International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

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Published online: 08 Jan 2015.

INTERNATIONAL JOURNAL OF
OCCUPATIONAL SAFETY AND ERGONOMICS 1999, VOL. 5, NO. 2, 247–278

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This report extends a control systems or cybernetic model of behavior to the behavior of groups of many individuals—organizations and institutions—operating together with technology as complex sociotechnical (ST) systems. The premise is that the level of quality in performance of a complex ST system is predicated upon the degree to which its organizational design incorporates elements of a closed-loop behavioral control system: control goals and objectives, sensory receptors, sensory feedback, learning and memory, effectors, and sensory feedback control. From a control systems perspective, ergonomics is essential to effective organizational self-regulation. If working conditions are poorly designed, work performance and safety and quality outcomes cannot be closely controlled. Conversely, as shown by field evidence, good design promotes synergism between ergonomics, safety, and quality as a closed-loop consequence of effective employee and organizational self-control of system performance, safety, and quality.

ergonomics management safety management hazard management
quality management sociotechnical systems synergism
breakthrough performance behavioral cybernetics

1. INTRODUCTION

Murrell first proposed the term *ergonomics* to refer to the natural laws (*nomos*) of work (*erg*; Konz, 1995, p. 12). In the ergonomics and human factors (E/HF) community, broad agreement has emerged that such "laws" refer to design factors, conditions, and strategies that accommodate the capabilities and limitations of the worker or user, and that E/HF science is intimately linked to design (Chapanis, 1991; Meister,

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1989). The former author offers the definition "human factors is a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design." The same article asserts that E/HF research, even so-called basic research, should be oriented toward the design of something.

As implied by the definition of the term, achieving "good" design represents a principal mission of E/HF science. Good design can make the difference between success or failure in usability, human-machine compliance, product acceptance, product quality, safety, health, worker productivity and company survival. Literally thousands of E/HF guidelines for achieving good design have been developed.

Given the fundamental focus of the field on design, it may be argued that the basic premise underlying E/HF science is that variability in the behavioral effects of human performance and work—such as safety, health, quality, productivity, or user acceptance—is critically influenced by design attributes of the environment in which performance occurs (Smith, T.J., 1993, 1994, 1998; Smith, T.J., Henning, & Smith, 1994). This premise forms the basis for the analysis offered here of the synergism of ergonomics, safety, and quality. In particular, the report describes a closed-loop or cybernetic theory of behavior to account for design or context specificity in human performance and behavior that prevails across the entire range of human enterprise (section 2), and applies this conceptual perspective to account for observed interrelationships of ergonomics, safety, and quality (section 3). The report goes on to summarize evidence from field observations that supports the conceptual model (section 4), and concludes with a discussion of how synergism between ergonomics and quality can support breakthrough in quality management (QM, section 5).

2. BEHAVIORAL CYBERNETICS OF CONTEXT SPECIFICITY IN PERFORMANCE

Behavioral cybernetic theory (Smith, K.U., 1972; Smith, T.J. & Smith, 1987) maintains that human behavior is guided as a closed-loop, feedback-controlled process. Specifically, the theory assumes that performance is guided through execution of movements to control sensory feedback both from design factors and from movements themselves, and to thereby control perception, cognition, and patterning of subsequent movements. The underlying premise is that control and guidance of performance is neurogeometric and neurotemporal—that is, dependent on relative displacements in space and time between design- and movement-induced sensory feedback (Smith, K.U. & Smith, 1962).

Figure 1 schematically depicts behavior as a cybernetic system. The essential elements of a behavioral cybernetics system are

- control goals and objectives;
- sensory receptors;
- sensory feedbacks,
    - reactive,
    - instrumental,
    - operational,
    - environmental,
- learning and memory;
- effectors;
- control of sensory feedback,
    - reactive,
    - instrumental,
    - operational,
    - environmental.

All of the following elements are required for functioning of a closed-loop behavioral control system: (a) a central controller capable of origination and predictive anticipation of system control goals and objectives; (b) sensory receptors that generate afferent traffic to; (c) a central nervous system that relies upon this sensory feedback, plus memory and learning, to generate efferent traffic to; (d) effector muscles that control sensory feedback by modulating stimulus excitation, orientation, and sensitivity of receptors. The premise of this model is that motor activity is used to directly and permissively control environmental stimulation ("E" in Figure 1) of sensory receptors. In this manner, reciprocal feedback links are established between sensory feedback control (mediated by motor behavior) and sensory feedback from design factors in the behavioral environment.

One of the major implications of the model in Figure 1 is that to a substantial degree, variability in the control system (behavior) should be referenced to variability in what is being controlled (sensory feedback). The cybernetic model of behavior thus establishes a biological basis for the interaction of performance and design.

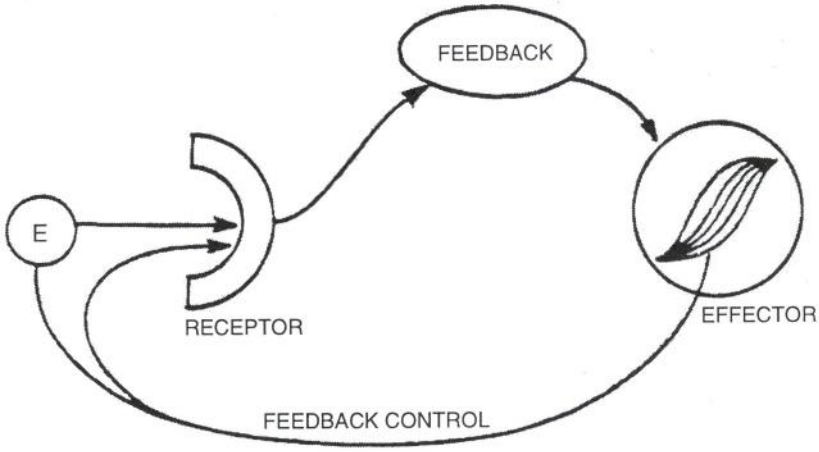

Figure 1. Cybernetic model of individual behavior. *Notes.* E—environmental stimulation.

From the perspective of this theory, task-specific variance in performance occurs as an inevitable consequence of dynamic spatiotemporal feedback interaction between sensory feedback (generated by design factors) and sensory feedback control (behavior), in addition to whatever contributions general ability and learning factors also may make. That is, in different interactive human-environment or human-machine design contexts, performance and design become coupled as a specialized, interdependent system (Flach & Hancock, 1992; Meister, 1989; Smith, T.J., 1994), through an ongoing process of behavioral control of sensory feedback originating with distinctive design factors of the system. Good design, therefore, may be defined as that giving rise to sensory feedback that can be effectively controlled through active behavior. Merken (1986) advances a similar viewpoint.

An extensive body of empirical evidence has been compiled to support the conclusion that design factors make a substantial contribution to the total variability observed in human behavior and performance (Smith, T.J., 1993, 1998; Smith, T.J. et al., 1994). Derived from differential learning, psychomotor, perturbed sensory feedback, work physiology, accident causation, social cybernetic, and organizational research, this evidence clearly indicates that levels of variability and proficiency observed in performance owe as much or more to the design context of the physical and social environment in which the performance occurs as to innate ability and learning factors. In particular, the contribution of task- or context-specific design factors to total performance variance observed in this body of research typically ranges from about 50% to well above 90%.

