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Human Performance in Lean Production Environment: Critical Assessment and Research Framework

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ABSTRACT

In the past two decades, emerging work production systems have pervaded a diverse number of U.S. manufacturing enterprises in an attempt to achieve quantum leaps in quality and productivity and to offer customers a variety of products with different options. Because the worker is at the heart of the application of lean production strategies, this article deals with human performance in a lean production environment. First, an overview of a lean production model is presented. Second, the evidence on human performance in a lean production environment is described and appraised. Third, a research framework is described to determine optimum human performance practices in a lean production setting. © 2003 Wiley Periodicals, Inc.

1. INTRODUCTION

The organization of work is a complex hierarchical concept that spans across three levels, namely, (a) the broad economic and public policy and other forces (i.e., economic, legal, political, technological, demographic) at the national and international levels, (b) the organization-level structures and processes (management and production methods and accompanying human resource policies that influence job design), and (c) the job demands and conditions in the workplace (i.e., the ways jobs are designed and performed; Sauter et al., 2001). Any successful enterprise in this new global economy must possess *effective* and *efficient* organization of work at the management level (i.e., management and production methods) in order to optimize the work demands and conditions of the workforce and, subsequently, establish the best work practices conducive for maximum human health and productivity and quality of work (Karwowski & Salvendy, 1994; Marek & Karwowski, 2000; Salvendy & Karwowski, 1994).

In the past two decades, emerging work production systems have pervaded a diverse number of U.S. manufacturing enterprises in an attempt to achieve quantum leaps in quality and productivity and to offer customers a variety of products with different options (Karwowski, Kantola, Rodrick, & Salvendy, 2002; Podgorski & Karwowski, 2000). In particular, lean production techniques have gained a great deal of attention when the

International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT) published its findings. Womack, Jones, and Roos (1990) reported that: (a) the Toyota Takaota auto assembly plant in Japan was twice as productive as the General Motors Framington auto assembly plant (16 assembly hours per car for the Tokaota plant versus 31 hr per car for the Framington plant), and (b) the quality of the Takaota plant was three times better than that of the Framington plant (45 and 135 defects per 100 cars for the Takaota and Framington plants, respectively). In general, there was a weak association between productivity and quality ($r = 0.15$) when the data were presented by the manufacturer's country of origin (e.g., Japan, North America, Europe). However, when the data were stratified by the manufacturer's country of origin, a trend emerged between productivity and quality. The Japanese assembly plants (in Japan and North America) reported both high productivity and high quality. Manufacturers from other parts of the world tended to have high quality or high productivity, but not both. Womack and coworkers attributed the superior performance of Japanese plants to the lean production systems.

Since its publication in 1990, the findings of the IMVP study have sparked interest as to whether lean production systems can be used by manufacturing enterprises to achieve and sustain both high productivity and high quality. Research on lean manufacturing has spanned into one or more of the following: human organization, quality system, and material handling (Babson, 1995; Kochan, Lansbury, & MacDuffie, 1997; Likert, 1997; Likert, Fruin, & Adler, 1999). In this research, we focus on the impact of these lean production strategies on work demands (i.e., characteristics of work factors "acting upon" and "experienced by" the worker that *negatively* impact his or her energy resources), work energizers (i.e., characteristics of work factors "acting upon" and "experienced by" the worker that *positively* impact his or her energy resources), and work outcomes (i.e., worker productivity and health, work quality). Although the IMVP study clearly demonstrated both high productivity and high quality for top lean production plants in comparison to mass production plants, what remains unresolved from the MIT study, however, is a quantitative assessment of the work demands, work energizers, and work health outcomes. This information is crucial because it reflects on long-term organizational performance. For example, if the work demands are "very high" and work energizers are "moderate," it is possible to achieve "high" productivity and "high" quality in the short and intermediate term. The work energizers must be truly compatible with the work demands to sustain superior organizational performance in the long run.

