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The Lean Manufacturing Enterprise: An Emerging Sociotechnological System Integration

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ABSTRACT

Lean production represents a change in production system paradigm that calls for integration of the human and technological practices. This article reviews previous models of lean production that concentrated mainly on some distinct features of its philosophy, organization, and techniques and presents a framework of lean production as a sociotechnological system. The proposed framework provides an integrated view based on the interactions of human and technological elements. The lean enterprise is viewed as a dynamic process that translates its goals (zero waste, flow, and pull) into combined techniques that should be implemented throughout the entire organization.

1. INTRODUCTION

Lean production represents a change in production system paradigm that can be compared to the introduction of mass production implemented by Henry Ford. Lean production has evolved from successful Japanese practices to a system that changed the way Western manufacturers assess performance. The paradigm of lean production calls for integration of the human and technological practices, parallel to the human-centered approach to the design and implementation of advanced manufacturing systems (Karwowski & Salvendy, 1994; Karwowski et al., 1994; Karwowski, Warnecke, Hueser, & Salvendy, 1997). In this context, the present article develops a framework of lean production as a sociotechnological system. The proposed framework provides an integrated view based on the interactions of human and technological elements.

Cherns (1976) described the concept of sociotechnical system as the required combination of technological and human factors in work design that ensures successful outcomes

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of the work organization. There are three different approaches to sociotechnical design (Herbst, 1974): (a) Complete specification design seeks to include all elements of the work organization in the design, (b) critical specification design works only with critical conditions for the operation of self-regulated units, and (c) evolutionary system design uses an initial set of conditions to develop only when they are implemented. Cherns (1987) proposed specific criteria to validate a sociotechnical design.

Lean production could be seen as an evolutionary sociotechnological design since it relies on the active interaction of individuals within the work design. Niepce and Molleman (1998) found similarities between lean production and sociotechnological design, by analyzing some lean performers. Their comparison is limited by the fact that there is not a unique notion of what elements constitute lean production. This article describes the lean production system and proposes a framework that could function as the basis for future field studies. To build an organizational design, this article follows the steps proposed by Carson, Cobelli, and Finkelstein (1983): (a) formulation (what lean production is), (b) modeling purposes (approaches to lean production), (c) review of extant models, and (d) model identification (integrated framework).

2. WHAT IS LEAN PRODUCTION?

Cost reduction has always been the goal of most changes in production systems. For the automobile industry, Womack, Jones, and Roos (1990) showed that the shifts from craftsmanship to mass production in the 1900s and from mass to lean production in the 1950s were driven by the need to ensure profitable results in a highly competitive environment as shown in Figure 1. The shift from craftsmanship started with the specialization of tasks for Ford's moving assembly line. Ford's Model T was to reach the goal of being an inexpensive car as compared to his previous Model N, which had a selling price of $600.

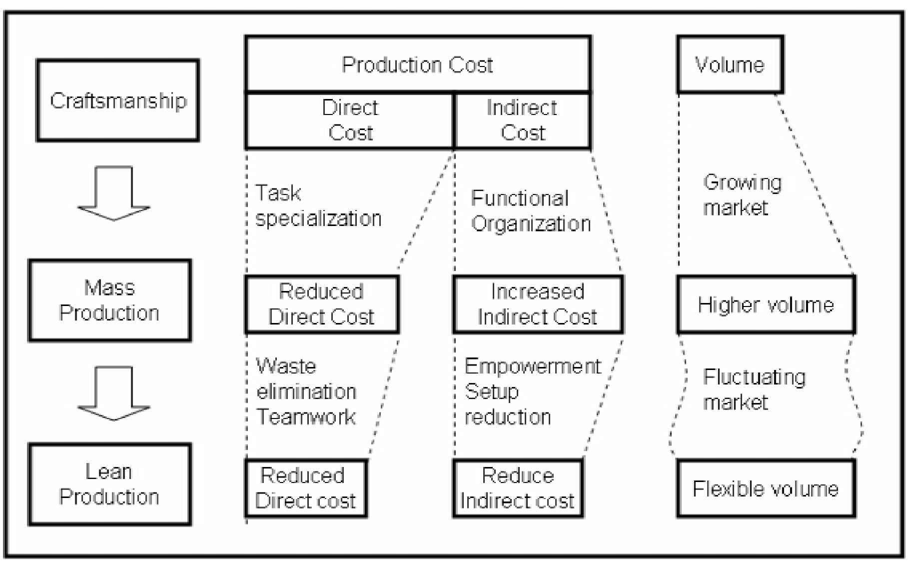

Figure 1 Shifts in production systems.

Ford realized he had to change the layout of the process itself. Sheldrake (1996) mentioned three core elements of mass production: accuracy or standardization, continuity, and speed. Production of the Model T in 1914 allowed output to jump from 8,000 to 250,000 units a year, profits to increase 27-fold, and the selling price to be reduced to less than $400. This was the realization of ideas that date back to Adam Smith, and that Frederick Taylor had been outlining as the task system during his work at Midvale Steel in the 1880s. Taylor believed that each job could be broken down into simple, basic elements, and an accurate control of those elements through time studies would ensure higher output and better compensation for workers. Taylor's *Principles of Scientific Management* was published in 1911, the same year the Model T went into production. The Model T brought the necessary capital to make further improvements. Conveyor belts were installed to transport components between assembly stations. The moving assembly line was complemented by Gilbreth's motion studies, reducing labor utilization from 12.5 to 1.33 man-hours per unit and increasing wages from $2.50 to $5 per day. In 1927, this trend changed when General Motors' Chevrolet outsold Ford's Model T. From 1921 to 1925, General Motors (GM) implemented a new organizational structure, extending Fayol's management principles to a complex business system that included various tiers of the automobile industry. A perfect coordination of its functional structure allowed GM to lower its prices below those of Ford. Ford's shop-floor operation and Sloan's GM management structure were the essence of what became known as the mass production system. Task specialization brought direct cost reductions in labor, energy, and materials as tasks were consistently tracked and standardized. Increases in overhead and technology were required to support such specialization, but larger production volumes reduced the impact of those costs.

