MACROERGONOMICS: A WORK SYSTEM DESIGN PERSPECTIVE

MICHELLE M. ROBERTSON
Liberty Mutual Research Center for Safety and Health
Hopkinton, MA 01748. michelle.robertson @libertymutual.com

ABSTRACT

Incorporating a macroergonomics approach, or work system design perspective, when new technologies are introduced can be beneficial and contribute to individual, group and organizational effectiveness. Based on the conceptual underpinnings of the sociotechnical system theory, macroergonomics integrates a work system analysis approach to understanding the technological, organizational, psychosocial, and physical work sub-systems and their interactions. An overview of macroergonomics, the concept and its applicability to designing work systems is described. Successful components and factors of incorporating a macroergonomic perspective in designing work systems to address technological and organizational change are presented. Macroergonomic models examining the impact that new office technologies have when introduced into an organization are explored, including designing office work systems. In conclusion, a case study illustrating how macroergonomics was applied to designing and implementing a human factors training program to change the safety climate of an organization is discussed.

Key words: Macroergonomics, work system design, sociotechnical system

INTRODUCTION

Macroergonomics can be viewed as a top down sociotechnical systems approach to the design of work systems and the application of an overall work system design of the human-job, human-machine, and human-software interfaces (12; 9). Dray (7) defines macroergonomics as a three generation paradigm: 1) user-machine interface; 2) group-technology interface and 3) organization-technology interface. Continuing with this paradigm, Hendrick (9) proposes that a human-system interface technology has at least five clearly identifiable subparts, each with a related design focus: 1) Human-machine interface technology, or hardware ergonomics, 2) Human-environment interface technology, or environmental ergonomics, 3) Human-software a interface technology, or cognitive ergonomics, 4) Human-job interface technology, or work design ergonomics, and 5) Human organization interface technology, or macroergonomics.

Macroergonomics is human-centered because it considers the worker's professional and psychosocial characteristics in designing a work system and subsequently carries the work system design through to the ergonomic design of specific jobs and related hardware and software interfaces (9). Integral to this human-centered design process is joint design of the technical and personnel subsystems, using a humanized task approach in allocating functions and tasks. Participatory ergonomics is a primary methodology of macroergonomics involving employees at all organizational levels in the design process (13).

Effective macroergonomic design drives a number of aspects of the microergonomic design of the work system and thus ensures ergonomic compatibility of the system components with the work system's overall structure. This approach, based on sociotechnical terms, enables joint optimization of the technical and personnel subsystems from top to bottom throughout the organization and harmonization of the work system's elements with its overall design and the external environments. (10). Optimal system functioning and effectiveness result leading to greater productivity, quality, and employee safety and health, psychosocial comfort, motivation, and perceived quality of work life.

MACROERGONOMICS: SCIENTIFIC AND CONCEPTUAL UNDERPINNINGS

Macroergonomics involves the development and application of human-organization interface technology and this technology is concerned with improving the organizational structure and related processes of work systems (9). The fundamental underpinnings of macroergonomics is a socio-technical systems model as applied to work system design (32). The socio-technical systems model was empirically developed in the late 1940's and 1950's by Trist and Bamforth (1951) at the Tavistock Institute of Human Relations in the United Kingdom. Follow-on research by Katz and Kahn (e.g., 1966) of the Survey Research Center at the University of Michigan, served to confirm and refine the socio-technical systems model. This model views organizations as transformative agencies; they transform inputs into outputs. Socio-technical systems bring three elements to bear on this process: a technological subsystem, personnel subsystem, and work system design consisting of an organizational structure and processes. These three elements interact with one another and the external environment on which the organization depends for its survival and success.