To date, there is debate among researchers about the impact of lean production on worker health (Landsbergis et al., 1998). According to one viewpoint, the short work cycle (i.e., 60 sec) of the Toyota Production System is considered a major risk factor for work-related injuries. The opposing view argues that the injuries reported at the New United Motor Manufacturing Inc. (NUMMI) plant in California (joint venture between GM and Toyota) were not due to the short cycle of the Toyota Production System. Rather, it is a matter of correctly implementing the lean production strategies. In a recent review of the impact of lean production on worker health, it has been suggested that lean production intensifies work pace and demands in auto industry, and in turn, these demands result in adverse health conditions such as musculoskeletal injuries (Landsbergis, Cahill, & Schnall, 1999). At the same time, increases in skill levels are modest and job control is low to modest. Rasch (1997) provided a different outlook based on a statistical analysis of data derived from 240 small suppliers of automotive component parts. According to Rasch, giving workers decision-making power and authority coupled with implementing just-in-time (JIT) techniques will increase productivity by increasing machine uptime. However, information on worker health and safety were not examined.

The goal of this research is threefold. First, we present an overview of lean production systems. Second, the evidence on human performance in a lean production environment is described and appraised. Third, we describe a research framework for determining optimum human performance practices in a lean environment setting.

2. OVERVIEW OF LEAN PRODUCTION SYSTEMS

In essence, lean production is a hybrid of both mass and craft production systems. Prior to the era of mass production, craft production was the dominant manufacturing method for producing goods (Genaidy, Karwowski, & Shoaf, 2002). This approach resulted in good quality of output; however, volume was low. 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 or her labor. Around the turn of the twentieth century, Henry Ford innovated and operationalized the concept of mass production. Initially, the work cycle time was 514 min, during which the worker was responsible for assembling a large part of a car (Womack, Jones, & Roos, 1990). Thereafter, the assembler was expected to perform only a single task, hence, the task cycle time dropped to 2.3 min. On the introduction of the moving assembly line in 1913, the task cycle time was further reduced to 1.19 min. As such, a typical assembly-line job in a mass production environment consists of duties that call primarily for physical task exertion with little mental requirements and little social contact with others (as in teamwork). In a cross-sectional study involving 180 auto assembly workers, Walker and Guest (1952) confirmed that assembly-line work includes mechanical pacing, repetitiveness, low skill requirements, performance of a tiny fraction of the product, limited social interaction, and predetermination of tools and techniques.

Lean production was pioneered by Toyota into what is now known as the Toyota Production System (TPS; Womack, Jones, & Roos, 1990). The roots of this system go back to the declaration made in 1945 by Kiichiro Toyoda, president of Toyota Motor Company, that Toyota should "catch up with America" in three years (Ohno, 1988). In order to accomplish this objective, Taiichi Ohno, the mastermind behind the TPS, reasoned that if it took nine Japanese to do the work of one American, then Japanese workers were wasting resources (Ohno, 1988). He argued that if this waste could be eliminated, production should rise by a factor of 10. This marked the beginning of the TPS, which was founded on two pillars: (a) JIT (i.e., the right parts needed for assembly reach the assembly line at the time they are needed and only in the amount needed), and (b) autonomation or automation with human touch (i.e., stopping the machines by humans whenever there are defects or troubles in the work system). Using the example of a baseball team, Ohno corresponded autonomation with the skill and talent of individual players, and JIT with the teamwork involved in reaching an agreed-on objective.