The shift from mass to lean production started in Japan when factories did not experience a growing market after World War II. In the 1930s, Toyota transferred Ford's practices to its assembly lines; however, Kiricho Toyota's goal was cost reduction without economy of scale. Toyota could not afford huge capital investments, so mass-production practices were adapted to Toyota's capabilities. Taiichi Ohno, an assembly-shop manager, brought additional elements from his experience with the textile industry. Setup time reduction, workstation layout, and reduction in inventories were gradually tested on Toyota's assembly line. The dynamic evolution of this system (Fujimoto, 2000) has become identified as lean production. Cost reduction was achieved by using fewer resources to compensate for the lack of growth. The International Motor Vehicle Program (IMVP) showed that Japanese assemblers, especially Toyota, were leading in terms of productivity, quality, and inventory minimization (Krafcik, 1988; Womack, Jones, & Roos, 1990). During the 1990s, while other assemblers tried to implement lean practices, Toyota addressed the issue of job satisfaction. A new workforce in Japan demanded a better work environment, changing Toyota's approach to work design and ergonomics. "*Lean on balance*" is a concept that extends lean production to both customer and employee satisfaction (Fujimoto, 2000).

Despite the interest that lean systems have aroused even beyond the automobile industry, there is not a widely accepted definition of lean production. In fact, lean production has been regarded as either an evolution or an alternative to previous production models (Bartezzaghi, 1999). The first reason for the controversy is that the Toyota Production System, or TPS (Monden, 1983), was not conceived as a general theory but a specific set of practices that were successfully tested and implemented. Second, Fujimoto (2000) explained that the TPS is a dynamic system that has evolved through random trials, environmental constraints, rational calculations, entrepreneurial vision, and knowledge transfer. Third, lean production was introduced not as static but as a dynamic concept that should be able to adapt itself to new trends in technology and marketing. In addition, Alford, Sackett, and Nelder (2000) emphasized that lean practices should be complemented by mass customization should vehicle manufacturers reach a saturated, more sophisticated market during this decade.

Katayama and Bennet (1996) provided a relatively succinct definition of the lean production system, as shown in Figure 2. Lean production is a dynamic system that requires fewer resources (material, labor, overhead) and brings better outputs (quality, variety, cost, and safety) to add value. These improvements must be achieved inside the lean system, so the question remaining is how the system achieves higher performance.

3. MODELING PURPOSES FOR LEAN PRODUCTION

James Womack, who introduced the notion of lean production, recognized that there are different ways to approach the lean enterprise. At a meeting of the joint economic committee of the U.S. Congress (1994), Womack identified three main features of lean production that lead to higher performance. First, lean production involves a new philosophy of manufacturing, focusing on customer satisfaction and continuous improvement. Second, lean production involves new organizational techniques to manage product development, supply chain relations, production operations, and coordination of the overall enterprise. Third, lean production uses techniques such as just-in-time, simultaneous engineering, and inventory systems that address specific problems. Almost all literature on lean production works within these approaches: lean as an organizational philosophy, lean as new organization, and lean as a set of specific techniques.

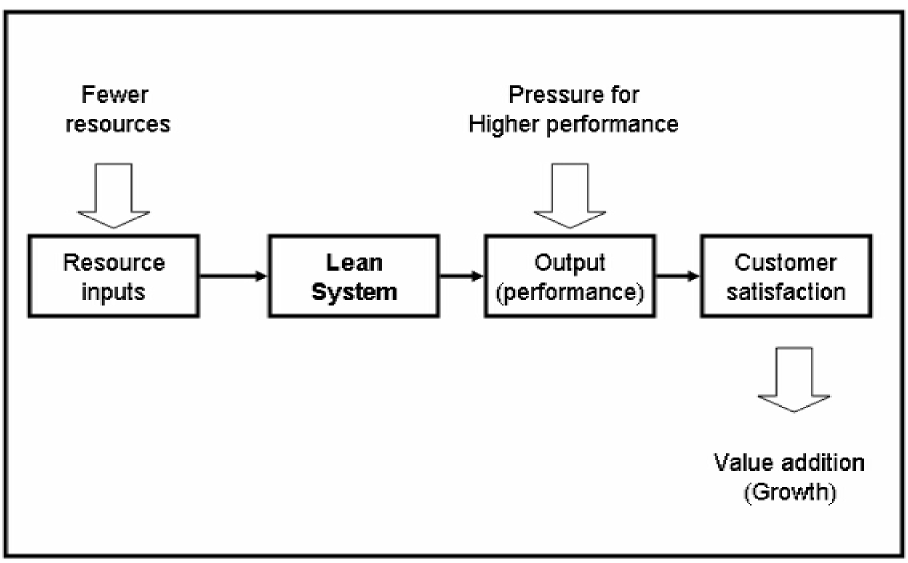

Figure 2 Lean production system (Katayama & Bennet, 1996).

4. REVIEW OF EXTANT MODELS

Most models work under three approaches: (a) the goals introduced by Womack and Jones's *Lean Thinking* (1996); (b) the activities introduced by Womack, Jones, and Roos's *The Machine That Changed the World* (1990); and (c) technological and human elements introduced by Monden's (1983) and Ohno's (1988) *Toyota Production System*. Researchers have tried to create an association between them. The goals and activities set the scope of lean production. A diverse number of elements conforms the human and technological system. However, most of the authors agree that these can be grouped into elements that address common techniques. A comparison of the most relevant elements of these models is introduced in Table 1. The details of each approach are given in the remainder of this section.