Figure 2 extends the cybernetic model to social behavior (Smith, T.J., Henning, & Smith, 1995), using both interpersonal and group social interaction as examples. As indicated by the muscle symbol and arrows connecting the two individuals depicted in the center of the figure, social interaction is mediated through use of motor activity by one partner to control sensory feedback generated by movements of the second. In turn, movements of the second partner control sensory feedback generated by motor activity of the first. In this manner, during effective social communication, the two partners become yoked or linked as a closed-loop,

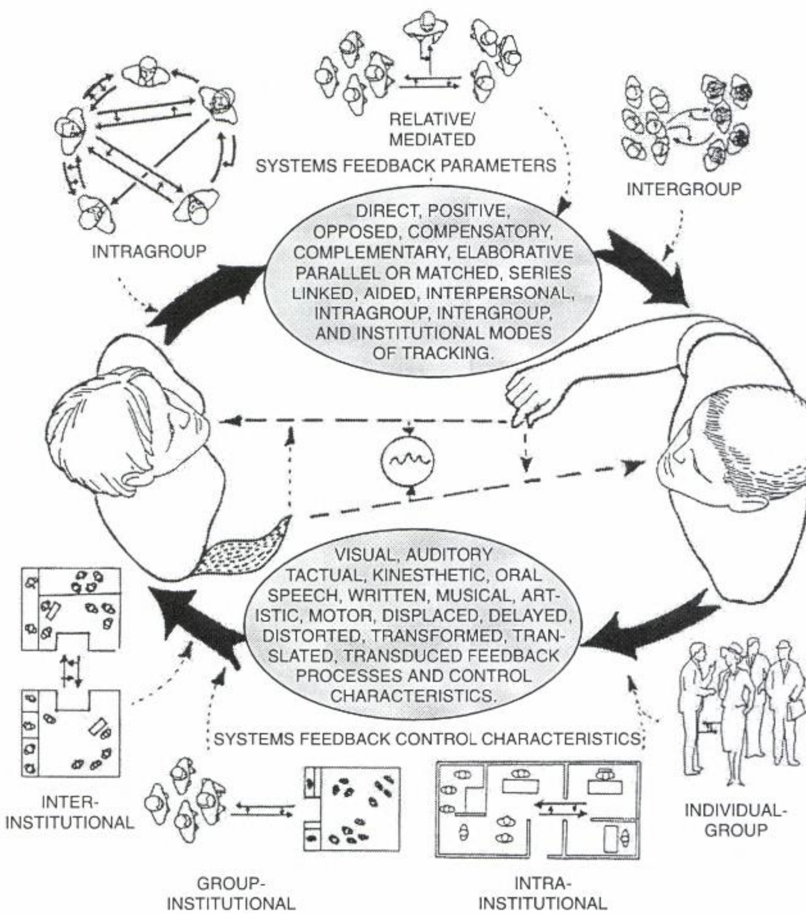

Figure 2. Cybernetic theory of social behavior, indicating systems feedback parameters and feedback control characteristics governing both interpersonal and group social interaction.

feedback coupled system whose behavioral performance relies on mutual, coordinate use of movement by the participants to exchange and control sensory feedback. This process is termed *social tracking*.

As suggested in Figure 2, social tracking typically requires each participant to control multiple motor, sensory, and cognitive modalities (vision, speech, writing, etc.) and transformations (displacements, delays, etc.) of sensory feedback. The social partners thus become dynamically yoked or interlocked behaviorally and physiologically, as a result of mutual body movement tracking and control of each other's sensory feedback. Through such interlocks, the participants in a social group begin to operate as an integrated system, with definite systems feedback parameters and feedback control characteristics, indicated in the figure. In particular, social cybernetic systems can involve many different types of social tracking modes (direct pursuit, compensatory, parallel, series-linked, etc.) in a variety of different social interactive contexts (interpersonal, group, and institutional social systems).

Group interactions among three or more individuals are mediated by two distinct social tracking mechanisms: (a) interpersonal feedback integration of movements and (b) interactions in which one or more individuals track the relationships between two or more other persons, as in a debate by two or more persons before an audience. Social cybernetic theory assumes that group behavior and communication are human factored at several levels in terms of a limited number of parameters of intragroup, intergroup, institutional, and interinstitutional interactions. Institutions are defined generally as organized group structures, such as families, neighborhoods, schools, communities, cities, states, nations, industries, commercial bodies, or governments, which may be integrated through social behavioral, ethnic, cultural, economic, and architectural ties. Figure 2 identifies seven patterns of social cybernetic group interactions, namely (clockwise from top left), (a) intragroup, (b) mediated intergroup, (c) intergroup, (d) individual-group, (e) intrainstitutional, (f) group-institutional, and (g) interinstitutional social tracking. These modes establish a theoretical framework to guide experimental E/HF analysis of group and institutional behavior.

In summary, social cybernetic theory as just outlined rests upon three basic premises: (a) The theory is applicable to conceptual and experimental analysis of all modes and dimensions of human social behavior and interaction; (b) Both individual and group social behavior are differentially specialized in relation to the organizational and environmental design features of the diverse group and institutional structures in which social interaction occurs; and (c) Social human factors dominate all aspects of the human condition, dictating not only the course and level of human development, but specialization of the processes of learning, performance, schooling, aging, organizational design and management, work, and machine-related behavior.

3. ORGANIZATIONAL CYBERNETICS OF COMPLEX SOCIOTECHNICAL SYSTEMS

What do behavioral and social cybernetics have to do with interdependence of ergonomics, safety, and quality? As suggested in the previous section, the answer to this question emerges from the premise that the theory can be extended and applied to the behavior of groups of many individuals—organizations, institutions, societies—operating together with advanced technology as complex, sociotechnical (ST) systems (Smith, T.J. et al., 1995). Although much has been written about factors underlying the success or failure of complex human systems, few coherent behavioral theories have yet been advanced to account for variability in performance observed with such systems. It is assumed here that concepts and principles of behavioral and social cybernetics can be applied to address this issue.

The basic thesis of the present approach is that the level of quality in performance of a complex ST system is predicated upon the degree to which its organizational design incorporates elements of a closed-loop behavioral control system, listed in section 2. When all of these elements are present, we may anticipate high quality organizational performance.

This concept is depicted in Figure 3, which presents a behavioral cybernetic model of safety and quality management (SQM) of a complex ST system. Safety and quality feedback (analogous to sensory feedback with individual behavior) is provided by system ergonomics and system production (output) design factors. Safety and quality feedback control (analogous to sensory feedback control with individual behavior) is mediated by the mutual influence of the system managers and workforce on SQM.

The model assumes system ergonomics to be absolutely essential to effective organizational self-regulation of system safety and quality. If the work performance environment is poorly designed, feedback from

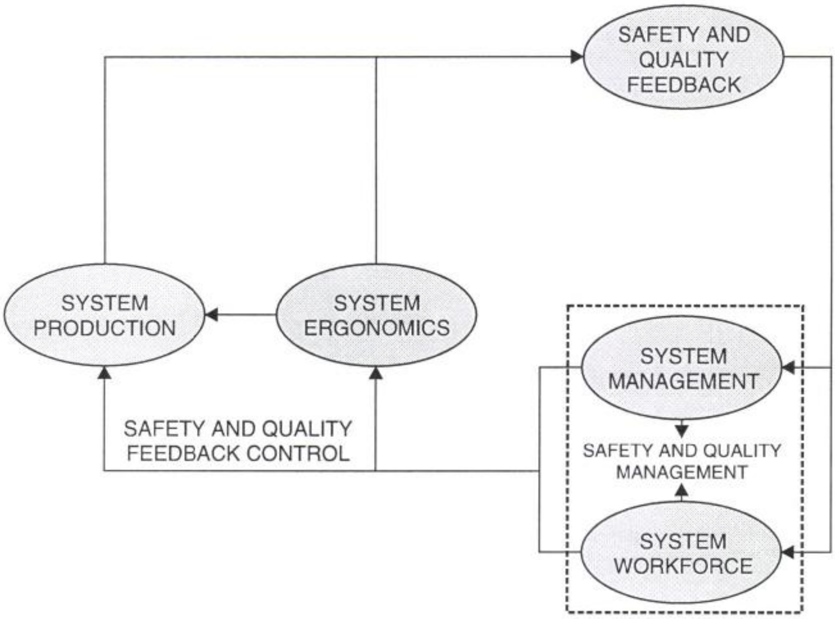

Figure 3. Behavioral cybernetic model of safety and quality management of a complex sociotechnical system.

design factors affecting safety and quality in this environment cannot be closely controlled. As with the behavior of an individual, all of the key determinants of organizational behavioral effectiveness are compromised under such conditions of impaired system feedback control, namely, quality, safety, health, efficiency, productivity, and competitiveness. The mutual influence of ergonomics, safety, and quality on one another, therefore, represents a manifestation of organizational cybernetics: It arises as an inevitable closed-loop consequence of effective self-control by an organization of its own quality performance.

