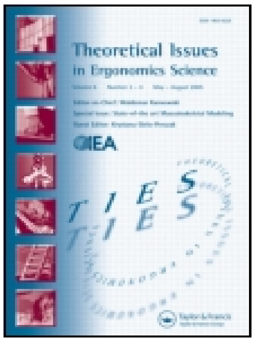

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The fundamentals of work system compatibility theory: an integrated approach to optimization of human performance at work

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Keywords: Compatibility; Productivity; Quality of work life; Symvatology; Work system design.

This paper presents a general framework for the work system compatibility (WSC) theory based on two fundamental premises: (1) the synergistic effects of the entire domain of work factors upon the performance of individuals in the workplace must be considered; and (2) the work system elements must be balanced to achieve simultaneous optimization of all facets of workplace human performance measures. The WSC theory is integrative on two levels. First, the WSC theory integrates previous human performance theories that only considered the impact of some sub-sets of work factors on selected outcome measures. Secondly, the WSC theory serves to integrate prior theories towards a multi-disciplinary systems approach to work system improvements. The WSC theory provides a methodology for achieving a balance among key elements of work system by simultaneous optimization of the relevant human performance measures.

1. Introduction

Traditionally, the work system optimization efforts undertaken by many of the contemporary enterprises focus on the maximization of one single output performance measure of interest at a time, for example work productivity, work (process and product) quality, environmental protection, or worker safety (Karwowski *et al.* 1997, Podgorski and Karwowski 2000). However, as discussed previously (see Karwowski *et al.* 1994, Genaidy *et al.* 1999, Genaidy 2000), in most industrial work settings these measures are inter-related (figure 1). Furthermore, such performance measures are influenced by a common set of work factors. A high quality of work life for all stakeholders in the organization is a pre-requisite for achieving optimum levels of work productivity and output quality. If the optimum levels of these outputs have not been achieved, the work factors and quality of work life are often negatively affected, i.e. through the feedback loop (Shoaf *et al.* 2000). Therefore, the ultimate goal of the work system optimization should be to provide simultaneous optimization of different performance measures (see Karwowski *et al.* 1994).

To achieve such a goal, the effects of the entire set of various factors in the domain of the work system must be examined. In this research, the work system is modelled as a complex system represented in terms of the organization that consists of functions, processes and jobs (Rummler and Brache 1995) (figure 2). In this

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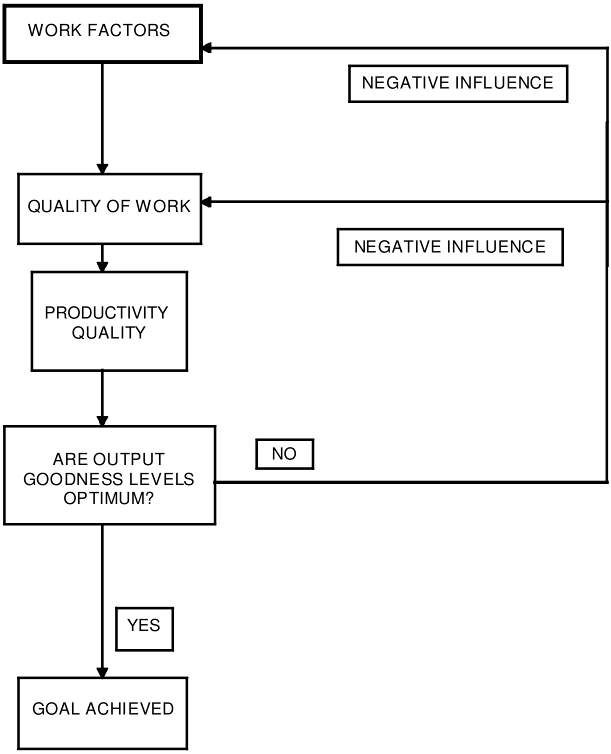

Figure 1. Interrelationship among quality of work life, productivity and output quality.

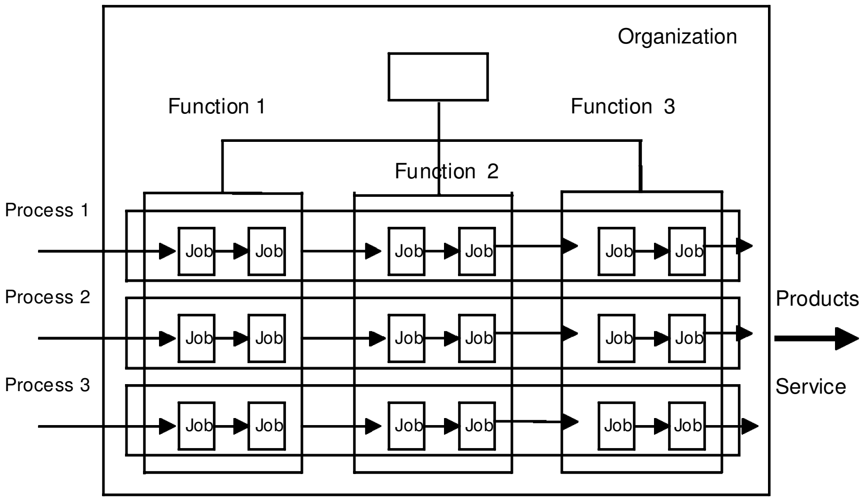

Figure 2. Work system structure.

complex system, a *function* is a vertical structure that deals with specialized work tasks (e.g. finance, sales, manufacturing, research and development), a *process* is a horizontal structure that consists of a series of steps designed to produce a product/ service and spans across one or various functions, and a *job* is considered the basic unit of organizational structure. As such, the hierarchy of work factors impacting human performance at the job level can be described in terms of global factors (i.e. organizational factors impacting all jobs in the work system and process factors impacting only the group of jobs that make up the process across one or more functions) as well as local factors (i.e. factors existing only at the job level).

This paper describes the fundamentals of work system compatibility (WSC) theory, the basis for a methodology designed to comprehensively evaluate and improve human performance in the workplace. The premise of such a theory lies in the framework of *symvatology*, or the science of an artifact–human compatibility, recently proposed by Karwowski (2000). The background information on previous human performance optimization efforts is also provided in order to outline the rationale as to how the WSC theory fills a void in the current research.

2. Background information

Below, we present an overview and critical discussion of the evolution of previous efforts focused on human performance optimization. More details regarding other developments in this evolution process can be found in the published literature (e.g. Filley *et al.* 1976, Davis and Taylor 1980, Feigenbaum 1991, Bassett 1993, Karwowski *et al.* 1994, Shoaf *et al.* 2000).