4.1. Womack and Colleagues

Womack's publications addressed each approach separately. In *Lean Thinking*, Womack and Jones (1996) introduced what they called "lean principles" that identify the lean philosophy: a problem-solving approach to eliminate waste.

1. Since waste is anything that creates no value, the first principle, or starting point, is *specifying value*. It states that the ultimate consumers alone can determine value, and they expect a combination of goods and services within a price and time framework. By establishing open communications with customers, it should be possible to achieve an unbiased definition of value.
2. The second principle is *value stream identification*. This is an assessment of the actions required to deliver the product specified by the customer. Womack and Jones (1996) considered three business tasks: problem solving (from design to product launch), information management (from order taking to delivery), and physical transformation tasks (from raw materials to finished goods). Once completed, the value stream will show steps that are immediately removable or removable with investment. This is an industry-wide study rather than company-wide and therefore should involve the assessment of the relationship with suppliers of goods and services.
3. The third principle, *flow*, is concerned with the interactions along the value stream. This principle changes the common idea of process-focused efficiency to a product-focused efficiency in which interactions between processes play a major role along the supply chain. The old notion of increasing batches to ensure process control is a suboptimization that does not always lead to better performance overall. Ford's monoproduct assembly line did not apply to Toyota's lines because the market demanded increased variety with smaller volumes. In lean production, machines and processes should be arranged to ensure a capable, available, and adequate workflow (work cell analysis).
4. The fourth principle, *pull*, is perhaps the most recognized of the principles due to the infusion of just-in-time (JIT). In lean systems, however, pull is not seen as an objective but as a driver of the value stream. The goal is to synchronize the value stream in terms of the customers' needs. Only when customers need a product should backward requests follow to ensure customer satisfaction. There are technical limitations that require some lead times or inventories, but they should not detract from the goal of keeping pace with the market.

TABLE 1. Comparison of Lean Production Models

Author	Model description	Goals	Activities	Technical elements	Human elements
Womack and Jones (1996)	Lean principles	Specifying value Value stream identification Flow Pull Perfection			
Womack, Jones, and Roos (1990)	Lean enterprise		Design Manufacturing Supply Customer relationship		
Monden (1983)	Toyota Production System			*Autonomation*: functional management and autonomous control *Just in Time*: kanban system and standard operations *Flexible workforce*: production smoothening and multi-functional layout	*Creative thinking*: improvement activities and set-up time reduction
Ohno (1998)	Toyota Production System			Improvement activities Problem solving focus (5 whys) Teamwork	Autonomous control Kanban system Standard operations Production smoothening Information at the source
Karlsson and Ählström (1996)	Lean production areas and factors	Multifunctional teams Vertical information systems No buffers No indirect resources Networks	Lean development Lean procurement Lean manufacturing Lean distribution	*Lean development*: simultaneous engineering and black-box engineering. *Lean procurement:* supplier hierarchies and larger subsystems from fewer suppliers. *Lean manufacturing*: elimination of waste, vertical information systems and pull instead of push. *Lean distribution*: lean buffers	*Lean manufacturing*: continuous improvement, multi-functional teams, and decentralized responsibilities

Oliver, Delbridge and Lowe (1996)	Lean production inside and outside the factory		Inside the factory Outside the factory	*External practices*: integrated material flows, active information exchange, joint cost reduction, and shared destiny relations	*Internal practices*: teamwork, problem-solving and human resource practices
Jenner (1998)	Characteristics of the lean organization			Requisite variety External focus Amplification Bounded chaos	Flexible units Communication expansion Direct authority
Rasch (1997)	Lean manufacturing system		Supplier system Core production system	*Core production system*: built-in quality system, just-in-time and enabling systems	*Core production system*: high involvement organization
James-Moore and Gibbons (1997)	Lean manufacture model	Flow Defect prevention Pull Teamwork Problem-solving focus		*People utilization*: housekeeping *Flexibility*: quick setup times and product development time. *Waste elimination*: high yield, low inventories, and low time through system. *Optimization*: financial optimization, supplier partnership, and effective R&D.	*People utilization*: teamwork and empowerment. *Flexibility*: multi-skilled workers
Shah and Ward (1999)	Lean practice bundles			*Just-in-time*: lot size reductions, continuous flow production, pull systems, cellular manufacturing, cycle time reductions, quick changeover techniques *Total productive maintenance*: predictive or preventive maintenance, maintenance optimization, safety improvement programs *Total Quality Management*: quality management programs, and formal continuous improvement program.	*Human Resource Management*: self-directed work teams and cross-functional frameworks.

(continued)

TABLE 1. *Continued*

Author	Model description	Goals	Activities	Technical elements	Human elements
Lewis (2000)	Lean production as an outcome and process	Flow Pull Continuous improvement	*Internal*: from inputs to outputs *External*: from suppliers to customers		On-going development of people
Nightingale and Mize (2002)	Transition to lean enterprise	Waste minimization Responsiveness to change Right thing at right place, at right time, and right quantity Effective relationships within the value stream Continuous improvement Quality from the beginning	*Entry/Re-entry cycle*: adoption of lean production *Long term cycle*: strategic planning *Short term cycle*: develop lean initiatives	Promote lean leadership at all levels Relationships based on mutual trust and commitment Make decision at lowest appropriate level Optimize capability and utilization of people Continuous focus on the customer Nurture a learning environment	Assure seamless information flow Implement integrated product and process development Ensure process capability and maturation Maintain challenges to existing processes Identify and optimize enterprise flow Maintain stability in changing environment

5. The fifth and final principle, *perfection*, draws attention to the fact that a fully synchronized flow is likely to break down every time something goes wrong. However, unlike the traditional mass-production practice of bypassing failures and postponing their corrections, lean production solves problems immediately and effectively so they will not recur. What might be a painstaking effort at the beginning eventually will result in achieving higher reliability, each time becoming closer to a "perfect" state. To approach perfection, people are empowered to assess their own problems and introduce alternatives that ultimately eliminate root causes.