The sociotechnical system concept view organizations as open systems engaged in transforming inputs into desired outputs (6). Open means that work systems have permeable boundaries exposed to the environments in which they exist (economic, social, political, etc.). These environments thus enter or permeate the organization along with the inputs to be transformed. The primary ways in which external environmental changes enter the organization are through (a) its marketing or sales function, (b) the people who work in it, and (c) its materials or other inputs (5). Because organizations are transformative agencies, they continually interact with their external environment, receiving inputs, transforming them into desired outputs, and exporting these outputs to their environments. They are thus both influenced by and influence the external environment.

As organizations perform this transformative process, they bring two factors to bear on the process: technology in the form of a technological subsystem, and people in the form of a personnel subsystem (9). The design of the technological subsystem primarily defines the tasks to be performed, whereas the design of the personnel subsystem prescribes the ways in which they are accomplished. Both interact at every human-machine and human- software interface. The technological and personnel subsystems thus are mutually interdependent. Both subsystems operate under joint causation in that they are affected because events in the external environment, for example, market competition or changes in government regulations. Joint causation leads to the related sociotechnical system concept of joint optimization of the work system in terms of its ability to accomplish the transformative process (9). Maximizing overall work system effectiveness requires the joint design of the technical and personnel subsystems in order to develop the best possible fit between the two, given the objectives and requirements of each subsystem and of the overall work system (5). Developing an optimal structure for the overall work system so that it will be compatible with the organization's sociotechnical characteristics is integral in this joint design process.

This development of the human-organization interface technology requires an understanding of the key dimensions of organizational structure. There are two concepts basic to defining the dimensions of a work system's organizational structure: 1) organization and 2) organization design. An organization may be defined as "the planned coordination of two or more people who, functioning on a relatively continuous basis and through division of labor and a hierarchy of authority, seek to achieve a common goal or set of goals" (26). Organizational design refers to the design of an organization's work system structure and related processes to achieve the organization's goals.

VALUE OF A MACROERGONOMIC APPROACH

Designing effective and optimal work systems using a macroergonomic approach can lead to benefits that are recognized throughout the organization. The macroergonomics framework incorporates a systems approach to understanding the organization. It also incorporates systems theory and embraces an natural systems or "organismic world view (1). Thus, the components of the system (people, technology, environment) cannot be thought of in isolation from each other. The purposes of designing an organization and work environment using this approach are to understand what the final product of the work unit or group is intended to be, and to keep a tight focus on that endpoint during the design of all other subsystems, including the work environment. This approach is in contrast to the design of individual tasks, job functions, or individual workstation as isolated components with no larger context.

There are several criteria that need to be met when designing a work system, including: (a) joint design with human centered approach, (b) humanized task approach, and (c) the organization's sociotechnical characteristics (9). Failure to consider these criteria leads to an inadequate consideration of the sociotechnical system elements, that is the technology, personnel, external environment and the organization design. Consequently the work system design is suboptimal (8; 32). When ergonomically designing a system's components, modules, and subsystems, attention to the macro-ergonomic design of the overall work systems is essential (12). Similar conclusions have been drawn from investigations by Meshkati and Robertson (17) of failed technology transfer projects and that of international major system disasters (18).

When work systems have compatible design and have been designed effectively and carried through to the micro-ergonomic design of jobs and human-machine and human-software interfaces, then the work system design is harmonized (9). Productivity, safety, employee satisfaction, perceived quality of work life, and worker well being are positively affected as a result of the synergistic functioning of these subsystems. Thus, the collective system effectiveness criteria will be must greater than the sum of the parts.

MACROERGONOMICS METHODS

There are several macroergonomics methods that are being developed and validated. One is that of participatory ergonomics, which appears to be a stable approach in macorergonomics analysis and design. Other common methods frequently used in various kinds of organizational studies have been adopted for use in macroergonomics analysis, intervention and evaluation. These include the laboratory experiment, field study, field experiment, organizational questionnaire survey, interview survey, and focus groups (10).