Womack, Jones, and Roos (1990) indicated that lean production is organized around the transfer of the maximum number of tasks and responsibilities to production workers, and the placement of a system for detecting defects that quickly traces every problem once discovered to its ultimate cause. MacDuffie and Pil (1997) outlined the differences between the characteristics of both mass and lean production. Mass production can be characterized by: (a) extreme specialization of resources, including narrowly defined tasks carried out by people dedicated to each task, equipment dedicated to each task, or both;

(b) standardized products that can be produced in large batches to achieve economies of scale and minimize setup time, coupled with large buffers of inventory stock, repair space, and utility workers to prevent any interruptions in production; (c) centralized hierarchy that handles the control and coordination tasks that accompany a highly specialized and narrow division of labor; and (d) separation of conception so that all the planning associated with production is specialized and isolated from the execution. Lean production, on the other hand, is typified by: (a) more general resources (multiskilled workers, general-purpose machines, fewer functional specialists); (b) small buffers and lot sizes that facilitate the handling of greater variety of product designs and, hence, support a market strategy of offering niche products and respond quickly to demand fluctuations; (c) authority that is more decentralized, greater lateral communication across functional boundaries, and faster response time; and (d) higher degree of integration of both conceptual and execution of production tasks. As such, the duties of a worker in a lean production environment should involve a higher level of cognitive work as well as a higher degree of social contact in comparison to the duties of a worker in a mass production environment. Very recently, Delbridge (2003) outlined the organizing principles of lean manufacturing. These include the following: (a) team work and group problem solving, (b) JIT and total quality management systems, (c) continuous improvement, (d) relationship with suppliers (including information, raw materials and parts, and knowledge), and (e) relationship with customers (including information, parts, and knowledge).

Womack, Jones, and Roos (1990) argued, without proof, that lean production offers “creative tension” in which workers are involved in solving complex problems. Indeed, they recognized an important distinction from mass production; that is, lean production is “fragile” in contrast to mass production, which is designed with buffers everywhere, extra inventory, extra space, extra workers. Womack and colleagues concluded that every worker in a lean production environment should try very hard, perhaps much harder than his or her counterpart in a mass production environment. Unfortunately, there have been no data presented by Womack and coworkers about the demands and resources available to the worker in a lean production environment.

The only pieces of information presented by Womack, Jones, and Roos (1990) are that Toyota offers its workers in Japan two guarantees: lifetime employment, and pay steeply graded by seniority rather than by specific job function and tied to company profitability through bonus payments. Furthermore, workers have the power to stop the assembly line if they detect any defects (i.e., autonomation), to solve problems, and to improve their work. The question then becomes: Are the work energizers (or resources) truly compatible with the high physical, cognitive, and emotional work demands that are expected of workers in a lean production environment to guarantee superior productivity, quality, and safety outcomes? The answer to this question will be explored in the remainder of this article.

3. OVERVIEW AND APPRAISAL OF EVIDENCE ON HUMAN PERFORMANCE IN LEAN PRODUCTION ENVIRONMENTS

The existing evidence on human performance in lean production environments is derived from a few cross-sectional studies and one case study. A description of evidence is summarized in Table 1. The cross-sectional studies sponsored by the Canadian Auto Workers suggest that the levels of work demands and work energizers in a lean production environment are not conducive for optimal human performance (Lewchuck & Robertson, 1996, 1997; Lewchuck, Stewart, & Yates, 2001). Similar findings have been reported by another cross-sectional study conducted by Babson (1993) at the Mazda plant in Michigan. In a case study of the NUMMI plant in California and financially supported by the IMVP, Adler, Goldoftas, and Levine (1997) conducted several interviews to determine the potential cause of ergonomic injuries at the plant. Adler and colleagues concluded that the source of ergonomics injuries is not due to the short cycle of the TPS. Rather, it is attributed to the incorrect implementation of the TPS. In essence, the preliminary reports obtained from workers provide anecdotal evidence about human performance practices in lean manufacturing in comparison to the claims made by the Womack study that represents management views. The concerns here are that work demands have intensified and the energizers for successful job performance have diminished, hence, worker health and safety have been compromised.