In *The Machine That Changed the World* (Womack, Jones, & Roos, 1990), the authors presented the lean enterprise as a new organization. The lean organization affects four different activities.

1. The first activity is *design*. For new products, a development leader should be assigned top-management authority of the project so that any trade-off can be resolved directly by the design team. Accordingly, a multidisciplinary team representing each department should support the leader to preserve efficient and harmonious communication among departments, suppliers, and projects. All departments and suppliers should be highly involved from the beginning of the project. By conducting simultaneous development, suppliers should be able to design their own elements with due anticipation. Higher-level research activities will work to accomplish long-term goals, but the research efforts must be closely related to market trends.
2. The second activity is *manufacturing*. By implementing problem-solving analysis, lean manufacturing is visibly different from mass manufacturing because waste not only includes inefficiency but elements such as inventories, rework, and supervision. Tasks are simplified and performed in a reduced space, quality at the source is consistently implemented as opposed to rework, and inventory in process is reduced to the minimum level that ensures continuous flow. However, the main changes are achieved at the workforce level by taking back responsibilities that mass production attempted to specialize, such as quality control, performance tracking, and material handling. Because the workforce masters the execution of the process, workers are the most capable of taking problem-solving skills to the operational level. Whenever a problem occurs, a workforce team is to identify the root cause of the problem and propose the solution required to prevent a recurrence. Management is involved only if the scope of the problem involves other participants such as suppliers, designers, or quality-specification experts. Such empowerment is not to be taken for granted, as workers must be provided the broad information and authority that enable their capabilities.
3. The third activity is *supply*. Lean systems require long-term relationships with a limited number of suppliers in order to reach intense interaction with suppliers. Suppliers are to support target costing, value engineering, and continuous improvement efforts. The design of components is a joint effort between the assembler and the supplier, varying according to the criticality of each component. Cost information is shared so that reasonable and mutual returns can be accomplished objectively. Material requirements should be smoothened to synchronize activities across the value stream. The performance of suppliers is tracked closely, but switching from a supplier should require a long-term action rather than a short-term decision.

4. The fourth element is *customer relationship*. Lean systems require smooth production, that is, regular volumes for most of the products offered to final customers. The proven best approach is to establish a close personal relationship with each customer. By knowing customers' interests, their purchase intentions, and their satisfaction with the company's service, Toyota estimates future requirements within a scope of 10 days. This estimate is updated to actual orders that should be fulfilled within three days. By reducing the noise among the customers, retailers and manufacturers, lean systems avoid unrequested inventory being sent to the retailers.

A framework of the lean principles and the lean organization is shown in Figure 3. Womack and Jones (1996) focused on the goals, the system (lean principles), and the scope of activities lean production addresses (lean organization). They recognized the role of technological and human elements, but they saw them as a result rather than a requirement of lean production. What has spread lean production worldwide is the superior performance of Japanese manufacturers, and especially Toyota Corp. Their production practices have been introduced to the West since the early 1980s and even before American manufacturers started to benchmark Japanese practices (Drucker, 1971; Schonberger, 1982).

4.2. Monden

In the publication *Toyota Production System*, Monden (1983) presented an overview of his research project at Toyota Corp. The goal of the system is long-term improvement that translates into cost reduction, quality assurance, and respect for humanity. To reach those subgoals, the system includes four basic elements: JIT, autonomation, flexible workforce, and creative thinking. JIT means the production of the right quantity at the right time.

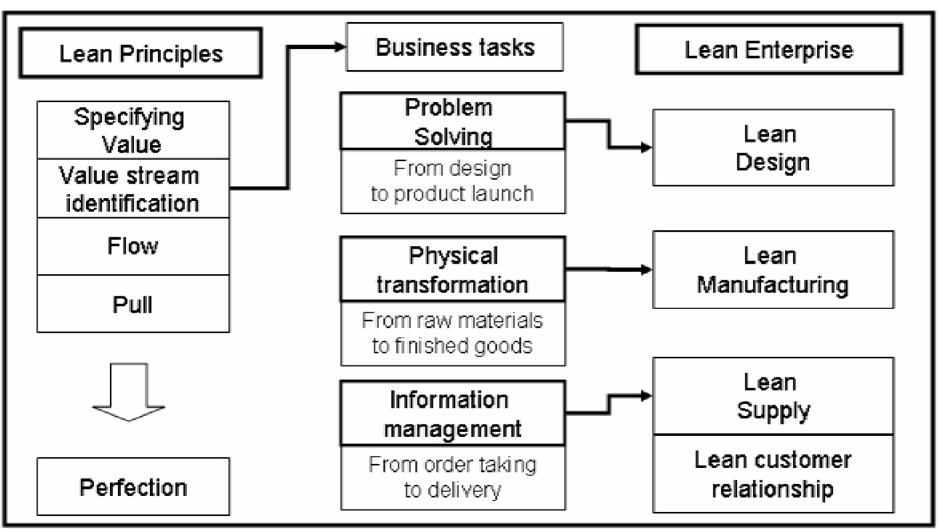

Figure 3 Lean thinking and the lean enterprise (Womack & Jones, 1996; Womack, Jones, & Roos, 1990).