2.1. *Era of general craftsmanship*

Prior to the Industrial Revolution in England, the general craftsmanship approach served as the dominant manufacturing method for producing goods. This approach resulted in good quality of output; however, volume was low in comparison to the mass production concept in today's economy. The general craftsmanship method was typically utilized in small shops where each worker or a small group of workers was responsible for producing a whole product. Goods such as hand-made rugs are still produced nowadays in this manner in many parts of the world (i.e. Asia). The fundamental strength of this approach was that each craftsperson, being accountable for the product as a whole, derived a great deal of satisfaction from seeing the output of his/her work.

2.2. *Era of specialized craftsmanship and scientific management*

As time progressed, technology advanced, growing from the roots of the Industrial Revolution, while the world population increased, thereby creating the need to produce large volumes and varied types of consumer goods. To meet these needs, efficient utilization of resources was required in order to produce cost-effective products. As such, the general craftsmanship approach gradually evolved into the specialized craftsmanship era fuelled by the principles of Scientific Management (Taylor 1911). Taylor instituted four major principles, which formed the cornerstone of mass production. These principles formed the basis for producing goods in American industry and were eventually exported to other parts of the world.

2.3. *A need for change*

Around the 1940s, new developments in American industry emerged which rendered the principles of Scientific Management outdated. These factors included: (1) continued technological advances, (2) increased educational level of the general workforce to satisfy, among other issues, the needs of technological advances, (3) government regulations to insure, among others, the well-being of the workers,

(4) the findings of the Hawthorne Studies (Roethlisberger and Dickinson 1940), and (5) the Theory of Hierarchy of Needs (Maslow 1943). Collectively, these developments signalled the beginning of a new era that was characterized by independent and specialized movements that aimed to improve specific aspects of the work system. Each effort dealt with only one facet of work place human performance (e.g. work productivity, work health and safety, or quality of output) or a closely-related outcome measure (e.g. work satisfaction).

2.4. *Independent movements*
The independent work improvement philosophies were implemented in industry (particularly American industry) in the form of isolated programmes, that is, with no apparent link between the various programmes with respect to their contribution to overall organizational performance. In effect, these programmes managed to create the 'silo' phenomenon, as each programme isolated itself to deal specifically with its own issues independent from other initiatives in the organization.

These efforts failed to consider the inter-relationships among the quality of work life (including work health and safety), work productivity, and output quality. Some references in the published literature recognized this omission. For example, the British Standards Institution (BSI 1959) acknowledged that the performance of a 'qualified worker' was tied to 'satisfactory standards of safety, quantity, and quality'. However, these references did not address how to evaluate or optimize these inter-relationships. A notable exception to this observation is the people-oriented approach to quality, productivity, and safety in the Japanese industry during the last seven decades (e.g. Imai 1986).

In recent years, many of the independent movements have realized the disappointing results when measured with respect to expected organizational performance. Consequently, they have acknowledged the benefit of interaction with other disciplines in order to share the experiences and lessons learned. Two selected examples are discussed below in order to demonstrate the evolution of these independent efforts, namely, the quality and ergonomics/human factors movements.

2.5. *Evolution of quality efforts*
The quality movement underwent six phases (Feigenbaum 1991) (see figure 3):

(1) *Operator quality control*. In this phase (during the era of general craftsmanship), one worker or at least a very small number of workers was responsible for the manufacture of the entire product and, therefore, each worker could totally control the quality of personal work .
(2) *Foreman quality control*. This and subsequent phases emerged during the era of specialized craftsmanship that was influenced and guided by the principles of Scientific Management. This period witnessed the grouping of many individuals doing the same task to be directed by a foreman who assumed responsibility for the quality of their work.
(3) *Inspection quality control*. Because of the growing complexity of the manufacturing systems during World War I, larger numbers of workers reported to each production foreman. Consequently, this resulted in full-time inspectors appearing on the scene.
(4) *Statistical quality control*. World War II demanded further improvements in the efficiency of quality procedures, which lead to this phase of the evolution.

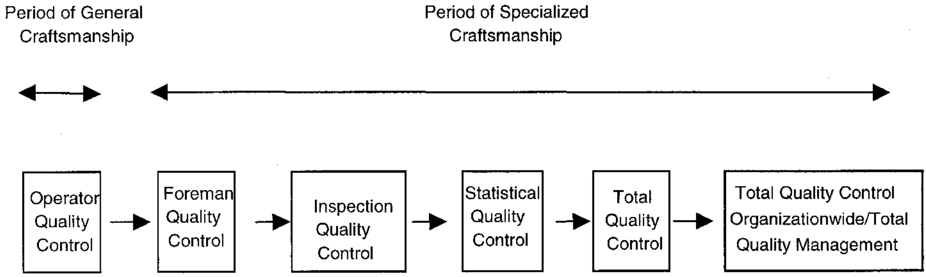

Figure 3. Evolution of quality movement.

Inspectors were then provided with few statistical tools such as sampling and control charts.

(5) *Total quality control.* This phase evolved from the unwillingness or inability of the business and government organizations to take adequate steps concerning the findings of the technical and statistical work. This total quality framework provided the means for regular vs occasional design reviews, analysis of in-process results and taking action at the manufacturing or supplier source, and finally production stoppage when necessary.

(6) *Total quality-control organization-wide and total quality management.* As total quality control evolved to make a major impact upon management and engineering practices, total quality-control organization-wide and total quality management emerged during the 1980s as a major business strategy. This phase realized the greater meaning of quality initiatives, that is a people-oriented approach, which should be implemented organization-wide.

In summary, the quality movement originated in the days when a worker or a small group of workers was responsible for the manufacture of a given product. Because of continued technological advances and associated growing complexity of manufacturing systems, the entire organization now owns the responsibility for the whole product. These changes illustrate the importance of incorporating organizational and process factors among the variables that impact work place human performance. However, the quality movement did not provide adequate emphasis to work factors at the job level.

2.6. *Evolution of ergonomics and human factors efforts*

The ergonomics and human factors engineering efforts, the second example of the evolution process, began in part out of the Motion and Time Studies (Barnes 1980), Industrial Fatigue Research Board (Burnett 1925), and health and safety concerns for the workforce (figure 4) (Genaidy 2000). Unlike the quality movement, the ergonomics/human factors efforts focused on the role of work factors at the job level. During the early days of ergonomics development in England, emphasis was placed on matching physical task demands with physical strength and endurance capabilities to minimize fatigue and risk of injuries and illnesses. In the US, human factors engineering efforts were mainly concerned with fitting of mental task demands, and perceptual and cognitive capabilities to minimize the likelihood of human error leading to industrial accidents. Moreover, both ergonomics and human factors engineering efforts emphasized the study of physical environment conditions