A basic assumption of the model in Figure 3 is that synergism between ergonomics, safety, and quality observed in operational contexts relies upon effective social tracking between its organizational, technological, and individual employee elements. That is, effective exchange and control of sensory feedback among individual employees or users, technological design features, and organizational and institutional design features of an ST system provides the operational foundation for overall system quality performance.

A key requirement for effective social tracking among ST system elements is employee or user involvement in system decision-making.

From a social cybernetic perspective, participatory ergonomic and SQM programs are effective because they enable workers to control sensory feedback from job-related decisions or working conditions that affect them, and to in turn generate sensory feedback for the control and benefit of other system participants. Conversely, lack of influence by system employees or users over decisions governing system design and operation essentially excludes them from social tracking interaction with the system. Under such conditions, when social tracking linkages between ST system elements are incomplete or ineffective, synergism between ergonomics, safety, and quality consequently is compromised and becomes difficult or impossible to achieve.

The social cybernetic significance of the participatory approach for integrating ergonomics, safety, and quality is illustrated in Figure 4, using manufacturing as an example (Smith, T.J. et al., 1995). Figure 4 com-

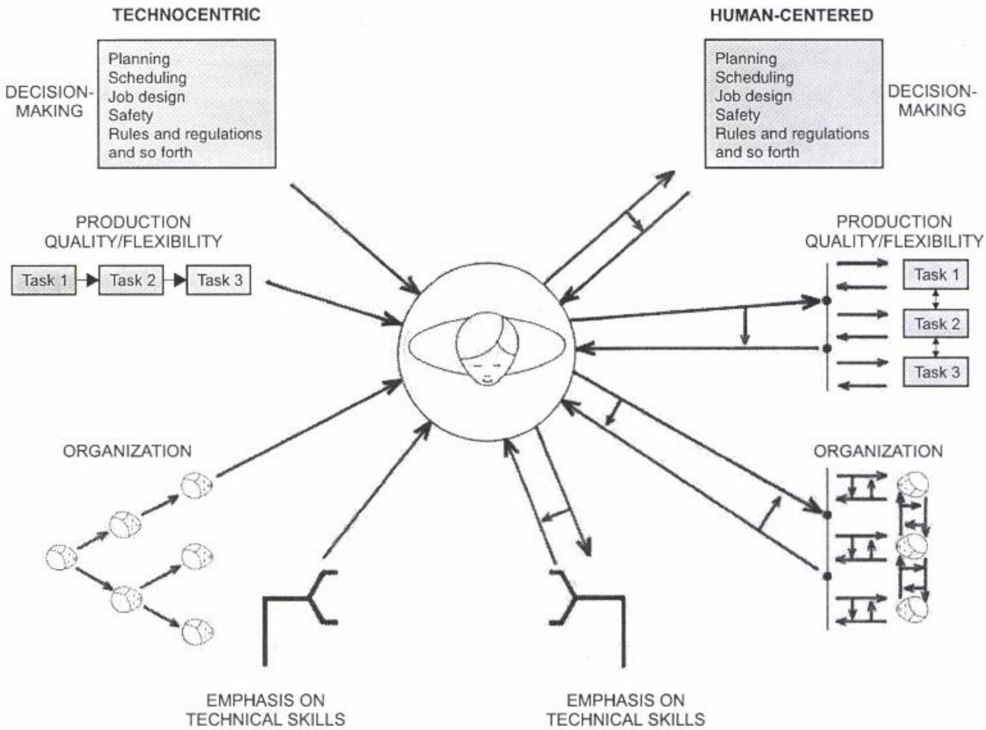

Figure 4. Social cybernetics of technocentric versus human-centered strategies for organizational design and management of a sociotechnical system. Unlike the technocentric approach, the human-centered approach provides an array of opportunities for the worker to socially track system operations and control sensory feedback from system design factors.

pares and contrasts social tracking opportunities available to a front line manufacturing system employee (center of figure) under technocentric (i.e., Tayloristic) versus human-centered (i.e., sociotechnical) strategies for system organizational design and management (ODAM). Four major areas of difference between the two ODAM systems are delineated in the figure. Starting at the top, under the technocentric ODAM strategy (left side of figure), the employee receives sensory information (one-way arrow) from decisions affecting performance, but is able to exert little if any control over this process. Conversely, under the human-centered ODAM strategy (right side of figure), the employee both receives and controls decision feedback (dual arrows), thereby enabling direct employee behavioral influence over the process.

Under the technocentric approach, production line tasks typically are ordered serially (assembly line fashion), with the employee assigned to only one or a limited number of tasks paced by the technology (one-way arrow) and not by the employee. Conversely, under the human-centered approach, the employee may be assigned responsibility for a collection of different tasks whose pace and quality is under employee control (dual arrows). This arrangement in turn promotes job enrichment and flexibility, and also provides greater opportunity for the employee to directly influence product quality.

Under the technocentric approach, organizational design tends to be top down and hierarchical, such that the employee only interacts with one manager. Typically, this interaction takes the form of directives and orders governing employee job performance and behavior issued by management that cannot be controlled or greatly influenced by the employee (one-way arrow; Sheridan, 1992, p. 339). Conversely, the human-centered approach typically is characterized by a flatter organizational structure built around self-managed teams. Team work facilitates mutual social tracking (Figure 2) among team members (dual arrows) that in turn promotes communication, cooperation, integration, and efficiency in team performance through development of tight social yokes that bind the team together.

Finally, under the technocentric approach, the employee interacts with system technology primarily in a passive fashion—typically technical skills are considered neither a resource nor a target for upgrading or training. Conversely, both skill training and utilization of employees as technical resource specialists are emphasized under the human-centered approach. This type of projective tracking of future skill needs on the part of the organization promotes professionalism and fosters career development.

In summary, as suggested by Figure 4, relative to the technocentric approach the human-centered approach provides substantially enriched social tracking opportunities for the employee to both receive and control sensory feedback from coworkers and also from both organizational and technological design factors. Worker involvement in decision-making, worker control over the production process, and job enrichment enhance the degree of worker control over sensory feedback from the organization and the job, and thereby enhance the overall level of worker self-control. Use of workers as resource specialists, and emphasis on skill development, encourage provision of more sensory feedback from the worker to the organization, and thereby benefits organizational decision-making governing both organizational and technological change and the consequent integration of ergonomics, safety management (SM), and QM of the system.