Autonomation means that there is autonomous defect control by the workforce. Flexible workforce means adjusting the number of labor hours to the demand changes, and creative thinking means capitalizing on employee ideas and suggestions. Monden identified eight methods to support the goals of the production system.

1. The first method is a *functional management* system to promote quality and cost management company-wide. Quality assurance and cost management are joint corporate tasks and should be reviewed at each step of the product life: design, preparation, purchasing, manufacturing, and sales. A corporate analysis is required to determine the contribution of each step and its importance. Based on their own tasks, functional department heads coordinate a team effort to exercise problem-solving skills in their activities.
2. The second element, *autonomous control*, is an improved quality-monitoring approach. Statistical quality control (SQC) includes an acceptable quality level (AQL), generally a small percentage of allowable defects. The AQL for the TPS is 0%; otherwise, the smooth flow demanded by the kanban system would not be accomplished. Inspections are still in place, but their goal is not just to monitor but to identify a defect problem, remove all defective units from the line, and take remedial action. This goal is the reason the TPS is wary of indiscriminate automation. If the machine does not ensure zero defects and does not allow the worker to prevent any defect, it is going to create material and labor waste. Autonomation is automation with automatic control of defects. That is, a device enforces the quality of the process and triggers an *andon* (emergency request) pull every time a defect is found. If that is accomplished, a worker monitoring the machine is not required and the automation really reduces the labor requirements. Regardless of the technology, visual inspection must remain to facilitate the identification of defective units (Shingo, 1985).
3. The third method is the *kanban system*. This method is an operational scheduling based on backward requests that are driven by the sales orders. The assembly line withdraws components from the preceding process and subsequently expands requests to all preceding processes, going back to the suppliers of the base components. Kanban cards are used to distribute the information flow: withdrawal kanbans for requests and production kanbans for processing. The flow starts with requests from the succeeding to the preceding process. The worker takes withdrawal kanbans to the store of the preceding process, then takes the required parts, detaches the production kanbans, and leaves the withdrawal kanbans with empty containers if used. The preceding process is to take the production kanbans, make the parts, and place them back at the store within the empty containers. Buffer sizes are limited to the lead-time required and any shortage will trigger an andon that takes priority on the production cycle. This system ensures that all processing activities are oriented to meet the schedule and that anomalies are handled immediately.
4. *Standard operations*, the fourth method, is a requirement for production smoothening. A routine with standard time should be established so that tasks can be allocated within the cycle time. The cycle time is the average time between the outputs of two units and is determined only by the daily demand. A combination of machines, operators, and activities could optimize time within the cycle. If one worker should fall behind, an andon pull acts as a warning system so that the other team members

can support the delayed task. The only allowance considered is for exchange of tools, if required.

5. The fifth method, *production smoothening*, is the adaptation of the production system to fluctuating demand. Based on market information, a monthly plan is determined with all product requirements scheduled into the same daily production pattern. This information is shared with all suppliers so that they can ensure synchronized deliveries. Labor allocation should be adapted to those requirements by overtime in case of high demand, or support activities during low demand, and machine capacity should be available for demand peaks. An updated request is received 10 days before production and actual requirements 1 day before production. The key elements for this method are the production sequence and the cycle time. By determining the best sequence, it is possible to reduce the idle time between the production of each component and its introduction into the subsequent process. This sequence allows workers to know what product is next and is supported by the kanban system to ensure all components are available for the process.
6. Even with standard operations, variable labor utilization would not be possible without a *multifunctional layout* design, which is the sixth method. Workers are to reach several positions within short distances (U-shaped layout) so that they perform different tasks in the line. In fact, job rotation occurs several times within the same shift, increasing the variety of work tasks.
7. The seventh method is the *reduction of setup activities* to reduce lead time. Setup time is optimized by identifying tasks to be performed on the machine (critical path). Those tasks are named internal tasks, as opposed to external tasks, which can be performed without the machine. Only internal tasks are to be performed during setup time, and they should be reviewed to identify improvements in terms of tooling, parallel tasks, or settings features. Manual tasks should be standardized and the operators trained to master the routines.
8. The eighth method is *improvement activities*. Manual operations include waste, operations without value added, and net operations. Waste means that the actions are not required by the product and could be eliminated immediately. Operations without value added, on the other hand, demand a design or structural change that cannot be accomplished in the short term. The target of all operating procedures is to include only net operations. Changes in layout, machinery, or design should not be the first option, and there should be realistic assessment of the savings they render in terms of workforce. However, most of the improvements are in methods, which is why the contribution of the workforce is essential. Quality circles, or small teams, are meant to increase the problem-solving skills of the workers, and guidelines are to help people understand what can be improved and how the improvements can be made. A suggestion system is to gather ideas and proposals from workers; assess them; and reward those who bring cost-effective solutions, or provide an explanation to those whose proposals are not feasible. Quality circles also can select problems to be solved beyond the typical product-quality and cost-reduction issues, such as those addressing maintenance, safety, and the environment. Quality circles should be seen as enablers of organizational improvement rather than mere cost-saving teams.

Monden's model of the TPS introduces the combination of technological and human elements required by lean production and their interaction, but this model overlooks the capabilities of the workforce that ensure long-term improvement. In *Toyota Production System* (1988), Ohno reviewed some additional elements of the TPS. He included *teamwork* as a new element because the TPS is not looking for the individual craftsman but for a group of people who can work as a group and achieve overall success. Repeating "why" five times is a method to find the root cause of problems. The five-why method is the application of a *problem-solving* approach to everyday problems. "My plant-first" is a method that requires looking for *information at the source*, the shop floor, as opposed to making estimations from a desk.