The evidence obtained from the cross-sectional and descriptive studies has been limited in a number of ways. First, prior research did not address the myriad factors to which the worker is exposed in manufacturing enterprises (Adler, Goldoftas, & Levine, 1997; Babson, 1993; Lewchuck & Robertson, 1996, 1997; Lewchuck, Stewart, & Yates, 2001). Thus, a comprehensive theoretical model is required to integrate the complex web of work-related variables both "acting upon" and "experienced by" the employee. Such variables should include physical, cognitive, organizational, economic, technological, and social parameters, and must be analyzed and examined with respect to work outcomes (productivity, quality, safety) to uncover the best human performance practices. An overview of prior research on the subject is provided in the next section.

Second, prior research did not examine and report the reliability of survey instruments used to quantify the work demands and work energizers. This is an important aspect of the research tasks in order to preserve the internal and external validity of any study findings.

Third, previous studies are cross-sectional and descriptive in nature. Therefore, causality cannot be inferred about the impact of work characteristics on work outcomes, hence, definitive answers about optimal human performance practices cannot be deduced. There is a need to examine these effects in a longitudinal design to determine the everlasting best human performance practices in lean production environments.

Fourth, in contrast to the homogeneous population in Japan, the diversity of the U.S. workforce should be accounted for in terms of changing demographics (i.e., women, ethnic minorities, aging workforce; Parker & Wall, 1998; Sauter et al., 2001). This is particularly important to investigate the broader impact of lean production on the quality of life for diverse worker populations including the underrepresented.

Fifth, the work demands and energizers should be studied from both worker and management standpoints. Such knowledge is essential to determine the optimal human performance practices from both perspectives and to remove any barriers for the successful implementation of lean production strategies. Finally, there is a potential bias about the data collected from the cross-sectional studies. The data were gathered by union representatives, and particularly at times when the unions were negotiating new contracts (e.g., Babson, 1993).

In summary, research on human performance in lean production environments has been hampered by the inadequacies of prior field studies both from theoretical and methodological standpoints. Therefore, the best human performance practices are yet to be established in a lean production environment.

TABLE 1. Description of Evidence

References	Design	Study Population	Exposure/Analysis Variables	Outcome	Main Results and Conclusions	Comments
Lewchuk & Robertson (1996)	• Cross-sectional	• 1,670 Canadian workers employed in 16 auto parts suppliers	• Workload • Control and skill levels	• Working in pain • Working in awkward position • Feeing tired • Being tense at work	• Workers in lean production plants reported that they were 17% more likely to report heavier workload in comparison to workers in traditional plants. • Compared with traditional plants, workers in lean production plants were over 25% more likely to report increasing workload. • Workers in lean production plants enjoyed less autonomy. • Both lean production and traditional plants reported similar adverse health outcomes. • Workers in lean production plants were over 20% more likely to report increases in tension and almost 17% more likely to report being tired after work.	• The reliability and validity of survey instruments were not reported. • No rigorous multivariate statistical techniques were employed. • No reference was made to potential confounders. • Participation rate was not discussed.
Lewchuk & Robertson (1997)	• Cross-sectional	• 2,424 Canadian workers employed in vehicle assembly departments of CAMI, GM, Chrysler, Ford	• Modifying one's work • Varying one's workplace • Leaving workstation to attend to personal matters • Management monitoring	• None	• Workers in the two most advanced plants in lean production reported that it is more difficult to modify their jobs, to vary their workplace or to attend to their personal matters in comparison to workers in the least advanced lean production plants. • Workers in the most advanced lean production plants had increased management monitoring.	• The reliability and validity of survey instruments were not reported. • No relation between exposure and outcome variables was examined.