4. SUPPORTING EVIDENCE FROM FIELD OBSERVATIONS

What evidence can be cited to support a behavioral cybernetic interpretation of synergism between ergonomics, safety, and quality? Possible limitations to the interpretation of evidence that may be forthcoming should be recognized. First, such evidence will be forged in the crucible of operational environments under relatively uncontrolled conditions. Ergonomics, safety, and quality of a complex ST system do not occur in the scientific isolation of a laboratory. Thus, documentation of a particular case of synergism between ergonomics, safety, and quality will not necessarily provide proof of underlying mechanism. Consequently, any evidence regarding the origins of such synergism necessarily will be inferential in nature, and in most cases is likely to be based on retrospective rather than prospective analysis.

With these limitations in mind, three classes of evidence are considered here. The first concerns evidence for the existence of design or context specificity in the performance of complex ST systems. Availability of such evidence implies that their organizational structures allow for interaction between their design features and their performance, which in turn creates the potential for synergism between system ergonomics, system safety, and system quality.

The second line of evidence concerns the degree to which "well-designed" ergonomics, safety, and QM systems incorporate all of the requisite elements of a behavioral cybernetic system (section 2). The assumption is that system design built around behavioral cybernetic principles establishes a basis for system self-regulation, and thereby establishes a basis for integrating system design with system performance manifested as synergism between ergonomics, safety, and quality. Evidence in this category thus establishes a logical link between good design, cybernetic design, and quality performance.

The third class of evidence concerns documentation of reciprocal influence between the performance of ergonomics, safety, and quality programs that may be observed in operational contexts. The existence of such reciprocal effects connotes between-program synergism suggesting effective social cybernetic linkages between the programs.

4.1. Design Specificity in Social and Organizational Performance

Limited evidence suggests that, as with individual performance, much of the variability in social and organizational system performance appears to be attributable to system design factors. For example, findings from laboratory studies of series-linked and parallel-linked social tracking between the participants of two-person teams indicate that a preponderance of variability in social tracking performance is attributable to the human factors design characteristics of the tracking task (Smith, K.U., 1974; Smith, T.J. et al., 1994). In their situational leadership model (whose validity is supported by some observational evidence), Hersey and Blanchard (1977) maintain that managerial performance improves when managers customize their leadership style (in social cybernetic terms, their social tracking behavior) for different subordinates in relation to both the differential capabilities of different subordinates (based on personal factors) as well as the differential demands of tasks being performed by these subordinates (based on design factors). Thus, the premise of this model is that variability in managerial performance should be referenced, at least in part, to task design conditions that prevail for different modes of subordinate-task interaction.

Finally, observations of two seminal contributors to the quality movement are worthy of note. Deming (1982) asserts that about 90% of the time, the success or failure of a QM program in industry depends upon how the program is designed. For example, Deming believes that adherence to a closed-loop Plan-Do-Check-Act cycle of QM is the macroergonomic design linchpin to continuous improvement in quality. Juran (1954, 1964) advocates a series of macroergonomic "universals" in organizational design, which he believes must be adopted and implemented to achieve success in both control and breakthrough improvement in QM. In two later books he (a) introduces the concept of a spiral of progress in quality (Juran, 1992; Juran & Gryna, 1980) that bears some resemblance to the cycle favored by Deming, and whose operational effectiveness presumably depends on QM adherence to these design universals; and (b) equates success in quality outcomes and progress directly with the design of the QM process (Juran, 1992).

4.2. Cybernetic Properties of Well-Designed Ergonomics, Safety, and Quality Programs

Using the analyses of Deming (1982) and Juran (1954, 1964) as starting points, we may ask what there is about the design of a particular program or system that distinguishes high quality from low quality performance. Based on field observations of the distinctive properties of well-designed systems, the answer offered here is that the success of ergonomics, safety, and quality programs can be equated directly with the degree to which program designs incorporate elements of the behavioral control system model (section 2).

For example, as outlined in Table 1, the designated quality system requirements of the ISO 9001 QM standard (International Organization for Standardization [ISO], 1994), which has achieved international acceptance and credibility and whose performance benefits for thousands of organizations are a matter of record (Peach, 1994; Struebing, 1996), encompass all of the requisite elements of a closed-loop behavioral control system.

As shown in Table 2, the same can be said for successful safety programs. Cohen (1977) describes results from a survey of 42 pairs of companies in the U.S. state of Wisconsin, matched in terms of industrial and geographic sector and workforce size, but distinguished by low versus high work injury rates. The analysis identified 11 program factors that appeared to have the most bearing on safety program success of the low work injury rate companies. Table 2 suggests that these factors

TABLE 1. Behavioral Cybernetic Elements of the ISO 9001 Standard (ISO, 1994)

ISO 9001 Standard Specification		Behavioral Control System Element
4.1	Management responsibility Quality policy	Control goals and objectives
4.20	Statistical techniques	Sensory receptors
4.8	Product identification and traceability	Sensory feedback
4.10	Inspection and testing	
4.19	Servicing	
4.2	Quality system (quality manual, procedures, and planning)	Learning and memory
4.5	Document and data control	
4.16	Quality records	
4.18	Training	
4.3	Contract review	Effectors
4.4	Design control	
4.6	Purchasing	
4.9	Process control	
4.11	Calibration	
4.15	Handling, storage, and packaging	
4.13	Non-conforming product	Sensory feedback control
4.14	Corrective and preventive action	
4.15	Internal quality audits	

TABLE 2. Behavioral Cybernetic Elements of Safety Programs in Companies with Low Work Injury Rates

Safety Program Factor (Cohen, 1977)	Behavioral Control System Element
Management commitment Safety motivation strategies	Control goals and objectives
Regular inspections and communication Accident and near miss investigations	Sensory receptors and sensory feedback
Safety training Recordkeeping	Learning and memory
Safety committee Compliance with safety rules Emphasis on worker experience Low worker turnover and absenteeism	Effectors
Hazard control strategies	Sensory feedback control

encompass all of the requisite elements of a closed-loop behavioral control system.

Finally, Table 3 indicates that well-designed ergonomics programs also encompass all of the requisite elements of a closed-loop behavioral control system. The ergonomics program elements specified in Table 3 are those recommended by the U.S. National Institute for Occupational Safety and Health (NIOSH; Cohen, Gjessing, Fine, Bernard, & McGlothlin, 1997), based on a survey and analysis of a large number of successful programs in the USA and elsewhere.

TABLE 3. Behavioral Cybernetic Elements of Well-Designed Ergonomics Programs

Ergonomics Program Element	Behavioral Control System Element
Management commitment	Control goals and objectives
Work place hazard analysis	Sensory receptors and sensory feedback
Training in ergonomics awareness, job analysis, control measures, and problem solving	Learning and memory
Worker involvement	Effectors
Hazard controls Engineering controls (i.e., design improvements), Administrative controls, Personal protective equipment, Work practices	Sensory feedback control
Health care management	

4.3. Reciprocal Operational Effects of Ergonomics, Safety, and Quality Programs

A comparison of Tables 1, 2, and 3 reveals that in their mutual adherence to common criteria for a closed-loop behavioral control system, successful ergonomics, safety, and quality programs share a number of parallel design features. The analysis in sections 1 and 2 suggests that if the programmatic designs of different operational programs in an organizational system all are patterned upon the behavioral cybernetic model, we may anticipate effective social tracking and performance synergism between them (Figures 2 and 4). This section considers evidence from field observations for functional synergism between ergonomics and safety programs, ergonomics and quality programs, and safety and quality programs, with most emphasis on the latter relationship.

For each type of relationship, possible evidence for mutual synergism is considered. This approach differs from the paradigm commonly adopted by E/HF science, which assumes that performance is the derivative beneficiary of design improvements. However, if different organizational programs are linked through social tracking as mutually coupled social cybernetic systems (Figures 2 and 4), there is no one-way, linear, cause-and-effect relationship between the two. Rather, as is inherent to the design of any closed-loop system, actions of one participant are both the cause and the effect of actions of the other.