The model of the TPS is presented in Figure 4. The main contribution of Monden and Ohno is the inclusion of a combined system of human and technological elements. While the technological elements are fully described in terms of specific methods, the human elements are not elaborated. Western manufacturers have often reviewed all Japanese techniques but failed to include the capabilities of the workforce, which are more difficult to achieve in Western organizations.

4.3. Karlsson and Ählström

As new lean performers have appeared during the 1990s, lean techniques have spread in the West. Accordingly, researchers have tried to identify the human and technological elements that support the implementation of lean production. In 1996, Karlsson and Ählström created a model based on available theory of lean production. The model shows the determinants of a lean system in a manufacturing company across functional areas. This model was tested in an international manufacturing firm producing mechanical and electronic office equipment. Karlsson and Ählström associated specific techniques with four elements of the lean enterprise:

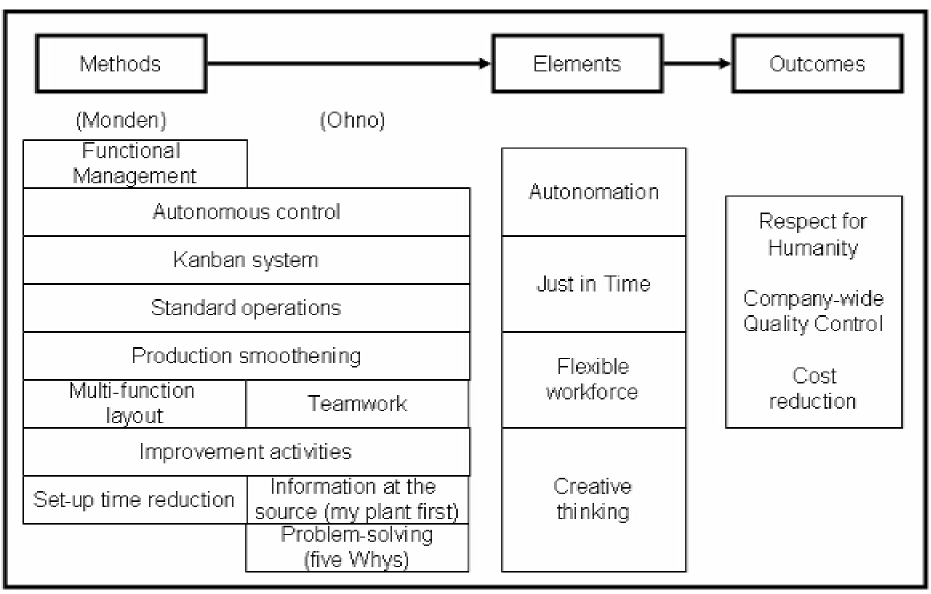

Figure 4 Toyota Production System (Monden, 1983; Ohno, 1988).

1. Lean development: supplier involvement, cross-functional teams, simultaneous engineering, integration instated of coordination, strategic management, and black-box engineering.
2. Lean procurement: supplier hierarchies and larger subsystems from fewer suppliers.
3. Lean manufacturing: elimination of waste, continuous improvement, multifunctional teams, vertical information systems, decentralized responsibilities, and pull instead of push.
4. Lean distribution: lean buffers, customer involvement, and aggressive marketing.

Karlsson and Ählström provided both human and technological elements to the production system, and they related them to activities of the lean organization. They included waste elimination, pull, and continuous improvement as part of the techniques, and they proposed new elements such as multifunctional teams, vertical information systems, no buffers, no indirect resources, and networks. This inclusion is ambivalent, however, since lean elements could be seen as either outcomes or enablers of lean production.

4.4. Oliver and Colleagues

Oliver, Delbridge, and Lowe (1996) presented their own description of the lean organization. Their framework was the basis for an exploratory cross-sectional study of 71 automotive component plants to test the relation between the implementation of lean manufacturing and performance outcomes. They split the organization into *inside* and *outside* the factory. Internal practices include elements from lean manufacturing and development. Lean factory practice, teamwork, problem solving, and human resource practices are the internal elements identified. External practices, on the other hand, refer to the extension of lean production practices along the supply chain, involving both lean supply principles and productive customer relationships. Integrated material flows, active information exchange, joint cost reduction, and shared destiny relations are the external elements mentioned.

Oliver, Delbridge, and Lowe (1996) underscored the difference of lean manufacturing as internal activity and lean supply as external activity. This difference is not clear though for design, which involves the interaction between suppliers and manufacturers. They included human and technological elements to the system, but it is not clear whether those elements are outcomes or requirements of lean production. For instance, joint cost reduction is the result of a strong relationship with suppliers, whereas team-based work organization is required for production smoothening.

4.5. Jenner

Jenner (1998) proposed a further extension of Womack's model. He stated that the success of lean production comes from the implementation of flexible, creative, and adaptive structures that could be applied to any organization. Furthermore, lean production has the characteristics of dissipative enterprises, and by using systems and information notions, it is possible to identify seven principles of lean systems. The first principle, *requisite variety*, is that the changes that lean systems create should surpass the disturbances threatening them. Change is essential for adaptation to a dynamic environment. The second principle, *flexible units*, allows new structures to emerge within the enterprise and promotes efficient exchanges of information. Working cells are an example of flexible structures that are set in terms of product and market conditions. The third principle, *communication expansion*, means that the organization should broaden the information received from the external world and fuel internal creative processes. The organization must remove noise from communication channels to ensure efficient interactions among its components. Principle four, *external focus*, implies that the ability of an organization to adapt to external changes depends on how consistently its goals are aligned. All units should have a goal defined in terms of a target value for their output. The fifth principle, *direct authority*, demands that decisions should be delegated to the person or team that has access to the broadest channels of information directly related to the decision. The sixth principle, *amplification*, is the ability of the lean system to partition an issue into a sequence of stages that are delegated to different levels so that an amplified effort is achieved. The seventh and final principle, *bounded chaos*, means that people should enjoy freedom to test new ideas so that innovation can flourish. Control systems should be cautiously limited to preclude change.