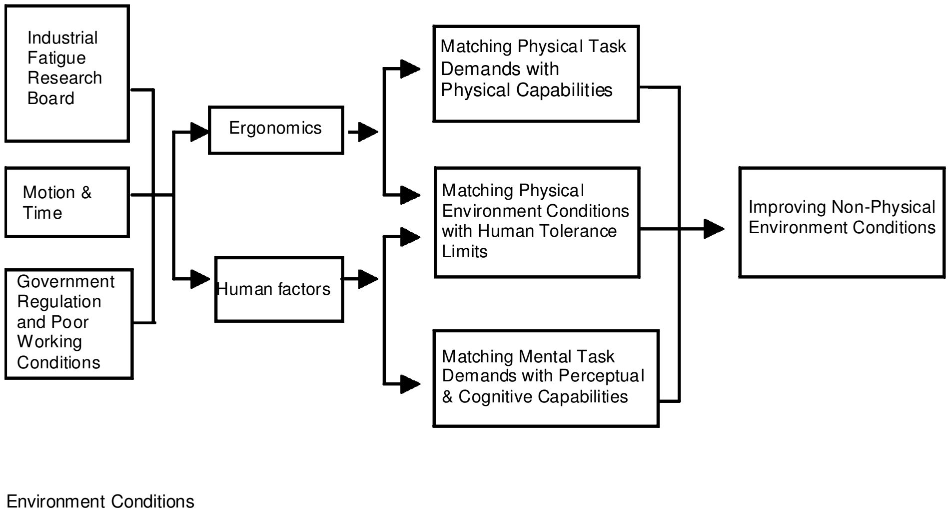

Figure 4. Evolution of ergonomics/human factors movement.

such as noise and vibration to ensure that such conditions were within the tolerance limits of workers.

Until recently, the ergonomics and human factors efforts focused on the study of task content (that is, physical and mental task demands) and physical environment conditions with no reference to non-physical environment conditions that include social, organizational and technical factors (Shoaf *et al.* 2000). However, in the past two decades, the macro-ergonomic approach has introduced the significance of non-physical environment conditions (i.e. organizational, social and technical factors) upon workplace human performance (Hendrick 1991, 1995).

In the last 5 years, professional ergonomists and human factors specialists have suggested that substantial benefits could be realized by uniting aspects of ergonomics and quality movements. Both disciplines are influenced by a common set of work factors (Hendrick 1995, Drury 1997, Eklund 1997, Genaidy 2000, Podgorski and Karwowski 2000). Eklund (1997), for example, determined the field of quality would be enhanced by incorporating ergonomics knowledge, particularly in the areas of work design and human capability. He further added that the field of ergonomics would benefit from developing a stronger emphasis on methodologies and structures for process improvement including a clearer link with leadership and company strategies. Hendrick (1995) suggested that, in light of the widespread adaptation of ISO 9000 to quality management, including employee health and safety requirements, macro-ergonomics could be adapted as a total quality management strategy. However, the aforementioned reports did not provide adequate information regarding how to synthesize the strengths from each field.

3. Fundamentals of work system compatibility theory

The work system compatibility theory (WSC) is presented below by outlining definitions, assumptions and relevant hypothesis. Characterization of the work factors impacting human performance and integrated improvement strategies are also discussed. Finally, a human performance model is described to illustrate how the WSC theory operates within the context of overall work system.

3.1. *Theory overview*

The proposed WSC theory is the basis for a methodology designed to comprehensively evaluate and improve human performance in the workplace. The premise of such a theory lies in the framework of *symvatology*, or the science of an artifact–human compatibility, recently proposed by Karwowski (2000).

The WSC theory is based on two fundamental premises: (1) the synergistic effects of the entire domain of work factors upon the performance of individuals in the workplace must be considered (see Shoaf *et al.* 2000); and (2) the work system elements must be balanced to achieve simultaneous optimization of all facets of workplace human performance measures. In this respect, the WSC theory integrates previous human performance theories that only considered the impact of sub-sets of work factors on selected outcome measures. The following are selected examples of prior work drawn from the different fields of human performance optimization:

(1) The Job Characteristics theory concentrated on the effects of sub-sets of motivational factors (i.e. skill variety, task identity, task significance, autonomy and task feedback) on work satisfaction (Hackman and Oldham 1975, 1976).
(2) The quality movement placed a strong emphasis on the work factors at the organizational and process levels (Hendrick 1995).
(3) The ergonomics/human factors efforts only took into account the factors at the job level (Genaidy 2000).
(4) The 'Motivation-Hygiene theory' made a distinction between two sets of work factors, those that influence work satisfaction and others that affect work dissatisfaction (Herzberg *et al.* 1959). A greater emphasis, however, was placed in this theory on the factors that affected work satisfaction.

The formulation of the WSC theory provides an integrative strategy for the work system evaluation and improvement in two respects. First, the total domain of work factors in the work system at the organizational, process and job levels are addressed. Secondly, the strengths of many disciplines considering work system design are integrated to form a multi-disciplinary perspective.

The WSC theory advances the current knowledge by proposing the methodology on how to achieve the balance among different elements in the work system, in order to simultaneously optimize all workplace human performance measures. Prior work has provided philosophical guidance, yet did not discuss specific strategies for achieving balance in the work system. For example, the Balance Theory of Job Design, from the field of job stress research, maintains that balancing the elements of the job (i.e. technology, task, environment, organization) leads to stress reduction (Smith and Sainfort 1989). This theory, however, did not demonstrate how the different elements of the job interact to produce the intended balance.

3.2. *Basic WSC definitions*

Work factors, elements in the work system resulting from requirements, conditions, practices and procedures in the environment, act on the worker as 'forces'. A force, by definition, has both magnitude and direction. In the work system, a force may be classified according to its effect into either 'energy expenditure' or 'energy replenishment' force. An energy expenditure force (e.g. the manual handling of objects or solving complex mathematical problems) leads to energy consumption and, therefore, has a negative effect. On the other hand, an energy replenishment force (e.g.

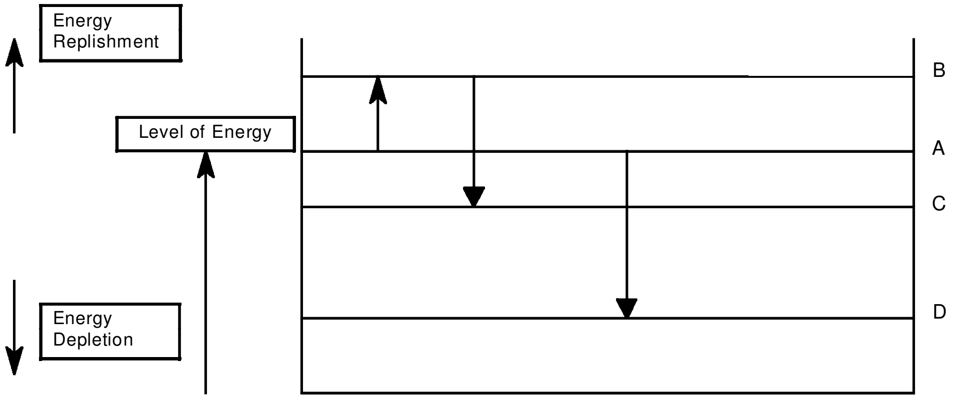

Figure 5. Interaction between energy expenditure and replenishment work factors.

good financial incentives) acts as a stimulus that helps activate human energy reserves and, therefore, has a positive effect.