4.3.1. Operational synergism between ergonomics and safety, and ergonomics and quality

There is unequivocal evidence to support the conclusion that an emphasis on ergonomics benefits safety and accident prevention. For example, in an evaluation of results from 91 field studies in which the effectiveness of ten different accident prevention strategies were considered, Guastello (1993) finds that comprehensive ergonomics programs were more effective than any other strategy in preventing industrial accidents. Cohen et al. (1997) cite 46 studies, dating from 1971 to 1996, documenting the effectiveness of ergonomic design improvements in reducing the risk of work-related musculoskeletal disorders.

Considering the converse effect of safety on ergonomics, I am unaware of any studies directly demonstrating that an emphasis on safety and hazard management benefits system microergonomics. However, the transformation of a safety and hazard management program to a program design based on behavioral control system elements (Table 2; Cohen, 1977) may be considered to represent an improvement in organizational macroergonomic design.

Observational study of mutual synergism between ergonomics and quality is still in its formative stages, as suggested by the publication of this special issue. Riley and Bishu (1997) list three examples from industry of links between poor work design and poor quality performance. Hendrick (1997) cites a number of examples from industry in which better ergonomic design resulted in improved quality performance. Based on findings from several field studies, Eklund (1997) concludes that about one third of quality defects are related to or directly caused by workplace design deficiencies.

Considering the converse effect of quality on ergonomics, Eklund (1997) points out that a number of QM principles and practices may be antithetical to accepted principles of system ergonomics. As examples he lists just-in-time delivery, statistical process control, standardization and reduction in variability in work operations, and reward systems. The continuing prevalence of these practices in QM systems suggests that synergism between ergonomics and quality in current systems may be one-way rather than mutual, and that QM and quality control systems have yet to reap the full benefits of E/HF science.

4.3.2. Operational synergism between safety and quality

This section describes findings from a field study of one particular company that I believe provide rather convincing evidence for mutual synergism between safety and quality (Smith, T.J. & Larson, 1991). The study documents the experience of a small manufacturing firm in the U.S. upper midwest that has developed outstanding QM and safety management (SM) programs.

The firm in question specializes in the manufacture of industrial floor maintenance equipment. It has a successful safety program dating back well over two decades. In 1980, it applied Crosby's approach (Crosby, 1979; Hale, Hoelscher, & Kowal, 1987) to install and develop a quality assurance program, which has achieved international prominence in the past decade (Youngblood, 1991). Separate line management is assigned to the two programs, namely, a Quality, Test, and Reliability Manager for the QM program, and a Corporate Facilities and Risk Manager for the safety program.

According to Hale et al. (1987), organizational design principles guiding management of the company's QM program are (a) management commitment; (b) employee involvement; (c) cooperative worker-manager relationships; (d) rewards for people; and (e) time, energy, and determination. According to the Corporate Facilities and Risk Manager (Smith, T.J. & Larson, 1991), organizational design principles guiding management of the company's SM program are (a) management responsibility for safe working conditions and work practices; (b) individual employee responsibility for safe work performance; (c) no sacrifice of safety for production quality or quantity; and (d) full worker-manager cooperation There are obvious parallels between the organizational design principles for the two programs.

Method. The safety record of the firm over a 21-year period (1970–90) was evaluated, with particular attention to possible changes in the lost-time injury incidence rate since 1980, when the firm's quality program was installed. The firm's quality performance record from 1980 to 1990 also was evaluated.

Questionnaires dealing with the firm's quality and safety programs were distributed to 14 senior, midlevel, and front line managers, and to 20 shop-floor workers. Respondents were asked 12 questions about possible reasons for each program's success, and about perceived similarities and differences as well as possible interactive effects between the two programs. The worker questionnaire included two additional questions dealing with the current and the desired level of worker involvement in decision-making in both programs.

The 14 manager respondents represent over 60% of manufacturing support managers. The 20 worker respondents represent less than 10% of shop-floor workers. The manager responses, therefore, are somewhat representative, but the low number of worker responses limits the generalizability of the results to the entire workforce.

Results. From 1980 through 1990, the quality and the safety performance of the firm showed concomitant improvement. Development of the firm's quality program during the decade of the 1980s was accompanied by over a two-fold reduction in the 10-year average injury rate, from 3.8 lost-time injuries per 100 employees per year for the period 1970–79, to 1.5 for the period 1980–89.

Figures 5 and 6 illustrate relationships between the performances of the QM and SM programs from 1980 to 1990. In Figure 5, the yearly quality record expressed in percentage of defective parts at installation is plotted against lost-time injuries per 100 employees per year for each of the 11 years. In Figure 6 the quality record expressed as manufacturing rework hours is plotted against the safety record. In both figures, the latter years of the decade exhibit fewer lost-time injuries associated with fewer defective parts and rework hours. For both relationships, the correlation of improved quality with improved safety performance ($r^2 = .608$ in Figure 1, $r^2 = .784$ in Figure 2) is statistically significant ($p < .05$).

Shop-floor worker perceptions about factors that contribute to the success of the firm's SM and QM programs are summarized in Tables 4 and 5. For both programs, the three most commonly cited factors are awareness (of quality or hazards), management commitment, and employee

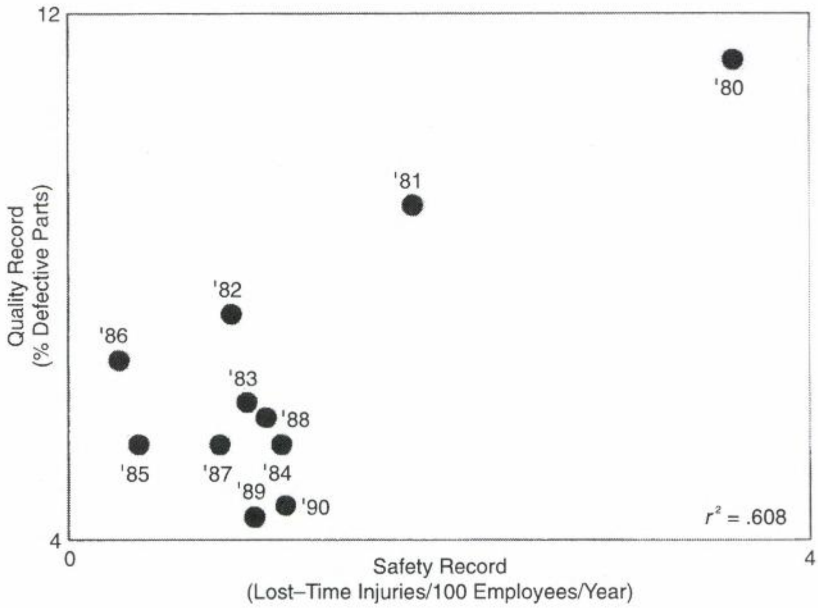

Figure 5. Company achievement in quality performance (percentage of defective parts) versus safety performance (lost-time injuries) for the years 1980–1990.