Lewchuk et al. (2001)	• Cross-sectional	• 2,424 Canadian workers employed in vehicle assembly departments of CAMI, GM, Chrysler, Ford •215 UK workers employed by GM	• Modifying one's work • Varying one's workplace • Leaving workstation to attend to personal matters • Management monitoring	• Working in pain • Working in awkward position • Feeing tired • Being tense at work	• In comparison to Lewchuk & Robertson (1996, 1997), similar conclusions were reached.	• Note—The article includes the same dataset as in Lewchuk & Robertson (1996) + data on outcome measures from the Canadian group + new data from GM (UK)
Adler et al. (1997)	• Descriptive—Case reports based on interviews of management and union personnel, as well as OSHA regulators	• American management and union personnel in NUMMI plant (GM-Toyota joint venture) in California	• Ergonomics risk factors—no formal assessment was made to quantify the demands of ergonomics risk factors.	• Musculoskeletal injuries	• If the Toyota production system is implemented without sufficient attention to ergonomics, one would anticipate poor work outcomes. • Ergonomics risks can be reduced if management makes health and safety priority so that the key features of the Toyota production system can be transformed from risk factors to improvement enablers.	• No quantitative assessment was made in this descriptive study.
Babson (1993)	• Cross-sectional	• 2,380 American workers from Mazda assembly in Michigan (out of plant population of approximately 2,800)	• Work intensity • Control • Job rotation and training	• Perceived injury	• Significant association between heavy workload and expectations of injury or burnout. • Diminished control over work and reduced job rotation.	• Instrument reliability and validity were not reported. • No rigorous multivariate statistical techniques were employed. • No reference was made to potential confounders.

4. OVERVIEW AND APPRAISAL OF HUMAN PERFORMANCE THEORIES AND MODELS ON WORK DEMANDS AND ENERGIZERS

In today's workplace, human performance is challenged by myriad work-related variables. We therefore focus in this article on those scientific contributions that have made attempts to address the large part of these work-related factors. In particular, we describe and appraise the evidence obtained from the following human performance theories and models: Motivation-Hygiene Theory (MHT; Herzberg, 1987; Herzberg, Mausner, & Snyderman, 1959), Job Characteristics Theory (JCT; Hackman & Oldham, 1975, 1976), Job Demand-Control Model (JDCM; Karasek, 1979; Karasek & Theorell, 1990), Effort-Reward Imbalance Model (ERIM; Siegrist, 1996).

1. The MHT maintains that work characteristics can be categorized into two major classes, one producing positive effects on the worker (i.e., satisfaction) and the other negative effects (i.e., dissatisfaction). The satisfiers include achievement, recognition, task characteristics (e.g., task variety), responsibility for work outcomes, advancement, and growth; the dissatisfiers consist of company policy and administration, supervision, relationship with others, work conditions, salary, personal life, status, and security. Recent research, however, suggests that some social and organizational factors may produce positive or negative effects depending on the magnitude of the work factor (e.g., lack of or little autonomy invokes negative effects; a good deal of work autonomy induces positive effects). Although the MHT has suffered from methodological problems, its contribution lies in (a) considering the multitude of work-related factors impacted by lean production strategies, and (b) the dual characteristics of work-related variables. It should be borne in mind that each work-related variable may exhibit positive effects, negative effects, or both.
2. According to the JCT, five job dimensions affect personal and work outcomes: skill variety, task identity, task significance, autonomy, and task feedback. These organizational factors are critical to workplace human performance, and they should be incorporated as an integral part of any comprehensive attempt to assess human performance in a lean production environment.
3. The JDCM theorizes that four kinds of psychosocial work experience are generated by the interactions of "high" and "low" levels of psychological demand and decision latitude or control: (a) high-strain jobs—the outcome of "high" demand and "low" control and resulting in the most adverse reactions of strain (fatigue, anxiety, depression, and physical illness); (b) active jobs—this kind of job, in which control is "high" and psychological demand is "high," calls for the highest levels of performance but without negative psychological strain; (c) low-strain jobs—this "low" demand and "high" control job category will result in lower-than-average levels of psychological strain and risk of illness; (d) passive jobs—this job category represents situations of "low" demand and "low" control in which a gradual decline of learned skills and abilities may occur. The JDCM was expanded to include social support (Johnson & Hall, 1988; Johnson, Hall, & Theorell, 1989). According to Karasek and Theorell (1990), the control–support dimensions further classify jobs into: (a) participatory leader ("high" control and "high" support); (b) obedient comrade ("low" control and "high" support); (c) cowboy hero ("high" control and "low" support); and (d) isolated prisoner ("low" control and "low" support). Although

the JDCM addressed an earlier limitation of the MHT about the classification of satisfiers as producing only positive factors, it still needs further addition of items to both work demands and work energizers.