Jenner's model attempts to explain behaviors that are related to the lean enterprise. In fact, Jenner's principles include the capabilities of the workforce that lead to higher performance: bounded control, communication expansion, direct authority, and flexible units. Though Jenner did not include the technological side of lean production, his model presented the human elements overlooked by other authors.

4.6. Rasch

Another system model was presented by Rasch (1997) as part of a research project of 249 small suppliers of automotive component parts in the Midwest. Lean production consists of two main subsystems: a supplier system and a core production system. The techniques included within the supplier system are the use of sole source suppliers, suppliers selected on noncost criteria, use of long-term contracts, a supplier certification program, and supplier self-inspection. The core production system is broken down into three components: high involvement organization, built-in quality system, and a JIT and enabling system. Additional elements are relaxed work rules and pay incentives for the human organization, and preventive maintenance for the JIT system, which involves actions that prevent equipment failures from occurring. Information from the process or inspections is required to determine when to execute those preventive actions.

Rasch effectively divided the lean organization into subsystems that implement specific practices, both technological (JIT and quality subsystems) and human (high-involvement organization). Supply and production have individual goals in terms of performance outcomes. It is difficult to understand, however, how it is possible to separate JIT from the supplier system. In fact, Rasch's supplier system looks more like a description of the partnership with suppliers than specific techniques. Rasch did not elaborate on how the outcomes of each subsystem contribute to the ultimate goals of the lean enterprise: value addition, flow, and pull.

4.7. James-More and Gibbons

James-Moore and Gibbons (1997) conducted a study to determine whether lean practices could be extended to low-volume, highly differentiated products. They reviewed relevant literature to identify core principles (flow, defect prevention, pull, teamwork, and problem solving) that will result in better performance outcomes: process control, people utilization, flexibility, waste elimination, and optimization. Specific practices support those principles by outcome. Process control comes from total productive maintenance, poka-yoke (visual control), and design for manufacturing. People utilization comes from housekeeping, teamwork, and empowerment. Flexibility comes from multiskilled workers, quick setup times, and product development time. Waste elimination comes from high yield, low inventories, and low time through system. Optimization comes from financial optimization, supplier partnership, and effective research and development (R&D). Their model, though, includes elements that could be regarded as outcomes more than enablers of the lean enterprise, such as high yield, short product-development time, and financial optimization.

4.8. Lewis

Lewis (2000) distinguished between lean production as an *outcome* and lean production as the *process* of becoming lean. As an *outcome*, lean production is influenced by external conditions from suppliers or customers. As a *process*, lean production consists of three principles: improvement of *flow* of materials and information, emphasis on customer *pull*, and a commitment to *continuous improvement enabled by the ongoing development of people*. After conducting a study at three multinational companies, Lewis concluded that lean production does not automatically lead to improved performance. Lewis's framework combines the capability of the workforce with the core goals of lean production. It fails to identify specific techniques to foster the sociotechnological elements of the system.

4.9. Nightingale and Mize

Based on research conducted by MIT's Lean Aerospace Initiative, Nightingale and Mize (2002) proposed an extension of Womack's model to an enterprise-level transition roadmap. This roadmap combines lean principles with strategic and structural issues in a dynamic sequence of three cycles. The first cycle, *entry/re-entry cycle*, is associated with the strategic planning that determines the adoption of the lean paradigm. The second cycle, *long-term cycle*, creates the environment for lean implementation and includes mapping of the value stream, involvement of stakeholders, adoption of goals, and organizing the lean structure. The third cycle, *short-term cycle*, refers to developing lean initiatives. A prioritized plan is set to allocate resources that enable transformation. Both the activities and the results of the process are assessed to capture knowledge for further exercises. Those results are also reviewed in the *long-term cycle* to determine if they are consistent with the lean vision. Nightingale and Mize explained how to adapt the lean enterprise to the strategic planning and how to achieve a continuous improvement cycle. However, this model relies on an architecture known as lean enterprise model (Murman et al., 2002). Accordingly, a set of core practices defines the enterprise-level goals (waste minimization; responsiveness to change; right things at the right place, the right time, the right quantity; effective relationships, continuous improvement, and quality from the beginning). This set of practices defines overarching, enabling, and supporting practices. The overarching practices identified by them resemble a sociotechnical design:

1. Human-oriented practices: promote leadership at all levels, promote relationships based on mutual trust and commitment, make decisions at appropriate level, optimize

capability and utilization of people, maintain continuous focus on the customer, nurture a learning environment

2. Process-oriented policies: ensure seamless information flow, implement integrated product and process development, ensure process capability and maturation, maintain challenges to existing processes, identify and optimize enterprise flow, maintain stability in a changing environment.

4.10. Shah and Ward

Shah and Ward (2003) identified common practices supported by substantive literature. Instead of assuming any combination of practices, they explored the best grouping (bundles) for all 22 practices by using data from the Industry Week's Census of Manufacturers. Contextual factors such as plant size, plant age, and unionization states were included. JIT, total preventive maintenance (TPM), total quality management (TQM), and human resource management (HRM) were selected as core groups including specific techniques:

1. JIT: lot-size reductions, continuous flow production, pull systems, cellular manufacturing, cycle-time reductions, focused factory production systems, agile manufacturing strategies, quick changeover techniques, bottleneck or constraint removal, and reengineered production processes.
2. TPM: predictive or preventive maintenance, maintenance optimization, safety improvement programs, planning and scheduling strategies, and new process equipment.
3. TQM: competitive benchmarking, quality management programs, quality systems, process capability measurements, and formal continuous improvement program.
4. HRM: self-directed work teams and cross-functional frameworks.