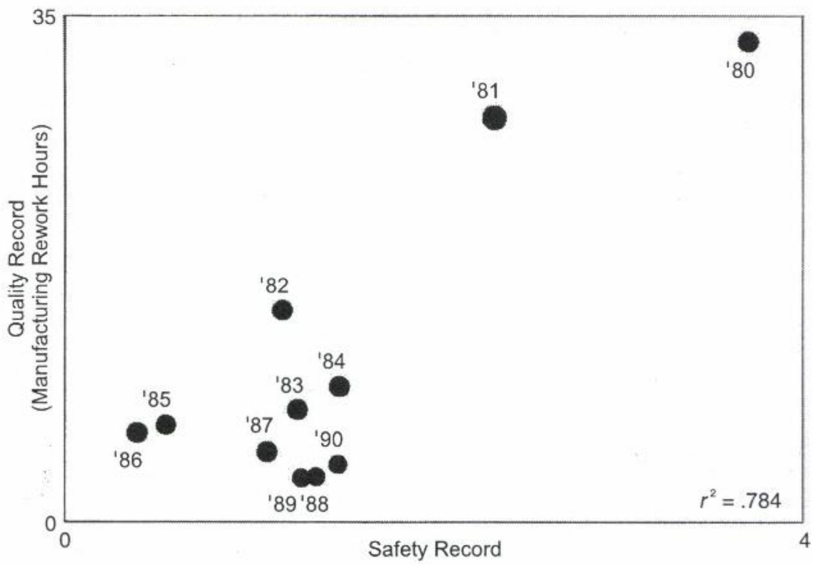

Figure 6. Company achievement in quality performance (manufacturing rework hours) versus safety performance (lost-time injuries) for the years 1980–1990.

involvement. Generally, worker perceptions of success factors appear to be closely aligned with principles guiding management of the two programs, summarized in section 4.3.2.

TABLE 4. Factors Contributing to Quality Program Success, Identified by Two or More Workers (N = 20)

Factor	Times Cited
Employee awareness of quality Pride in job and program Do-it-right-the-first-time approach	10
Employee involvement in program	7
Management support and commitment	3
Setting quality goals and standards	3
Problem-solving feedback from quality reports	2
Quality meetings	2
Training	2

TABLE 5. Factors Contributing to Safety Program Success, Identified by Two or More Workers (N = 20)

Factor	Times Cited
Employee awareness of hazards	12
Management support and commitment	4
Employee involvement in program	4
Safety inspections	2

TABLE 6. Manager and Worker Responses as to Reciprocal Influences of Quality and Safety Programs

	Manager Responses (%)			Worker Responses (%)		
Question	N	Yes	No	N	Yes	No
Does safety program contribute to success of quality program?	14	100	0	20	50	50
Does quality program contribute to success of safety program?	13	31	69	20	35	65

Table 6 summarizes responses to key questions dealing with subjective perceptions as to possible reciprocal effects of the firm's quality and safety programs on one another. All of the manager respondents, and 50% of the worker respondents, believe that the safety program contributed to the success of the quality program. Conversely, only about one third of both manager and worker respondents believe that the quality program contributed to the success of the safety program.

Table 7 summarizes results from worker responses as to current and desired level of decision-making in both the quality and safety programs, in relation to 7 quality program decision-making areas, and 8 safety program decision-making areas. For both programs, results are essentially identical, in that workers perceive that they currently have some input (rating = 2.0) into the decision-making process, but they express the desire for a higher level of input, between influencing and sharing responsibility for decision-making (rating = 3.3 to 3.5). By analysis of variance, differences between current and desired levels of decision-making input are statistically significant for both the safety ($F_{1,7} = 125.7$, $p < .001$) and the quality ($F_{1,6} = 106.9$, $p < .001$) programs.

TABLE 7. Current and Desired Levels of Worker Input Into Program Decision-Making ($N = 20$)

	Level of Decision-Making Input[a]	
Program	**Current**	**Desired**
Safety[b]	2.0	3.5
Quality[c]	2.0	3.3

Notes. a—based on a 5-point rating scale: 1—no input, 2—some input, 3—influence, 4—share responsibility, 5—sole responsibility; b—mean rating for 8 decision-making areas (work station design, housekeeping, incentive programs, safety inspections, training, protective clothing, work rules, and goal setting); c—mean rating for 7 decision-making areas (product design, quality measurement, training, quality awareness, corrective action, goal setting, and manufacturing process).

Discussion. The observations outlined in the previous section offer intriguing insight into possible synergism between safety and quality programs in place at this firm. Objective evidence (Figures 5 and 6) indicates that after installation of the quality program in 1980, both safety and quality performance of the firm improved concomitantly as the decade progressed. This evidence suggests that the performance of each program reciprocally affected the other in a pattern of mutually beneficial synergism. Subjective responses of both managers and workers (Table 6) convey the view that the influence of the safety on the quality program is primarily responsible for this pattern.

One explanation for this finding is that individual responsibility for working safely and for participating in hazard management, enunciated in the firm's safety policy (Table 5), naturally carries over to careful workmanship in producing defect-free products. The more general social cybernetic interpretation is that the emphasis placed on employee involvement in both programs introduces intimate behavioral feedback links between the safety and the quality of work performance that leads inevitably to the pattern of program interaction observed. The linchpin of both quality and safety is worker performance, and management commitment to support and encourage self-responsibility in the effective execution of work can be expected to benefit results in both areas.

The E/HF basis for this assumption resides in the high degree of consistency in design principles guiding management of both programs, summarized earlier. Worker perceptions about success factors (Tables 4 and 5), and about current and desired levels of input into decision-making (Table 7), for the two programs likewise are highly consistent. In light of parallels in organizational design of the QM and SM programs instituted by the firm, parallels in performance variability of the two programs, therefore, are to be expected.

Given that the firm's quality and safety programs may have mutually benefitted one another (Figures 5 and 6) under conditions of separate line management for each program, what arguments can be raised for a more integrated management approach to both programs? A conceptual argument has just been presented—from the standpoint of work performance, accident prevention and defect prevention undoubtedly have intimate behavioral feedback links. Moreover, with their common emphasis on the participatory approach both programs already have an appreciable degree of organizational design integration.

Most persuasive perhaps are comments from some worker respondents that the greater emphasis placed by company management on the quality program does not positively serve the safety program. Indeed, only about one third of both managers and workers feel that the quality program contributes to the success of the safety program (Table 6). These points suggest that workforce perceptions as to how the programs dovetail with one another, as well as performance outcomes of the programs themselves, might benefit from a more integrated program management approach.

A social cybernetic interpretation of the performance advantages of an integrated relative to a dual approach to managing safety and quality programs is given in Figures 7 and 8. With the dual program approach (Figure 7) employed by the company, the shop floor worker must sense and control psychosocial feedback from three managers, organizational design sensory feedback from two programs, and ergonomic design sensory feedback from workplace design factors and conditions. It seems reasonable to suggest that the demands of these multiple sources of social and design sensory feedback on the behavioral control capabilities of the worker may be considerable, and may compromise safety and quality performance at times.

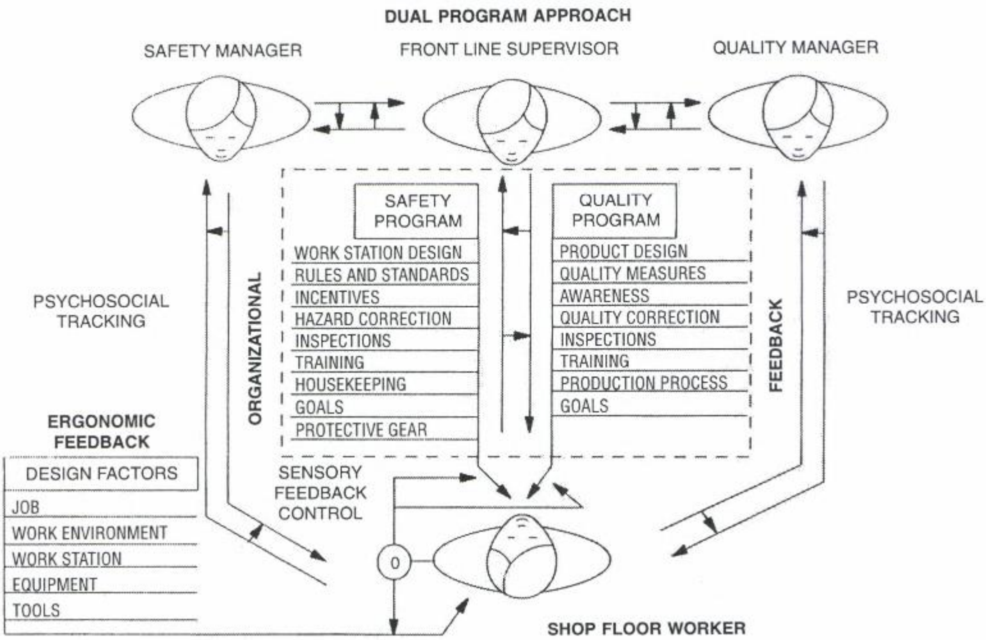

Figure 7. Psychosocial tracking and sensory feedback control demands on shop floor worker under dual program approach to safety and quality management.