Participatory ergonomics

Participatory ergonomics is a macroergonomics approach that involves end users planning, developing and implementing workplace changes (13). Participatory ergonomics includes end users designing useful work tools as well as developing and implementing ergonomics training programs. End users take an active role in the identification and analysis of ergonomic risk factors, workers' knowledge and skill deficits as well as the design of ergonomic solutions (e.g., job redesign, training, work organization). The participatory ergonomics process allows workers to get a better understanding of the ergonomic risk factors that can affect their behavior at work as well as their health and safety.

In the planning stage, participatory ergonomics is particularly useful by involving workers in the identification and analysis of ergonomic problems. There are several approaches to participatory ergonomics, such as design decision groups, quality circles and worker-management committees. Some of the common characteristics of these various programs are worker involvement in developing and implementing ergonomic solutions, dissemination and exchange of ergonomics, health and safety information, pushing down in the organizational structure ergonomics expertise, and the cooperation between experts and non-experts (e.g., workers) and consideration and respect for workers' opinions (13).

Using a participatory ergonomics approach in designing and implementing workplace changes and training programs, creates a sense of individual ownership and commitment to supporting the training program and organizational goals. Being a member of a team that is developing and implementing an ergonomics training program is motivating, rewarding, and beneficial to both the individual and the organization. This involvement creates a willingness on part of the workers' to support the training program, and to engage in the required cultural change process. Further, working together on a cross-functional, interdisciplinary team provides a unique strength in designing and developing a training program (24; 13). If there is a lack of active worker participation in the training program, the worker's motivation for and understanding the material presented is low and their resistance to change is high.

MACROERGONOMICS SYSTEMS ANALYSIS AND DESIGN OF WORK SYSTEM PROCESS

Work system structure

The design of a work system's structure and related process involves consideration of the three major sociotechnical system components that interact and affect optimal work system design: the technological subsystem, personnel subsystem, and relevant external environment that permeates the organization (10). Each of these components are studied in relation to its effect on the three organizational design dimensions, that is complexity, formalization, and centralization (26). Complexity is the degree of differentiation and integration that exists within a work system. Differentiation is the extent to which the work system is segmented into parts. Integration refers to the number of mechanisms that exist to integrate the segmented parts for the purposes of communication, coordination, and control.

The technological subsystem is operationally classified in several distinct different ways, such as: (a) production technology (33) or by the mode of production; (b) knowledge-based technology or by the action individuals perform on an object to change it (21); and (c) work-flow integration or by the degrees of automation, work-flow rigidity, and quantitative specific of evaluation of work activities.

The personnel subsystem analysis consists of at least three major characteristics critical to an organization's work system design (a) the degree of professionalism, (b) demographic characteristics, and (c) psychosocial aspects of the workforce (10). Based on open systems theory, organizations require monitoring and feedback mechanisms to follow and sense changes in their relevant task environments and have a capacity to make responsive adjustments.

Task environments refers to that part of the firm's external environment that can positively or negatively influence the organization's effectiveness (10). Survival of organizations depends on their ability to adapt to their external environment. Negandhi (19) identified five types of external environments that significantly affect organizational functioning: 1) socioeconomic; 2) educational, 3) political, 4) cultural, and 5) legal.

In a macroergonomic framework, structural analysis involves more than considering how sociotechnical system variables should shape the basic dimensions of the work system. It also involves integrating these dimensions into an overall structural form (9). Selecting the optimal structural for the work system that best fits the organization's sociotechnical characteristics and related work system dimensions is the key for enhancing organizational functioning. The four general types of overall organizational structure are: (a) machine bureaucracy, (b) professional bureaucracy, (c) matrix organization, and (d) free-form design (26). In general, the larger the organization, the greater the likelihood that it will utilize more than one type of work system structure.

