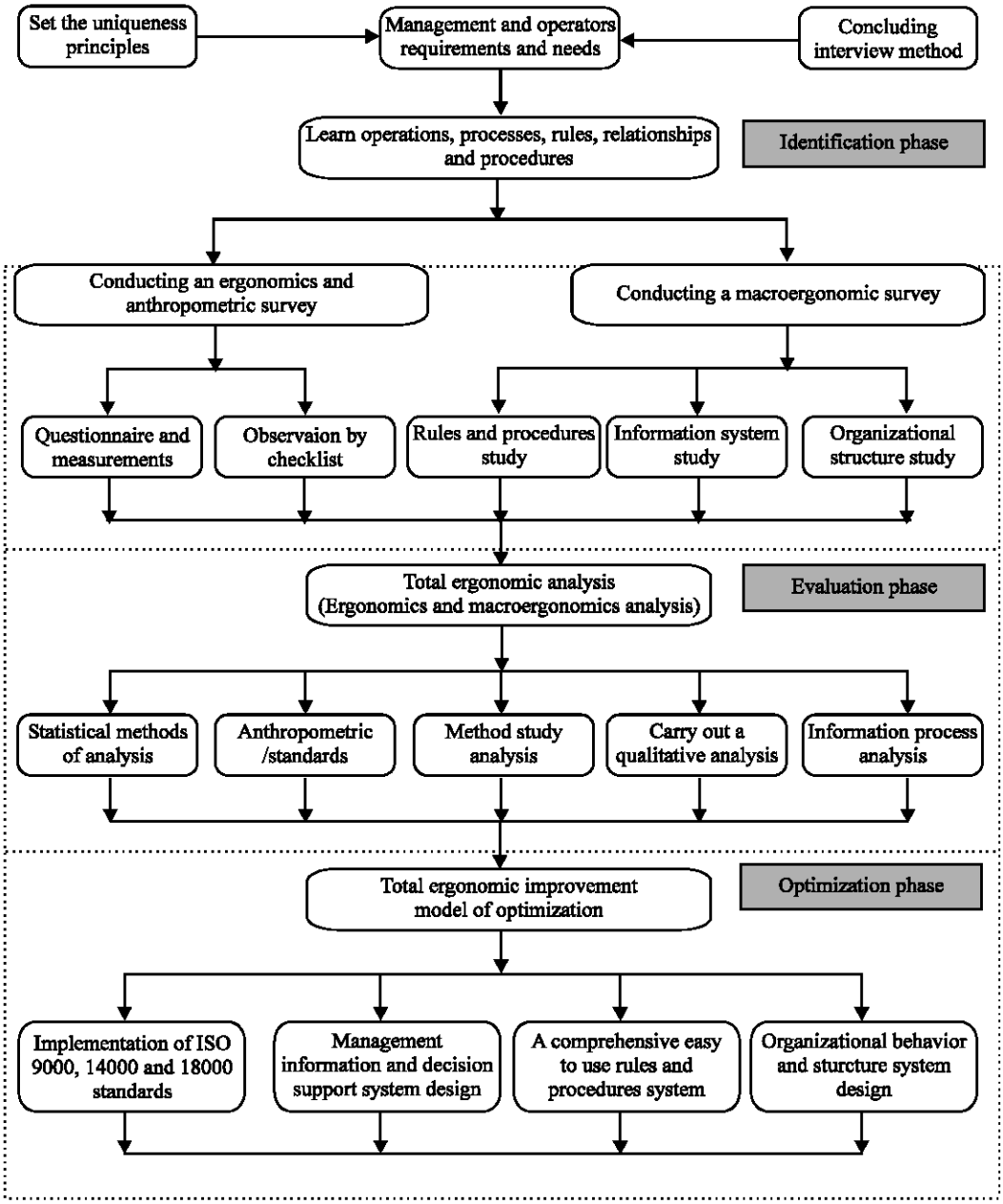


Fig. 1: The general steps required achieving total ergonomic design program

highlight major deficiencies and enable us to implement an integrated ergonomics and macroergonomics in the supposed system.

In developing phase the results of two discussed phases, must be understood carefully in order to prepare a practical suggestion that can be used as a diagnose for decreasing the deficiencies and increasing the efficiency, all over the studying system. Considering the obtained results of analyzing phase, researcher should develop a new model for designing: interfaces, work environment, work stations, organizational structure and behavior, methods of relations, communication directions, teamwork and etc. This model must be based on ergonomics standards and managerial concepts. Implementing a total system design or developing a diagnostic suggestion can be the real output of such studies. Our experiences indicate that using this algorithm; can be successful for increasing the productivity of the whole system outputs.