Conversely, with an integrated approach to safety and quality management (Figure 8), psychosocial feedback from only two managers (production and E/HF managers, with the production manager also responsible for quality control) and sensory feedback from one set of

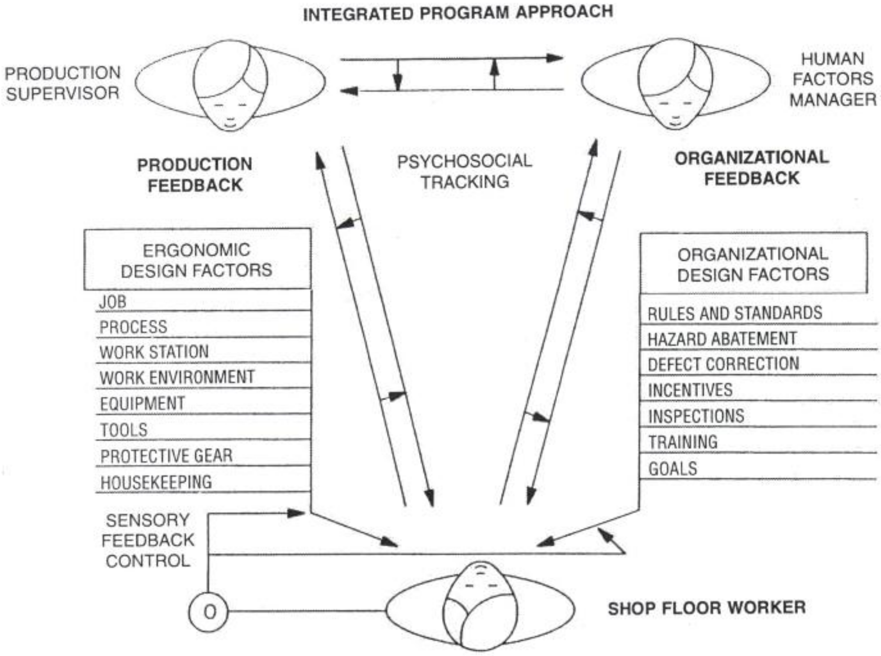

Figure 8. Psychosocial tracking and sensory feedback control demands on shop floor worker under integrated program approach to safety and quality management.

organizational plus ergonomic design factors, must be controlled by the shop floor worker. It seems reasonable to suggest that this integrated approach simplifies behavioral control demands placed on the worker, which may in turn benefit both safety and quality performance in a mutually synergistic manner.

5. ERGONOMICS AND BREAKTHROUGH IN QUALITY

This report is not the first to suggest a cybernetic or closed-loop design model (Figure 3) of organizational behavior, in which management decisions are guided by feedback from system performance attributes such as quality (Table 1), safety (Table 2), or ergonomics (Table 3). For example, the Plan-Do-Check-Act cycle of continuous quality improvement advocated by Deming (1982) implies closed-loop linkages between the behavioral cybernetic elements (section 2) of control goals and objectives (Plan), sensory feedback (Check), effectors (Do), and sensory feedback control (Act). Juran's spiral of progress in quality (Juran, 1992; Juran & Gryna, 1980) specifies similar closed-loop linkages. As applied to goods production, for example, the Juran spiral links market research, product development and design, and production planning (control goals and objectives), production (effectors), inspection and market outcomes (sensory feedback), and process control (control of sensory feedback).

The most explicit application of a closed-loop design model to organizational systems management is that of Juran. In 1954, he introduced a servomechanism model as a design universal that all managers employ (with varying degrees of success) for controlling their system operations, a concept that he later elaborated upon in his seminal texts on managerial breakthrough (Juran, 1964, 1995). The Juran model assumes that effective management control of an organizational system is mediated by comparison of feedback from actual system performance with performance targets (standards or specifications). As with an engineering servomechanism, error between actual and desired performance is used to guide management decision-making directed at tightening system control and reducing performance error.

Given that Juran advanced his servomechanism model of management control over four decades ago, what new insights are provided by the conceptual approach offered here? One basic objective is to call attention to explicit parallels between the cybernetic properties of individual behavior (Figure 1, section 2) and those of the behavior of complex sociotechnical systems (Figure 3; Tables 1, 2, and 3). Support for such homology is provided by evidence indicating that the behaviors of both individual and organizational systems display (a) design specificity in performance variability (sections 2 and 4.1); and (b) social cybernetic attributes (Figure 2; section 3), which can be used to account for social tracking performance synergism observed between organizational systems with compatible cybernetic designs (section 4.3).

The second objective of the model in Figure 3 is to indicate that the cybernetic paradigm provides an explicit basis for interaction between ergonomics and the performance of quality and safety programs. Deming (1982) does not appear to recognize this linkage. Juran and Gryna (1980, pp. 198–199) refer to the human factor as one of the variables affecting the reliability of quality performance, but do not emphasize the central role that ergonomics can and should play in improving quality performance through improved design. Figure 3 suggests that managers and workers (effectors) guide their control of the organizational system based on feedback from quality and safety performance, which in turn is influenced by various attributes of system design (Juran's [1964, p. 187] term for these attributes is "variables affecting performance"). The application of ergonomics to improve system design (a major goal of E/HF science), therefore, can be expected to benefit system reliability by reducing perturbing effects of inadequate design on system performance variability.

Yet another implication of the model in Figure 3 is that it points to a role for ergonomics in facilitating breakthrough in quality performance. The key to maintaining and sustaining performance of a system at any given level is the operation of system control, defined by Juran (1995, p. 1) as "staying on course, adherence to standard, prevention of change." As he points out (1995), "under complete control, nothing would change—we would be in a static, quiescent world." As noted, Juran (1995, pp. 199–206) assumes that managerial control is mediated as a closed-loop process, in which feedback from actual performance is compared with desired performance in order to identify and abate performance error. However, Juran (1995, p. 3) goes on to observe that: "control can be a cruel hoax, a built-in procedure for avoiding progress—we can become so preoccupied with *meeting* targets that we fail to challenge *the target itself*—this brings us to a consideration of breakthrough."

Juran (1995, p. 3) defines managerial breakthrough as "change, a dynamic, decisive movement to new, higher levels of performance." He assumes that there is an unvarying sequence of events that occur in breakthrough from one level of performance control to a new, improved level, namely, (a) breakthrough in attitude, (b) Pareto analysis, (c) diagnosis, (d) cultural adaptation, (e) breakthrough in results, and (f) achieving control at a new performance level.