Energy expenditure and replenishment forces do not act independently upon the worker. They are interactive in nature. For example, a company may decide to institute a competitive financial incentive plan. Consequently, this plan expects a worker to achieve a certain level of safety and productivity, and output quality. Thus, the plan will constitute an energy replenishment force for the person. At the same time, the plan calls for the consumption of human energy in terms of the expected physical and mental demands situated within the context of environmental conditions.

A possible scenario depicting the interaction between the forces of energy expenditure and replenishment is shown in figure 5. 'A' represents the normal level of energy readily available to the person for consumption. Then, the energy replenishment manifested in the form of an incentive plan comes along and raises the level of energy supply to perhaps 'B'. Consequently, the energy expenditure forces will expect the depletion of energy to level 'C'. This level is, however, higher than the level of energy supply (i.e. 'D') without the incentive plan (assuming that the same force is expected without the incentive plan). The difference between the 'C' and 'D' energy levels represents the value added due to the introduction of the incentive plan.

Outcome measures of human performance in this work are defined in terms of work productivity, output quality and work safety. Work productivity is defined in terms of output produced to resources consumed in producing the output. Output quality is considered the goodness of an output with reference to some standards or specifications. Furthermore, work safety is calculated in terms of the frequency and severity of workplace injuries/illnesses and accidents. It is only one element of the quality of work life. The elements of quality of work of life may include safe/healthy and comfortable workplace, social integration in work organization, supportive organizational and technical environment, and rewarding workplace (from organizational and social standpoint).

Work system compatibility is defined as the degree of equilibrium between the energy expenditure and energy replenishment forces. Thus, if the magnitude of energy expenditure forces exceeds that of energy replenishment forces, the forces of energy depletion are not balanced with adequate benefits in the work environment.

Also, if the magnitude of energy replenishment forces exceeds that of energy expenditure forces, the magnitude of energy depletion forces can be increased to achieve a more stable condition, resulting in a more optimum output. In both cases, the larger the mismatch between energy expenditure and replenishment forces, the lower the WSC level.

3.3. *Theory assumptions*

Workplace human performance in the WSC theory is applicable to the general population. This is similar in concept to the normal or standard performance in motion–time studies where standard performance covers 95% of the worker population.

3.4. *Research hypothesis*

It is our hypothesis that the higher the work system compatibility, the better the outcome measures of human performance (fewer work accidents and injuries/illnesses, higher work productivity and output quality, and higher work satisfaction). Two possibilities are suggested for expressing this class of relationships (figure 6).

The first class of relationship is characterized by a slow rise or fall around the extremes and a steep rise or fall in the middle (see figure 6(*a*)). For example, this case may occur in an organization which has a very low quality of work life as well as output quality and productivity problems. At first, as areas (e.g. physical work conditions) are redesigned, WSC increases; however, output performance measures improve only slightly as the level of organization health is poor. In this case, to improve organizational health more dramatic changes are required to realize substantial results. As the dramatic changes are made, WSC increases and all output measures greatly improve due to the improvement in organizational health, thus accounting for the steep slope in the middle of the curve. Finally, when a high level of WSC has been achieved, the results obtained are less dramatic again, as the most significant gains have already been realized.

The second class assumes that the considered relationship can be described by a steep rise or fall around the extremes and a slow rise or fall around the middle (see figure 6(*b*)). For example, this case may occur in an organization which is already fundamentally healthy in terms of quality of work life; however, there are problems at the process level which affect output productivity and quality. In this case, the organization members may exhibit high morale and job satisfaction; yet, the productivity and quality levels standards are not being met. As WSC is increased as a result of some obvious changes at the process level (e.g. work team operational changes), dramatic results are seen in output productivity and quality. After this point, increasing WSC in the moderate region may yield only moderate results, as the process is now functioning successfully. When a high level of WSC is achieved after further efforts, significant gains can again be obtained, as the optimization of the process factors further improve the quality of organizational life due to the financial benefits of increased productivity and quality levels.

It is further hypothesized that there is no static relationship within each class of functions. Therefore, each level of WSC can result in several levels of output measures due to expected fluctuations in work factors (e.g. seasonal changes, external market demand) and be described as a family of curves bounded by upper and lower limits.

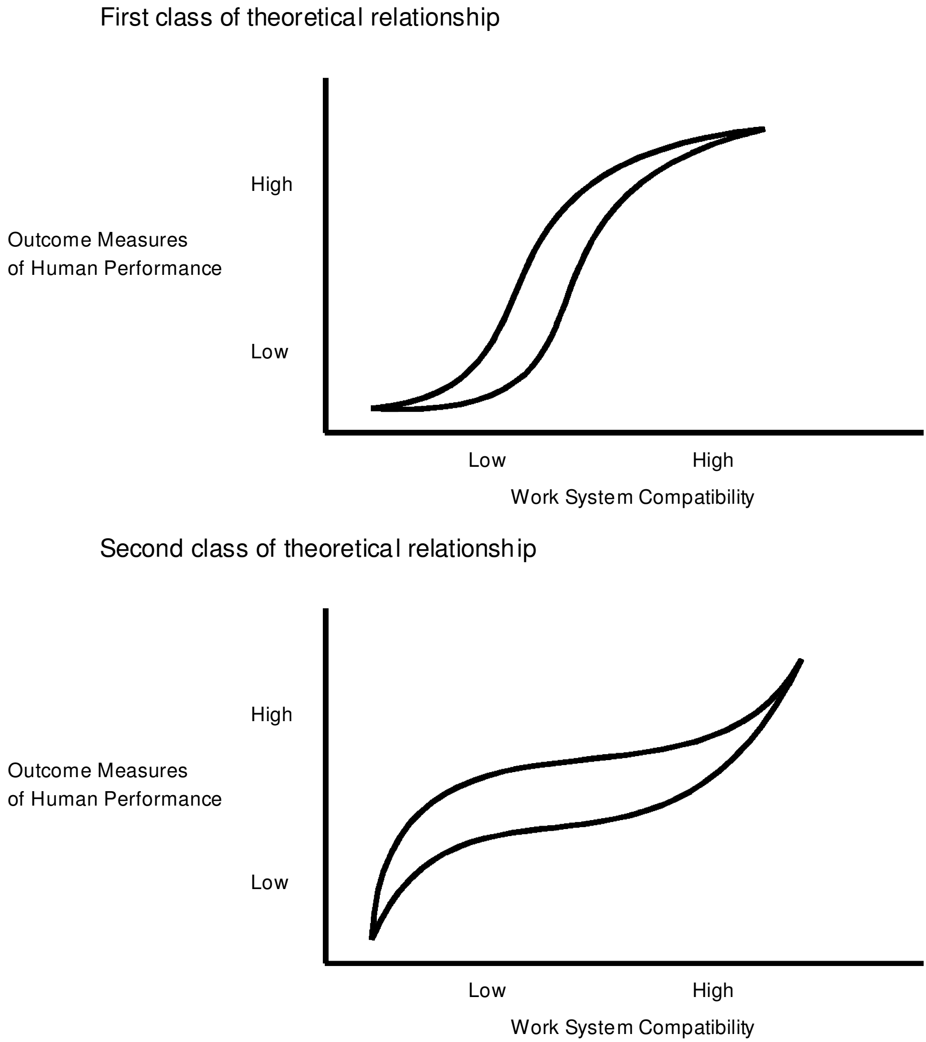

Figure 6. Theoretical relationship between work system compatibility and outcome measures of human performance.