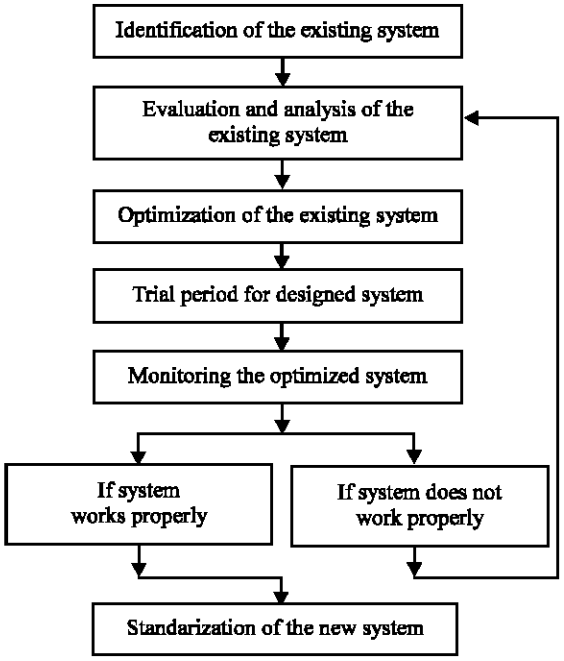


Fig. 2: The cycle of total ergonomic design program as an optimizing method

Figure 1 and 2 are to presents a schematic diagram for introducing this total system approach as a flowchart and the optimized cycle of total ergonomic design program.

## RESULTS AND DISCUSSION

One of the great thermal power plants in Iran was considered as the case of our study. The managers were familiarized with the benefits of utilizing a total ergonomic approach to enhance the productivity at the power plant during a short seminar. The objectives of this investigation were defined as improvement of working conditions, reduction of lost workdays as the result of injuries, utilization of proper operating procedures for operators and reduction of plant' trips statistics during the year.

**Identifying phase:** Maintenance shops and control rooms were selected and all operators and supervisors, also the managers were involved in our study. The hierarchical algorithm prescribed in this paper was applied to the power plant. For the successful implementation of macroergonomics program, the rules and procedures, operations and processes, relationships and communications were carefully studied. A detailed flowchart and a schematic diagram were developed. The questionnaires were designed and presented to all operators. Also a complete anthropometric study was conducted. All the gathered data were analyzed, by respect to ergonomic standards and macroergonomic rules. The statistical analysis, comparing to standards and organizational studies, were conducted as analyzing methods.

**Evaluation phase:** The results show numerous problems in regard to microergonomics and macroergonomics conditions. Poor workstation and job design, not efficient interfaces, lack of training and teamwork, lack of well defined rules and procedures, lack of job descriptions, not enough light and dangerous situations for working are the most important findings of this research. The results of questionnaires also were as useful as an analyzing device. All the results evaluated as an independent statistics' variable and also they investigated in meaningful pairs of dependent statistics' variables by using analysis of variance method. The statistics' analysis results were compared with existing standards and the differences were marked for more evaluations.

**Developing phase:** Then as a solution we design a total ergonomic system based on the existing system of power plant. All the procedures documented in accordance with ISO 9000 series standards of quality assurance, the descriptions of each one defined, the ergonomic conditions improved and a training plan prepared. The plant is at the stage of implementing our system for improving productivity and reliability.

## CONCLUSIONS

It should be noted that the traditional ergonomics techniques would not have been able to locate all of the preceding problems. The distinguished aspect of this study is the employment of a total system approach based on integration of the traditional human factors as well as macroergonomics factors. To conduct an integrated ergonomic study, we must consider the whole and avoid the trap of dealing with specialties with which we feel comfortable in conducting such a study. Such a program requires teamwork between operators, supervisors and managers. The hierarchical technique should be cautiously implemented to avoid local or short-term improvements. This requires a team of experts specializing in human factors, organizational design and statistics.

Moreover, the experts should familiarize with the concept of macroergonomy. It should be noted that each system is unique and the problem solving approach of each system must be based on systems uniqueness philosophy. In order to create an intellectual interface between operators, machines and management, the following steps are suggested:

- Human factor designers must utilize an integrated method to identify the gaps at various workstations and overlooked weak points.
- Design and utilization of instruments and equipment must be based on simplicity, flexibility, visibility and accuracy.
- Develop a set of rules and procedures, which are acceptable and easy to use by team of operators.
- Provide on-the-job training to operators using simulators and training classes.
- The supervisors should foster a sense of unity by convincing the operators that cooperative work serves a purpose that is superior to their independent contributions.
- Providing automated information to work groups may increase performance by providing the capability to detect and correct errors and consequently higher productivity.
- The design philosophy and basis of and integrated macroergonomics program is implemented and functions properly.

Peter Drucker states that the emerging theory of manufacturing will require that every manager be responsible for integrating people, machines and time (Drucker, 1990). The managers need to adopt a more systemic approach understanding the complex interrelationships 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.

## FURTHER RESEARCH DIRECTIONS

We have developed an integrated approach to study ergonomics and macrogramics issues to complicated control systems. This approach is applied in a large power plant and the results have been presented. The approach that developed here is useful for further ergonomics an macroergonomics studies. Now a days organizational aspects of information technology and information systems (IT, IS) play vital role in macroergonomics studies. Infact, in any macroergonomics study regardless of theoretical or practical must consider IT, IS aspects of organization (Boyer *et al*., 1997; Brynjolfsson and Hitt, 2000; Hitt and Brynjoflsson, 1996). Specifically, advanced digital control equipments are introduced and utilized in control rooms. Advanced technologies need new organizational infrastructure, which could be considered in a macroergonomics study since it looks at the whole organizational infrastructures. We therefore propose to study the macroergonomics aspects of IT,IS as the future application of the approach discussed in this study.

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