4. Similar to the JDCM, the ERIM has a dual formulation of work characteristics; that is, effort and reward. Effort consists of two components: extrinsic and intrinsic. Extrinsic effort is equivalent to the demand dimension in the JDCM; intrinsic effort is not addressed in the JDCM and accounts for Lazarus's (1991) view of the cognitive appraisal of stress. The reward component includes status control (i.e., promotion prospect, status, mobility, and job security), wages, and recognition from superiors and coworkers (Bakker, Killmer, Siegnist, & Schaufeli, 2000; Siegrist, 1996). Although the reward variables were not included in the JDCM, they were elements of the MHT. Recently, the association between the JDCM or ERIM and coronary heart disease or depression has been examined (Bosma, Peter, Siegrist, & Marmot, 1998; Tsutsumi, Kabaya, Theorell, & Siegrest, 2001). Significant associations were found in both studies, but the strength of association was different. These differences cannot be interpreted at this time because (a) both models do not account for the wide array of variables that make up the entire spectrum of work demands and work energizers, (b) certain variables are more important than others for some jobs, and (c) the work factors "experienced by" the worker may play a stronger or weaker role than the impact of work factors "acting upon" the worker.

The aforementioned human performance models are limited in a number of ways. First, there are measurement issues, which have not been examined in prior research. For example, the psychological demand in the JDCM assumes that there is one-to-one relation between time pressure and psychological demand. Because some people may work better than others under "a lot" of pressure, one cannot always infer that "a lot" of pressure corresponds to a "high" psychological demand.

Second, prior research did not consider the multitude of work factors impacted by lean production strategies. It is particularly important to consider the entire spectrum of work energizers because (a) a true lean production model requires great work demands, and therefore should be balanced with an integrated battery of work energizers, and (b) the U.S. workforce is heterogeneous in comparison to the Japanese workforce in terms of age, ethnic background, and gender.

Third, a distinction ought to be made in terms of the work factors impacted by lean production strategies. One should consider the work factors "acting upon" and "experienced by" the individual in the workplace. This is in line with the argument made by Hart (1986) about the components of human workload. Hart (1986) pointed out that human workload should consist of two elements, that is, "imposed" and "experienced." "Imposed" workload is determined in terms of the situation encountered by the individual and is created by task objectives, structures, environment, and incidental events that occur during a given task performance; thus, the task demands influence the level and type of effort exerted, and the environment in which a task is performed contributes to its difficulty. "Experienced" workload refers to the effect on the operator of performing a task. Tasks affect behavior and thus performance as well as physiological responses associated with workload. Hart (1986) emphasized that the sources of workload are different and may depend on the different combinations of "imposed" and "experienced" workload. Finally, any work-related factor should be examined in terms of its characteristics as work demand, work energizer, or both.

5. RESEARCH FRAMEWORK

The lean production model differs radically from the mass production model in terms of the work demands and work energizers acting on the workers. Theoretically, a true lean production model may tax the worker's muscular, cognitive, and emotional resources to the limit. At the same time, a true lean production model must deploy an integrated battery of work energizers to bring compatibility with the muscular, cognitive, and emotional demands. Work energizers may include, among others, task variety, employment security, financial incentives, development and utilization of skills and knowledge, and knowledge of organizational performance.

To date, a quantitative assessment of the work demand and work energizer profiles in a true lean production environment is not readily available. Furthermore, the relation between the work demand—energizer compatibility—and worker health is not known. Such information is vital to assess the best human performance practices that promote the optimum worker health and productivity and work quality in lean production environments.