3.5. *Characterization of work factors*

The two main factors that impact human performance at work are the energy replenishment and energy expenditure forces. The energy replenishment forces include specific non-physical environment conditions, namely, autonomy, task organization, individual growth, rewards and knowledge of results (see figure 7). Autonomy, task organization, and individual growth are part of the organizational environment, while rewards and knowledge of results are shared by the organizational and social environment conditions. These forces of energy replenishment are detailed below:

(1) Autonomy describes the job characteristic that leads the individual to a mental and emotional state in which he/she feels personally accountable and responsible for the results of their own work. Particularly, this job

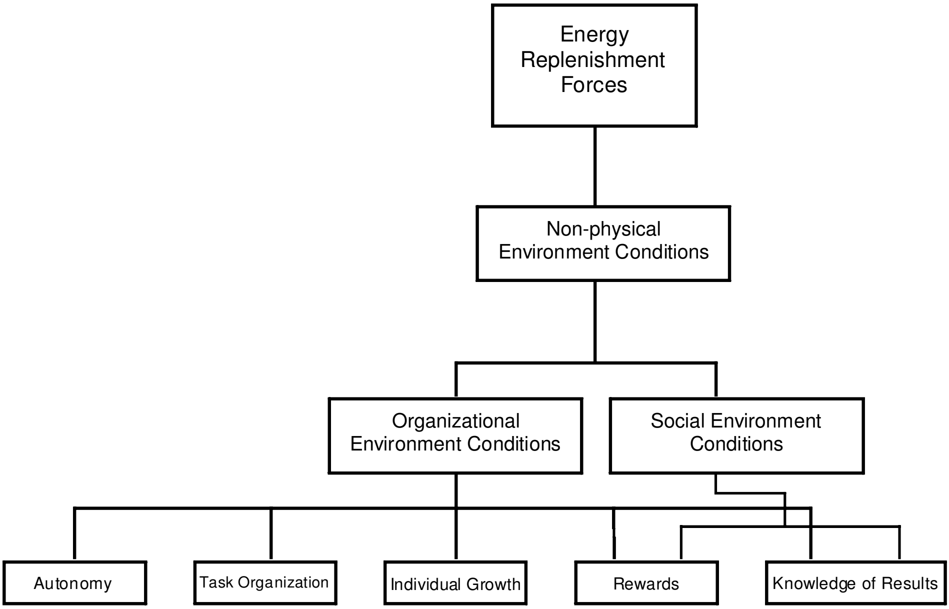

Figure 7. Hierarchical structure for energy replenishment forces.

characteristic deals with the freedom/independence/discretion given to the individual in: (a) scheduling the work, and (b) determining the procedures to be used in carrying it out.

(2) Task organization includes the factors that lead the individual to experience the job as generally meaningful, valuable and worthwhile. This is described in terms of skill variety (i.e. different activities that make use of a number of different skills and talents), task identity (i.e. a job that requires completion of a whole and identifiable piece of work), and task significance (i.e. whether the job has a substantial impact on the lives or work of other people in the immediate or external organization).

(3) Individual growth is concerned with future opportunities for continued growth in terms of personal development (opportunities to expand capabilities rather than lead to obsolescence due to current work activities), prospective skill application (opportunities to use expanded or newly acquired knowledge and skills in future assignments) and advancement (opportunities to advance in organizational or career terms recognized by peers, family members or associates).

(4) Rewards deal with the consequences of output produced by the worker and are instituted in the work system to provide the worker with incentives over and above the basic compensation and benefits package supplied by the employer. They include financial incentives as part of organizational environment conditions and other benefits in the social environment conditions (i.e. praise and recognition, nurturing and participation in decision-making).

(5) Knowledge of results involves how the individual knows and understands, on a continuous basis, (a) organizational information (e.g. job and organizational goals, how effectively the organization and its various units are performing or performance management results, how the organizational

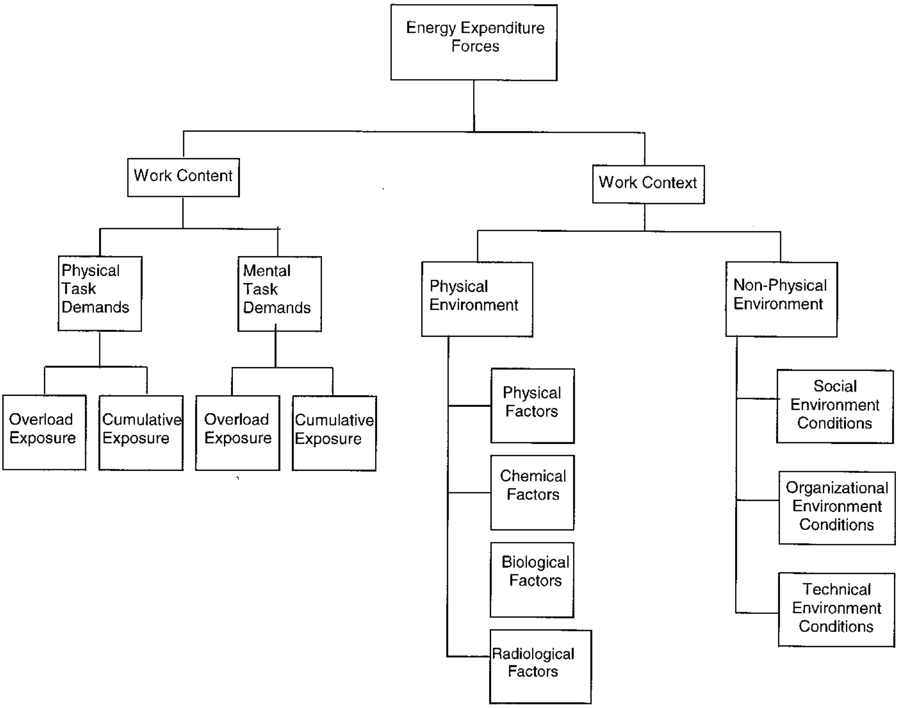

Figure 8. Hierarchical structure for energy expenditure forces.

goals guide those of various units and jobs, and task feedback, that is whether a job is set up so as to provide information about work performance aside from any feedback provided by managers or co-workers), and (b) social information (feedback management, that is, feedback information provided by managers and co-workers).