Unlike the model for system control, defined by Juran as a servomechanism, his model for breakthrough in system performance is not presented as a cybernetic process. Nevertheless, it can be argued that breakthrough can be conceived as a closed-loop process involving **feedforward** rather than feedback (i.e., servomechanism) control. Feedforward control is ubiquitous among biological systems. It enables them to rely upon sensory feedback from present conditions to project their behavior into the future. Similarly, the impetus for breakthrough in organizational performance is some feedback or error indicator suggesting that the current level of performance (Juran's "the target itself") is no longer adequate, thereby prompting the system to initiate a breakthrough sequence to project its behavior into the future in a feedforward manner to achieve a new, improved performance level.

It is likely that often if not always, the root cause of inadequate performance at any given level is some sort of design flaw, either in microergonomic design of the work process or environment, or in macroergonomic design of the organizational system, or both. This is where ergonomics comes into play. Ergonomic analysis can be used to detect poor system design. Ergonomic intervention can be used to improve system design in order to facilitate the breakthrough process. The application of ergonomics can thus serve as a key breakthrough strategy by means of which the system elevates its behavioral performance from one control level to the next.

This concept is illustrated in Figure 9, applied to the interaction of ergonomics and quality. The shaded region in Figure 9 depicts Juran's servomechanism model of quality control (1995, p. 202), in which the organizational system of managers and workers acts upon feedback from system design variables (sensed by inspection or quality audit) to effect a product or service, whose actual level of quality is compared with a desired quality target or goal set by the system. Error between

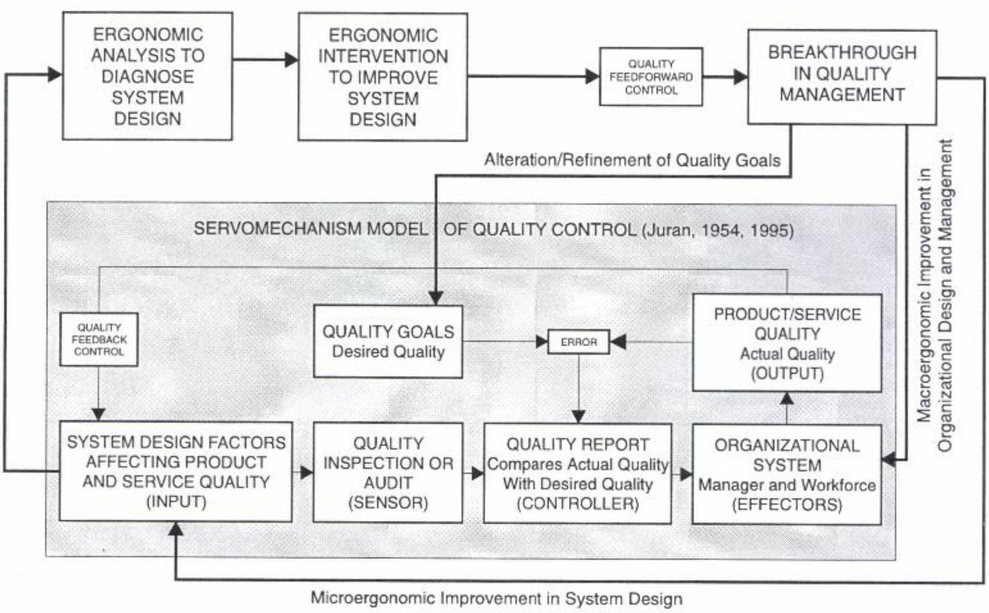

Figure 9. Model of breakthrough in quality management as a feedforward control process, with ergonomic analysis and intervention specified as key contributors to feedforward control.

desired and actual quality (recorded in a quality report) is used in a quality feedback control manner to adjust system design variables, with the aim of reducing quality errors. With a tightly controlled system, error is close to zero and the system (because of its apparent near optimal level of performance) consequently is highly resistant to change.

However, as Juran points out (1995, chap. 1), change is essential for system survival. System design, therefore, must include some provision for alteration or adjustment of the quality goals themselves, a process Juran terms breakthrough. The basic premise in Figure 9 is that breakthrough is actually a process of feedforward control superimposed upon the servomechanism or feedback control process. Feedforward control means that the system projects its performance into the future by relying upon perceived inadequacies in system design as a predictive indicator that performance breakthrough will be required for the system to continue to prosper.

The further premise in Figure 9 is that ergonomics can greatly facilitate the breakthrough process in two major ways, namely, through ergonomic analysis and ergonomic intervention. Methods of ergonomic analysis are admirably tailored for detecting inadequacies or shortcomings in system design; results of this analysis, therefore, can serve as early warning sentinels for the need for initiating a breakthrough process. Once design problems have been identified, methods of ergonomic intervention then are admirably suited for contributing to problem resolution, through microergonomic improvement in system design features, macroergonomic improvement in organizational design features, and alteration or refinement of quality targets and goals.

Finally, the model in Figure 9 assumes that ergonomics can and should serve as a key universal in the armamentarium of techniques that managers employ to guide the breakthrough process, along with others specified by Juran (1995). In particular, ergonomic analysis can contribute in a major way to breakthrough in knowledge for purposes of diagnosis (Juran, 1995, chap. 8), and ergonomic intervention can contribute in a major way to breakthrough in performance through action (Juran, 1995, chap. 10). In this manner, managerial control of system ergonomics becomes tightly integrated with managerial control of system quality such that, on an operational level, the two control functions become functionally indistinguishable.

6. CONCLUSIONS

The thrust of the foregoing analysis is that synergism between ergonomics, safety, and quality observed with a variety of complex ST systems, can be understood in the context of behavioral cybernetic theory (Figure 1). In particular, such synergism emerges as a social cybernetic consequence of closed-loop coupling (Figure 3), based on social tracking (Figures 2 and 4), between behavioral performance of the system (safety and quality performance and management) and microergonomic and macroergonomic design features of the system.

From a behavioral control systems perspective, ergonomics may be considered as absolutely essential to effective organizational self-regulation. If the performance environment is poorly designed, sensory feedback from design factors in the environment cannot be closely controlled. As with the behavior of an individual, all of the key determinants of organizational behavioral effectiveness are compromised under conditions of impaired sensory feedback control, namely, quality, safety, health, efficiency, productivity, and competitiveness. The mutual influence of ergonomics, safety, and quality on one another, therefore, represents a manifestation of organizational behavioral cybernetics: It arises as an inevitable closed-loop consequence of effective employee self-regulation and control of sensory feedback from system ergonomics.

This interpretation rests upon three basic assumptions: (a) The idea that behavioral performance is design or context specific, extensively documented in the case of individual performance (Smith, T.J., 1993; Smith, T.J. et al., 1994), can also be applied to the performance of complex ST systems; (b) The nature and extent of design specificity in the performance of a given complex ST system depends upon the degree to which it self-regulates its own performance, in that a self-regulatory system design that incorporates all of the essential elements of a behavioral cybernetic system (section 2) establishes, by its very nature, closed-loop linkages between system performance and system design; and (c) Synergism between safety performance, quality performance, and ergonomic design of a system is defined and established by these linkages.

Some evidence from field observations (section 4) can be cited to support these assumptions. However, at present, the evidence is inferential, indirect, and sparse. There is vast opportunity for further research to assess the applicability of the behavioral cybernetic model to complex ST systems, and the validity of the aforementioned assumptions on which it rests. I believe that such research can be most productively applied to evaluating the heuristic value of the model by exploring such questions as (a) to what degree is the safety and quality performance of complex ST systems design or context specific? (b) does design specificity in system performance grow out of its self-regulatory properties? (c) to what degree is achieving better safety and quality performance of a system predicated on making improvements in system ergonomics? or (d) what ergonomic design factors have the greatest influence on variability in system safety and quality performance?

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