Currently, research on work energizers in Japanese plants concentrates on the examination of human resource policies and practices without reference to the work demands (Adler, 1999). Also, very little is known of the impact of lean production strategies on worker health in Japan. According to Nishiyama and Johnson (1997), the impact of Japanese production methods on cardiovascular disease is of concern. In particular, sudden death due to cardiovascular disease has been coined *karoshi*, or "death from overwork." It is suspected that karoshi victims worked long hours, perhaps equal to 3,000 hr per year, just before death (an average of 60 hr/week).

A survey of the human performance literature reveals that there is a lack of a comprehensive model that takes into account the complex web of work demands and work energizers. Therefore, a framework is proposed in this article to guide future research efforts in assessing the impact of lean production strategies on work demands, work energizers, and work outcomes. This framework builds on the theoretical and experimental work of Hart and Staveland (1988) on work demands and extends its application into work energizers as well. Based on an extensive number of experiments, Hart and Staveland (1986) developed a workload index that integrates three classes of variables: task related (objective demands imposed by the task), behavior related (effort exertion to satisfy task requirements and opinions about how successful the individual is in doing the task), and subject related (psychological impact of task demands and behavior factors on the operator). In total, the workload index consisted of six variables:

1. Mental demand—How much mental and perceptual activity is required?
2. Physical demand—How much physical activity is required?
3. Temporal demand—How much time pressure does the individual feel due to the pace at which the tasks occur?
4. Performance factors—How successful is the individual in accomplishing the task goals? How satisfied is the individual with performance in accomplishing the goals?
5. Effort—How hard does the individual work physically and mentally to accomplish the level of performance?
6. Frustration level—How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent does the individual feel during task performance?

In summary, this index integrates the "imposed" (i.e., physical, mental, temporal demands) and "experienced" (i.e., effort, performance, psychological impact) elements of human workload or work demands.

In the proposed framework, factors impacting human performance in the work environment operate at two levels: (a) factors emanating from the work environment by "acting on" the individual, and (b) factors "experienced by" the individual in the work environment that are the product of the interaction of factors "acting on" the individual and his or her personal characteristics. The "acting" factors are referred to as "acting demands" and "acting energizers," and the "experienced" factors are termed "experienced demands" and "experienced energizers." The following is an operational definition of the different terms.

1. Acting Demand—Characteristics of work-related variables *acting on* the individual in the work environment that *negatively* affect his or her energy (e.g., lifting heavy objects, work conflict).
2. Acting Energizer—Characteristics of work-related variables *acting on* the individual in the work environment that *positively* affect his or her energy (e.g., work autonomy, financial incentives).
3. Acting Compatibility—Degree of synchronization between acting demand and acting energizer. This degree of synchronization depends on (a) the degree of match between acting demand and acting energizer and (b) the level of acting demand and acting energizer.
4. Experienced Demand—Characteristics of work-related variables *experienced by* the individual that *negatively* affect his or her energy (e.g., perceived risk of harm from the work environment, work dissatisfaction).
5. Experienced Energizer—Characteristics of work-related variables *experienced by* the individual that *positively* affect his or her energy (e.g., work satisfaction, good performance).
6. Experienced Compatibility—Degree of synchronization between experienced demand and experienced energizer. This degree of synchronization depends on (a) the degree of match between experienced demand and experienced energizer, and (b) the level of experienced demand and experienced energizer.

The acting demands and energizers consist of the following variables: (a) physical, (b) cognitive, (c) social, (d) organizational, (e) technological, (f) economic growth, and (g) individual growth (Figure 1a). The experienced demands and energizers include four parameters: (a) work effort, (b) experienced risk or benefit from work tasks and environment, (c) work performance, and (d) work satisfaction-dissatisfaction (Figure 1b).