The forces of energy expenditure include work content (i.e. physical and mental task demands) and work context (i.e. physical and a sub-set of non-physical work environment conditions). These forces are detailed below (see figure 8).

(1) The physical task demands are comprised of work factors that directly result in muscular effort exertion (e.g. repetitive arm work). These include two general classes of muscular work: object handling in upright position and other activities. The variability of physical task demands are assessed in terms of both overload (heavy loads or high forces over a short period of time) and cumulative exposure (moderate loads or forces over an extended period of time) .
(2) The mental task demands encompass the work factors that directly result in mental effort exertion (e.g. planning and scheduling work). These involve two classes of work: skill-based activities (i.e. actions that are routine and executed automatically with little mental effort) or cognitive-based tasks (i.e. mental tasks that are performed in situations which are either familiar but not routine by recalling past experiences or unfamiliar, where the worker sets an objective, performs actions to achieve the desired goal, observes the

results and adjusts his or her activities if the goal is not met). Similar to physical task demands, the mental loading variability is evaluated in terms of both overload and cumulative exposure.

(3) The physical environment conditions are shaped by the conditions in the work environment that are defined by physical (e.g. noise), chemical (e.g. toxic chemicals), biological (e.g. bacteria), and radiological (e.g. X rays) factors. These conditions enhance both physical and mental effort consumption as well as a direct source of emotional effort consumption.

(4) The non-physical environment is defined by the social, organizational and technical factors. The social factors exist through the interaction with others in the organization and may include social support provided by supervisors/peers/subordinates, sense of community, interpersonal openness, and work in groups. The organizational factors are governed, among other things, by time organization, sequence of job activities, work responsibility, resource and interface management, and compensation and income security. The technical variables are characterized by work factors that impact the adequacy of technical requirements for job performance such as the availability of the right tools/equipment/machinery, information received, necessary skills and knowledge, as well as technical procedures and supervision. The non-physical environment conditions directly impact emotional effort that in turn influences both mental and physical effort. It should be noted that the non-physical environment forces in the energy expenditure domain are distinct from those forces in the energy replenishment domain.

4. Principles of work system compatibility

The principles of work system compatibility are designed to achieve the balance between different elements in the work system (table 1). Many of these principles represent a synthesis of prior improvement efforts within the framework of WSC theory. They were derived from the fields of industrial and organizational psychology, industrial engineering/engineering management/business management, ergonomics and human factors, and systems thinking (e.g. Tichauer 1978, Ackoff 1981, Deming 1986, Imai 1986, Dul and Weerdmeester 1993, Gaillard 1993, Hammer and Champy 1993, Karwowski *et al.* 1994, Neerincx and Griffioen 1996, Karwowski and Marras 1999, Karwowski 2001).

These design guidelines are grouped into four categories, namely: (1) compatibility principles, (2) energy replenishment principles, (3) energy expenditure principles, and (4) general work system principles. The compatibility principles are designed to be the guiding set of rules for system improvement efforts. In essence, these principles serve to balance the work system in the short, intermediate and long-term. In the short and intermediate terms, it is necessary to maintain a balance between the energy replenishment and energy expenditure forces, i.e. the magnitude of both forces should be equal. Then, both types of forces should be bounded within the moderate range to achieve long-term stability in the work system.

The principles of human performance improvement are derived from the energy expenditure and energy replenishment principles and should be interfaced with the compatibility principles. The energy expenditure principles provide the architecture, allowing one to conserve energy by minimizing the depletion of the respective resources in the human. This can be achieved through the following general laws:

Table 1. Principles of work system compatibility.

Compatibility principles		(1) Strive to continually maintain a balance between the energy expenditure and replenishment elements in the work system in order to simultaneously optimize all facets of workplace human performance (i.e. quality of output, work productivity, and quality of work life). (2) Moderation of elements of the work system (e.g. work factors, output measures) may be necessary to ensure long term stability.
Energy replenishment principles	Organizational environment—*Task organization*	(3) Work design should focus on the creation of whole jobs by combining smaller tasks and forming natural work units (i.e. to achieve skill variety, task identity, task significance). (4) Workers must be allowed to make decisions about their work scheduling and procedures (i.e. to achieve autonomy).
	Organizational environment—*Individual growth*	(5) Work should provide the following opportunities for individual growth in the organization: (a) To expand capabilities rather than lead to obsolescence (i.e. personal development); (b) To use expanded or newly acquired knowledge and skills in future assignments (i.e. prospective skill application); and (c) To advance in organizational or career terms recognized by peers, family members or associates (i.e. advancement opportunities).
	Organizational environment—*Financial rewards*	(6) Align financial incentives with excellence at work in terms of the degree of achieving work goals at the job, process, and organizational levels. (7) Financial incentives should be meaningful and provided in a timely fashion.
	Organizational environment—*Knowledge of results*	(8) Institute an information-based highway in the organization where everyone knows and understands, on a constant basis, work goals and performance at the organizational, process, functional and job levels. (a) A goal-based information system should include (figure 9): • a clear statement of organizational goals; • how organizational goals guide functional and job goals; • how process goals guide functional goals; • how process goals contribute to organizational goals; • how job goals contribute to process goals; • a clear statement of expected output and expected performance standard; and • how a performance standard is attainable.

		(b) A performance-based information system should include: • how the performance of each function or process is measured with respect to its contribution to organizational performance; • management feedback on functional and process performance; • identification and solution of problems that impede progress towards achieving functional and process goals; and • how functional and process goals are reset to meet organizational goals. (9) The work tasks should provide the person with information about work performance (aside from feedback provided by co-workers and managers), that is, task feedback.
	Social environment—*Social rewards*	(10) Align social rewards (i.e. praise and recognition, participation in decision-making) with excellence at work in terms of achieving work goals at the job, process and organizational levels. (11) Social rewards should be meaningful and provided in a timely fashion. (12) The organization should establish a mentoring programme to nurture the workforce.
	Social environment—*Knowledge of results*	(13) Institute a social feedback system where management and co-workers provide the person with relevant, accurate, timely, specific and easy to understand feedback information.
Energy expenditure principles	Work content—*Physical task content*	(14) Practice good body mechanics: (a) Avoid sudden movements and stress concentration; (b) Keep the work close to the body; (c) Avoid working around the limits of range of motion (i.e. awkward static postures); (d) Alternate postures and movements; and (e) Optimize skeletal configuration. (15) Limit the duration of any continuous and repetitive muscular effort. (16) Be careful of manually handling objects in the upright position (i.e. lifting, lowering, carrying, pushing, pulling): (a) Restrict the number of tasks which require manual object handling; (b) Create optimum circumstances for manual object handling (e.g. hold the load as close to the body as possible, loads should be fitted with hand grips); and (c) Replace manual object handling with the use of load handling and transport accessories.