Work system process
The sociotechnical analysis of work system structure precedes the soicotechnical analysis and design of work system processes. Work system process is concerned with the method by which variances are analyzed and design changes are made over time. A general framework that integrates ergonomics interface design, function allocation and other macroergonomics tools, can be used to prescribe sociotechnical analysis and function allocation associated with function and task design (8, 4). Two general methodologies for macroergonomic assessment of work system process are proposed: 1) Macroergonomic Analysis and Design (MEAD) (16), which has been applied in industrial environments, and the "Systems Analysis Tool" (SAT) (23) used to examine office work systems. These methodologies are based on systems and modeling, and consist of a process with a series of sub-analysis and modeling to conduct a comprehensive micro and macroergonomics analyses (8).

A MACROERGONOMICS OCCUPATIONAL STRESS MODEL

Numerous researchers have identified organizational variables and factors that contribute to the health and well-being of workers, such as Karasek and Theorell (14) job control and demand model and Szilagyi & Wallace, (31). Examples of these factors include: work organization, job design (shiftwork), job content, participation, job satisfaction, job demands, job functions (responsibility, authority, information flow, work methods, coordination requirements) and relationships (teams, inter-personal skills, intra-group communication), organizational processes (communication, cooperation, commitment, decision making), and organizational culture (formal policies, design of facilities and physical space, role modeling; explicit symbols, structure-centralized or de-centralized), and fatigue and job stress. Further, studies have shown how design of jobs, work organization and organizational culture may affect the health and safety of workers, their performance and organizational effectiveness (12; 2; 30; 29, 3).

The balance model of a work system "misfit," described by Smith et. al.(30), conceptualizes the various elements of a work system, that is, the loads that working conditions can exert on workers. In this model these various elements interact to determine the way in which work is done and the effectiveness of the work in achieving individual and organizational needs and goals. The individual is at the center of this model with his/her physical characteristics, perceptions, personality and behaviors. The worker has technologies available to perform specific job tasks. The design and capabilities of the technologies affect the worker's performance and also the required skills and knowledge. The job tasks and technologies affect the job content and the physical demands of the job on the worker. These job activities occur within a work setting that consist of a physical and social environment. An organizational structure that defines the nature and level of individual involvement, interaction and control is included in the model. Thus to reduce the stress load and to eliminate strain, re-designing and modifying the elements of the office work system is suggested. This model has been used to describe the imposed work system loads and their effects on office workers (30).

MACROERGONOMIC MODELS OF MUSCULOSKELETAL DISORDERS IN OFFICE WORK

A macroergonomic approach and models for addressing Work Related Musculoskeletal Disorders (WMSDs) in office work are discussed by several researchers (12, 23 20). These authors suggest that WRMDs have been reduced somewhat by micro-ergonomics interventions (e.g., providing furniture and work environments with ergonomics design characteristics) and through ergonomics training on proper workstation layout and adjustment. In both cases, however, WRMDs generally have not been reduced to the levels that should be achieved.

O'Neill (20) proposes an integrated macroergonomic model applied to office work systems. He suggests that the linkage between the physical space in which work occurs and organizational effectiveness needs to be made in order to justify the shift in thinking about the relevance of the work environment to organizational goals. Core to this model is integrating the internal work sub-systems of the organization, that is the social, technical and work environment and align these to achieve the desired objectives and the mission of the business. Individual factors are considered and how workers interact with the design the these sub-systems. Outcomes of this model include enhancing the health and well-being of the individual, reducing WRMDs, and improving organizational effectiveness.

A MACROERGONOMIC CASE STUDY: HUMAN FACTORS TRAINING IN AVIATION MAINTENANCE

Background of program

Aviation maintenance operations are complex, demanding, and dependent upon good communication and teamwork for their success. Success in aviation maintenance is measured by the safety and quality of a maintenance operation. Aviation maintenance operations are most successful when crews function as integrated, communicating teams -- rather than as a collection of individuals engaged in independent actions. Over the past decade, the importance of teamwork has become widely recognized (27, 24, 28). This has resulted in the emergence of Maintenance Resource Management (MRM) training programs, and other safety-related programs within the aviation community. Maintenance Resource Management (MRM) training is a human factors intervention designed to improve communication, effectiveness and safety in airline maintenance operations. Effectiveness is measured through the reduction in maintenance errors, and the increase in individual and unit coordination and performance. MRM training is also used to change the work "safety culture" the organization by establishing a positive attitude toward safety by maintenance personnel. Attitudes, if positively reinforced, can lead to changed behaviors and performance. Safety is typically measured by occupational injuries, ground damage incidents, reliability, and aircraft airworthiness. MRM improves the reliability of the technical operations processes by increasing the coordination and exchange of information among team members, and among teams of airline maintenance crews.