We hypothesize in this research that the higher the work compatibility, the better the work outcomes and the better the human performance practices in a true lean production environment. This hypothesis is partially supported by the work of Karasek and Theorell (1990) and Wallace, Shoaf, Genaidy, and Karwowski (2003). According to the Job Demand—Control Model (Karasek & Theorell, 1990), optimum human performance is achieved when "high" psychological demands are compatible with "high" job control. In a case study, Wallace et al. (2003) demonstrated that high work compatibility was associated with high work productivity, quality and safety. Of course, the concept of work compatibility should be established mathematically and examined with respect to work productivity, quality, and safety.

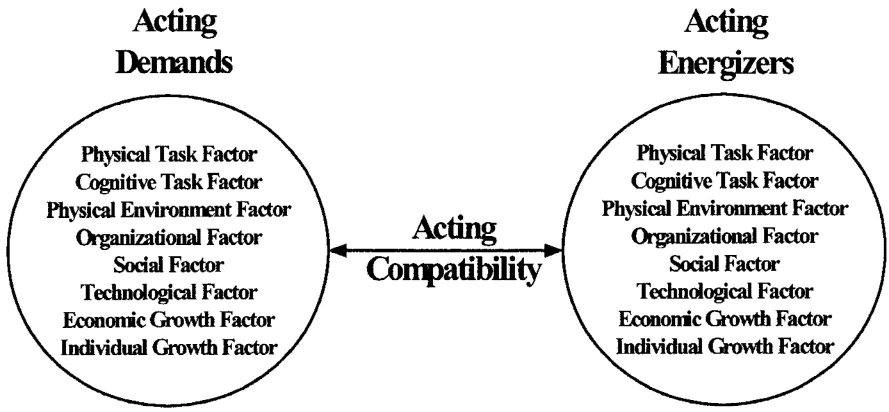

Figure 1a Elements of *acting* demands, energizers, and compatibility.

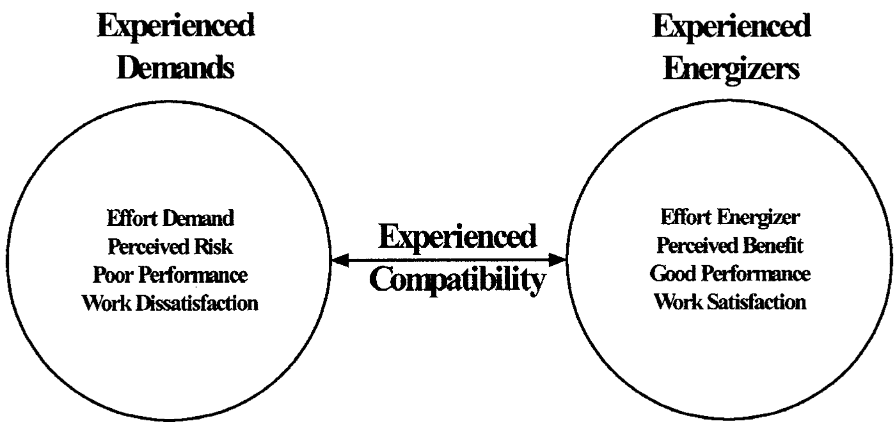

Figure 1b Elements of *experienced* demands, energizers, and compatibility.

6. CONCLUDING REMARKS

The lean production model emerged over the years out of a need to survive in a world dominated by the mass production model. Today, it is quite clear that the lean production model is preferred over the mass production model because of its ability to produce high-quality, diversified products that meet the needs of diversified customers. However, what remains unclear is the impact of lean production strategies on the work demand and energizer profiles, and worker health. This is an extremely important subject because the worker is at the heart of application of the lean production model, hence the human asset is the key to long-term superior organizational performance. Thus, one must look deeper into this issue to chart the best human performance practices required to achieve and sustain work productivity, quality, and safety. In this regard, the issue of work compatibility will become an important concept that should be mathematically developed and examined with respect to work outcomes.

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