(*continued*)

Table 1—(*continued*)

	(17) Hand tools should not be heavy.
	(18) Take account of differences in body size and gender.
	(19) Use anthropometric tables for specific populations.
Work content— *Mental task content*	(20) The total number of mental actions in a period should have an upper and a lower limit so that there is sufficient time to carry out these actions (i.e. to allow time for task execution).
	(21) The task content must call for several levels of mental information processing (i.e. routine, semi-familiar and non-familiar work).
	(22) There should be no long-term period in which only one sort of routine work is performed continuously (e.g. performance may decrease after 10 minutes of continuous vigilance).
	(23) The task content should not allow momentary overloading: several non-familiar mental tasks should not be performed in rapid succession in a short period of time, and semi- and non-familiar mental tasks do not have to be performed almost simultaneously.
	(24) The demands on working memory should be kept to a minimum (e.g. by using pictograms and colour coding).
Work context— *Physical environment*	(25) Eliminate or reduce adverse effects of the physical environment: (a) At the source level: eliminate or reduce source; (b) In the transmission between source and human: isolate source and/or human; and (c) At the individual level: reduce exposure duration and use personal protective equipment.
Work context— *Social environment*	(26) Institute social integration in the work organization to allow the opportunity to interact favourably with co-workers and managers: (a) Build supportive work groups to instill reciprocal help, socio-emotional support, and affirmation of uniqueness of each individual; (b) Build a sense of community that extends beyond face-to-face work groups; (c) Maintain interpersonal openness to allow members of the work organization to relate to one another their ideas and feelings; and (d) Acceptance of the worker for work-related skills, abilities and potential without regard to race, gender, national origin, life style and physical appearance.

Work context—*Organizational environment*	(27) Optimize the organizational environment to achieve the goals of the work system and its elements: (a) Break down barriers between functions to ensure the collaboration of various functions towards achieving organizational goals; (b) Balance resource allocation (i.e. people, equipment and budget) across functions; (c) Institute a pay and work benefit system that is adequate and fair; (d) Establish a sense of security in the work system; (e) Institute an organizational design that is conducive for job performance: • all relevant and necessary functions should be in place; • the flow of inputs and outputs between functions should be appropriate; and • the formal organizational structure should support the strategy and efficiency of work system. (f) Institute a process design that is conducive for job performance: • all relevant and necessary jobs should be in place; • the flow of inputs and outputs between jobs should be appropriate; and • the process structure should support the efficiency and effectiveness of the entire process. (g) Ensure the clarity of work responsibility with respect to the lives and safety of others, work of others, and material assets. (h) Institute an adequate system of rest allowances (e.g. allow frequent short breaks rather than a single long one). (i) Ensure that working long hours, night shifts and irregular or alternating shifts is adequately compensated. (j) Ensure the adaptability of the work force towards working long hours, night shifts and alternating or irregular shifts.
Work context—*Technical environment*	(28) The organization should provide adequate technical resources for job per-formance: (a) Availability of right tools, equipment and machinery; (b) Availability of maintenance programmes to keep equipment and machinery run-ning in case of malfunction; (c) Adequacy of information received; and (d) Presence, availability and attainability of necessary technical skills, knowledge, procedures and technical supervision.

(*continued*)

Table 1—(*continued*)

General work system principles	(29) Abolish the 'silo' phenomenon in the work system. Adopt the laws of work systems. Every work system and each element in it should satisfy the following: (a) The behaviour of each element in the work system has an effect on the behaviour of the whole work system; (b) The behaviour of elements and their effects on the work system are interdependent; and (c) Each group of elements has an effect on the behaviour of the whole work system and none has an independent effect on it. (30) The concept of total quality should embrace not only the quality of products and services but also the quality of work life for all stakeholders affiliated with the work system. (31) The work system should be continually aiming at the simultaneously optimization of all facets of work place human performance, that is, quality of work output/quality of work life/work productivity. (32) Institute leadership throughout the work system and its different elements. (33) Institute a vigorous programme of education and self-improvement as a pre-requisite for ongoing performance optimization efforts. (34) Support workers and managers by employee assistance programmes.

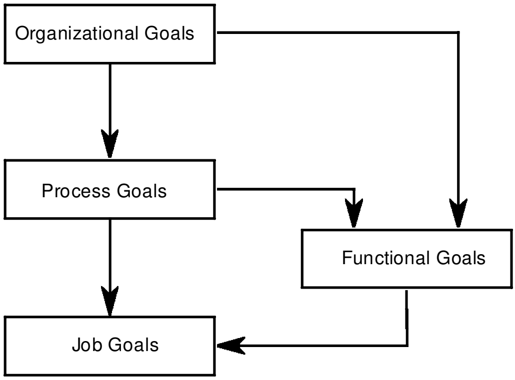

Figure 9. Interrelationships of organizational, functional, process and job goals.

(1) the physical task content principles attempt to preserve the physical energy;
(2) the mental task content principles reduces the depletion of mental energy;
(3) the physical environment principles of improvement are designed to reduce the environmental impact on all types of human energy (physical, mental and emotional); and
(4) the non-physical environment principles lessen the depletion of emotional energy, which, in turn, preserves the further depletion of both physical and mental energy.

The energy replenishment principles are engineered to increase the energy reserves of the human. In particular, these principles are designed to expand the resources of emotional energy, the most powerful and dominant form of energy for humans. It is the pre-requisite for, among others, innovation and creativity in the workplace. These principles can be achieved by enhancing task organization (autonomy, skill variety, and task identity and significance), creating the opportunities for individual growth and being rewarded, instituting an information-based system to know and understand on a continuous basis the work goals and performance at the organizational, process and job levels, as well as a feedback mechanism whereby managers and co-workers advise the individual on how well he/she is doing.

The general work system principles are global in nature, i.e. applicable to all efforts, to facilitate the successful implementation of the compatibility and energy expenditure/replenishment principles. They are based on the following tenets: (1) establishment of leadership throughout the work system; (2) embracing the concept of total quality for all stakeholders; (3) continued education and training for the work force; (4) eliminating the barriers among the different initiatives of human performance in the organization; and (5) adoption of continuous process improvement based on the simultaneous optimization of all performance indicators.