One of the early activities when starting a MRM program, is to gain the understanding, commitment, and visible support of the senior management. Management must actively support and value MRM. The relevance of the MRM program to business objectives must be clear, or management will question the investment in time and costs associated with such a program. It may also be necessary to develop some simple return on investment models to justify implementing the program. For example, the cost of one ground damage incident, in-flight shutdown, or turnback, vs. the cost of a MRM training course plus the benefits of reducing maintenance errors and increasing safety results is a positive return on investment. Once support has been established, the first step towards designing a MRM training program is to step back, and view the entire maintenance operation as a larger "system". This system is composed of numerous sub-systems, including: Aviation Maintenance Technicians (AMT's), engineering, quality control, planners, document support, inspectors, maintenance control, materials and stores, management, and administrative support. When viewed as a system, it is apparent that the overall success of the maintenance operation is dependent on the quality of information exchanged among the team members making up each function, and among the functions themselves.

Once the functions involved are identified, and their roles understood, a MRM training program can be designed. However, as with senior management, it is important to establish a clear rationale for all employees in maintenance operations about the relevance of the MRM program to the airline business. It is important for employees to understand the relevance of any changes they make in their work, and the effort they must put into that change, to the broader business objectives of the airline. Maintenance Resource Management, as with other human-factors-oriented processes, is based on a systems approach. It incorporates a variety of human factors methods, such as job and work design, and considers the overall socio-technical maintenance system. For example, the SHELL model (S=Software, H=Hardware, E=Environment, L=Liveware) shows how we define human factors as a system and illustrates the various interactions that occur between sub-systems and the human operator (24). The interactions in this model can affect both individual and team performance. MRM training typically focuses on the interaction between the individual AMT and other team/crew members: liveware/liveware interactions in SHELL terminology. This person to person interaction can be considered the micro level of communication and team building, while the interactions among teams and departments is at the macro level. There are also external forces that can affect individual and team performance. These include political and regulatory considerations (e.g., FAA, OSHA, NTSB) and economic factors (e.g., global competition). Achieving the goals of MRM requires improving interactions at both the micro and marco levels. These improvements must occur within the context of external factors, and require an understanding of their effects. To this end, the SHELL model depicts the systems approach to integrating human factors methods and principles to design an MRM program (Robertson, 1998).

Participation and feedback

Participating in the creation, development, and implementation of an MRM program promotes a feeling of individual ownership, and a sense of commitment to supporting the MRM program goals. Being a member of a team that is developing and implementing a MRM program is motivating, rewarding, and beneficial to the individual and organization. Working together on a cross-functional, interdisciplinary team also provides a unique strength in designing and developing such a MRM program (24). Feedback provides information to accomplish two performance improvement goals. 1) Identifying necessary corrective actions to improve the program, and 2) Reinforcing the positive outcomes of using MRM skills. Internal newsletters can be used to describe specific MRM outcomes. For example, one organization reports how an MRM group exercise led to initiating a positive change in a specific maintenance operation. A more active feedback method is to have AMT's write their own "MRM story" describing their experiences using MRM principles and skills (24).

MRM evaluation: one company's experience
Evaluation results of a MRM training program at a major airline company, demonstrates positive and significant effects of the MRM training program (25, 28). A systematic evaluation of the effects of the MRM team training program on maintenance personnel attitudes, behaviors was used based on the five level evaluation model ((25, 28). Multiple measures and assessments of the managers' attitudes and self-perceptions of behaviors as well as maintenance performance results were used spanning a 4-year period. This provided an unique opportunity to longitudinally measure and track the long term training effects. We also conducted analyses of the association between attitudes and organizational performance over time. Data were gathered through the use of the "Maintenance Resource Management/Technical Operations Questionnaire" (MRM/TOQ), on-site interviews and observations, trends of maintenance performance measures and attitude-performance analysis (25, 28). Overall results of the evaluation demonstrated a positive and significant effect of the MRM training on attitudes, behavior and organizational performance. The significant and positive improvements of the maintenance personnel attitudes reflected the expected and intended training effects on the participants' attitudes and their stability over time.

Step I evaluation - baseline assessment. Two baseline measurements were taken before the training intervention occurred to measure any changes in the trainees MRM attitudes and knowledge before the training commenced. With these two measurements prior to the training a stronger quasi-experimental field research design is created. There were no significant changes found in the AMT's attitudes and behaviors as measured by the baseline and pre-training MRM/TOQs.

Step II evaluation--reaction. This level of evaluation involved the participants' written reactions to the value and usefulness of the team training program as measured by the MRM/TOQ. Several questions were developed to assess the trainees' reactions to the training course materials, objectives, organization, training climate, and instructor skills. This level of evaluation also serves as a formative evaluation of training materials and delivery methods in the initial phases of the training program. Level II evaluation show that the participants' immediate responses to training are positive, as over 90% rate the training as "very useful" or "extremely useful" including that over 96% felt that is was one of the best training courses they had attended. Other positive aspects of the course was the having a mix of participants in the class. This was beneficial as the managers were able to gain an appreciation of other managers' job functions, what their constraints and problems are and how the outputs of their jobs affect others in the work system.

Step III evaluation--learning. The knowledge gained and immediate changes in the participants' attitudes and the stability of these changes in time were measured by the pre and post-training MRM/TOQ questionnaires. Changes in relevant attitudes measured immediately before and after training are significant with positive changes following training for three of the four attitude indices measured ("command responsibility," "communication and coordination," and "recognizing stressor effects"). The attitude measure of assertiveness rose significantly between the post measure and the 2 month follow-up survey. Follow-up results indicated that all four attitude scales remained high and stable over the two, six and twelve month surveys following training.

Step IV: performance-behavior. Step III evaluation results, derived and content coded from the open responses on the follow-up surveys, indicated how the trainees actually use the training on the job. The trainees' self-perception of their behavior on the job significantly shifted from "passive" responses (e.g., "be a better listener" and "being more aware of others") to improvement of more "active" responses, such as "having more daily meetings to solve problems," "gathering more opinions" and "getting more feedback from others." Field interviews and observations over a one year period were conducted to validate the contents of the self-reported behaviors.

Step V: organizational results. Step IV evaluation examines trends in maintenance performance before and after the onset of the MRM team training program. One of these performance trends for occupational safety (lost time injuries--rate of lost time injuries, per 1000 hours worked, for 55 work units). Overall, the injury rate remains at a low level for the year and a half after training was introduced. To correlate attitude changes with performance, the individual maintenance personnel data are combined into averages for the units to which they belong. The organizational performance measures included were aircraft safety (ground damage), personal safety (occupational injury), dependability based on departures within 5 minutes and on-time maintenance. Results from this analysis for the follow-up surveys shows a significant number of correlations between maintenance unit performance and attitudes.

CONCLUSION

Macroergonomics provides a system approach to integrating the human-technology interface to design effective work systems design. Based on sociotechnical theory, and viewing systems as organic and open, the concept of macroergonomics has developed and continues to be validated and applied to the design of various occupational work systems. In the future, the field of macroergonomics will further demonstrate that to conduct a macroergonomics analysis, not only will the individual components of the work system be effectively designed, but that the work system, the human-organization technology, is harmonized leading to the attainment of the organizational goals and enhancing the well being and safety of the worker.

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