5. The work system compatibility model

Figure 10 shows a simplified, closed-loop model that illustrates the various components impacting the worker performance. This model is a complex, dynamic adaptive system. The input to the worker consists of an interactive network made up of energy expenditure forces (e.g. physical work conditions, requirements) and energy replenishment forces (e.g. social support, job autonomy). This interactive network includes the sub-domains of work factors at the job, process

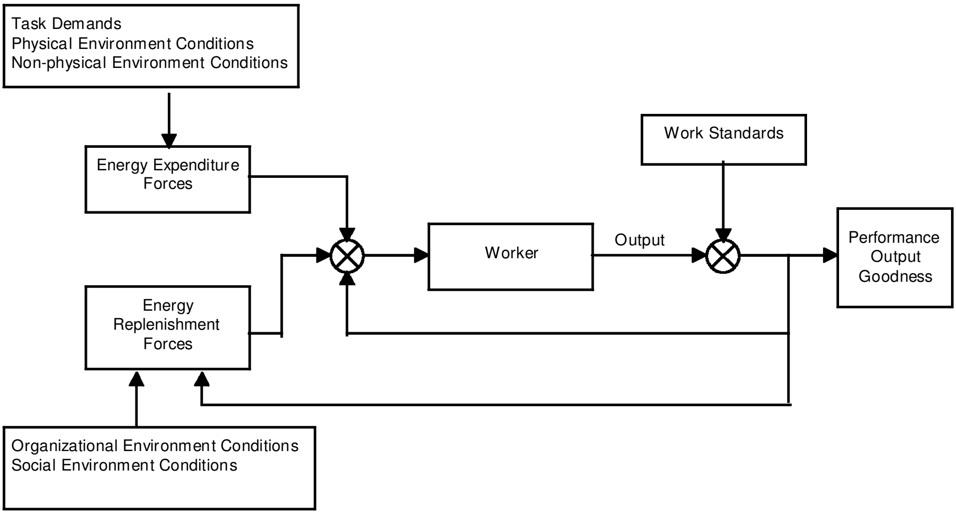

Figure 10. Work system compatibility model.

and organizational levels. The worker, affected by the energy expenditure and energy replenishment forces, produces an output. The output is then compared to the work standard to determine the goodness of performance.

Performance goodness is characterized in terms of output quality as well as work productivity and work safety and feeds back to the energy replenishment forces, affecting work factors such as social and financial rewards, management feedback. The performance goodness also feeds back to the worker as a measurement as to how well he/she is doing. The worker can then choose to adjust the work factors which he/he can control based on this information.

Figure 11 shows a detailed representation of the feed-forward loop in the model shown in figure 10. In figure 11, work factors act as forces upon the worker resulting in human energy changes, namely energy exertion and replenishment changes. In particular, the physical task demands consumes physical energy. The mental task demands lead to mental energy exertion. The physical environment conditions result in the exertion of the three forms of energy, that is, physical, mental and emotional. A sub-set of non-physical environment conditions is directly responsible for emotional energy exertion. The three forms of energy exertion interact with each other.

Another sub-set of non-physical environment conditions (e.g. autonomy, rewards), distinct from those leading to energy exertion, stimulates human energy reserves through emotional energy replenishment. In turn, the emotional energy replenishment forces recharge both physical and mental energy.

The exertion and replenishment of energy result in an output described in terms of work productivity as well as quality and safety measures. The process of energy exertion may lead to a certain level of work dissatisfaction as well as perceived risk of injury/illness and accidents. Furthermore, the process of energy replenishment may progress into a state of work satisfaction. The resultant of both energy exertion and replenishment processes is the principal determinant of achieved levels of work productivity and quality. As such, the work system compatibility is ultimately responsible for these outcome measures. However, in some instances, extreme cases of work satisfaction and dissatisfaction may influence the outcome measures.

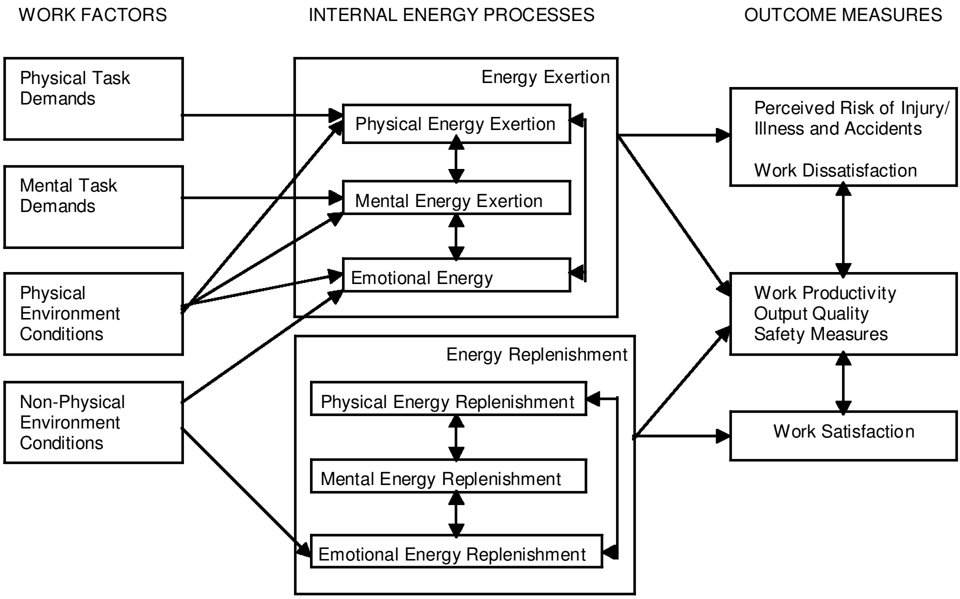

Figure 11. Detailed representation of feed-forward loop in work system compatibility model.

6. Concluding remarks

Rapid advances in information and communication technology, particularly in the last decade, have significantly influenced the global economy. These technological advances require that companies continually search for improved methods, procedures and work practices to assure that the work systems in place remain efficient and effective. One of the critical and fundamental assets in any company is the performance of people. A continuous challenge is how to organize and motivate the available human resources. The contemporary business world further complicates this challenge, as the needs of many workers have shifted from the lower (e.g. fair and adequate pay system and work benefits) to the higher needs (e.g. recognition, participation in decision making at the organizational and process levels). Furthermore, the cognitive, organizational, social and technical demands of work have become dominant influences, as opposed to the traditional physical task demands and environmental conditions.

In order for the human optimization efforts to be responsive to the needs and requirements of the new era of global economy, the following issues must be addressed:

(1) The need for global or macro-tools (i.e. tools that evaluate the entire spectrum of work factors) in addition to the traditional emphasis on micro-tools (i.e. tools that evaluate a handful of work factors in greater details) to assess work factors;
(2) The study of inter-relationships among quality of work life, work productivity, and output quality to optimize organizational health;
(3) The inclusion of workplace human performance within the context of work processes and systems; and

(4) The shift in work design principles from job level to job, process and work system levels.

As discussed above, the advances in optimization of human performance at work typically lagged behind technological progress. Recently, the field of human performance optimization has embraced the benefits of a multi-disciplinary approach to work system improvements. In this paper, we began the process of expanding the philosophy of the integrative approach to a scientific framework and methodology for practical application. This general framework, i.e. the work system compatibility theory, is an integrated approach which aims to quantify and balance all work system elements with the ultimate goal of achieving simultaneous optimization of the relevant human performance measures (i.e. quality of work life, work productivity and output quality) for the gene

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