A sample of lean practices was taken from 1,757 manufacturing plants, and the implementation of those practices was tested. The most significant factor was the size of the plant. Shah and Ward (2003) successfully grouped the elements into general elements that could be compared across plants. The technological system consists of JIT and TPM. The human system consists of HRM.

4.11. Miscellaneous

There is varied literature available on field studies comparing lean practices across industries (Forza, 1996; MacDuffie, 1995; Soriano-Meier & Forrester, 2002). Although these studies are supported by the correlation between certain practices and performance outcomes, each study works with a different construct, and only a small group of techniques is consistently tested.

5. DEVELOPMENT OF AN INTEGRATED FRAMEWORK

There are many different paradigms for lean production since it is an organizational system that involves human-driven activities. Checkland (2001) described organizational systems as soft systems for which it is not possible to form a consensus. To develop an integrated framework, the starting point is to identify the root elements of the system, which are the customers, the participants, the transformation process, the *weltanschauung*, the owner, and the environmental constraints.

1. The *customers* of the system are those who would benefit from it. Emiliani (1998) identified investors, suppliers, and consumers as beneficiaries of lean production. Knuf (2000) included employees also as beneficiaries. Employees expect not only economic compensation but opportunities to improve their capabilities and working conditions. Fujimoto (2000) introduced Toyota verification of assembly line (TVAL) as an ergonomic evaluation of the workload of each assembly job. Jackson and Martin (1996) showed that JIT implementation does influence job content. These facts have an important implication for the lean production system because the additional demands on the workforce have to be balanced by job satisfaction (Genaidy & Karwowski, 2003).
2. The *participants* of the system are those who would perform the activities. Managers, employees, and suppliers are responsible for the implementation of lean production. It is important to stress that lean production is not a plant-wide but an enterprise-wide model. It involves all functions, all tiers, and all concerns of a specific industry. Jones, Medlen, Merlo, Robertson, and Shepherdson (1999) identified a lean provider as an independent unit; however, an enterprise model is interested more in the joint interaction of suppliers from all tiers.
3. The *transformation process* is the purposeful activity of the system. The purpose of a lean system is to move the enterprise into a perfect "lean state" characterized by minimum resources and maximum performance as shown in Katayama and Bennet's (1996) framework (Figure 2). All companies are in transition to reach such an ideal state.
4. The *weltanschauung* is the view of the world that makes the lean approach meaningful. Lean production is not a goal but a capability to achieve long-term improvement (Hayes & Pisano, 2000). What makes lean production relevant as a concept is that it regards the interaction between activities as more important than the outcome of isolated elements of the system. This assertion is supported by the fact that many U.S. manufacturers began working with JIT, TQM, and continuous improvement before the 1990s, and according to the IMVP findings, they had not yet attained competitive levels.
5. The *owner* is the person or entity that starts and stops the development of the activity. For lean production, the owners are the managers, because lean production demands management commitment to entrusting workers with decision making at the operational level. *Environmental constraints* are determined by contextual variables of each industry. Market size, process complexity, and business life cycle do not preclude lean implementation but could influence performance outcomes. In general, the model should be extended to those functions in which the enterprise can exercise value addition; otherwise, it is not practical.

Figure 5 presents the integrated framework of the lean enterprise. The first step occurs when management commits to the lean philosophy explained by three goals: zero waste, flow, and pull. Waste elimination is the product of specifying value and getting rid of what does not belong to the value stream. The second step is to identify the scope of activities that conform the value stream: design (problem-solving task), supply (information-management task), and manufacturing (physical-transformation task) as presented by Womack and Jones (1996) and Warnecke and Hüser (1995). The third step is to develop the workforce capabilities. As a new practice of manufacturing, lean production demands new capabilities from people: problem-solving focus, teamwork, and creative

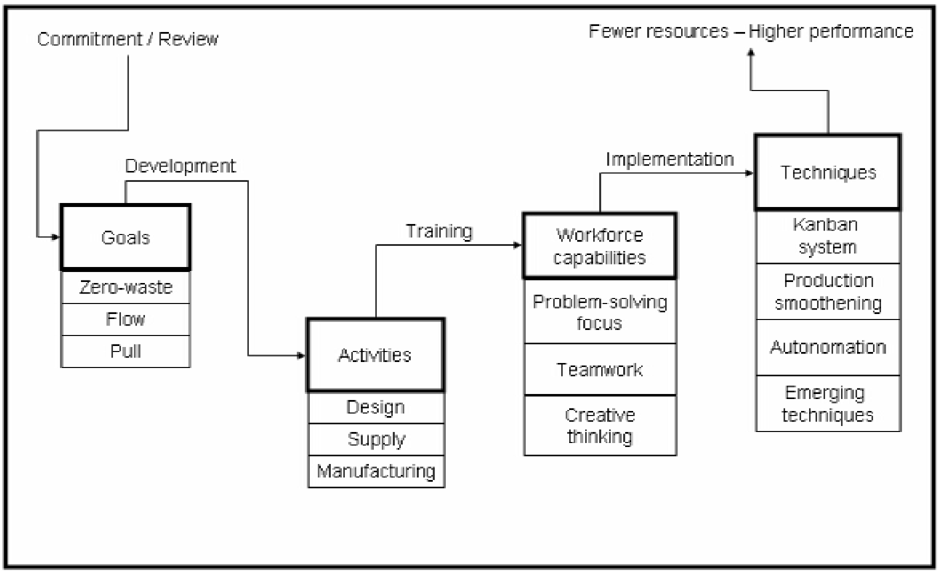

Figure 5 Dynamics of the lean enterprise.

thinking. Teamwork is seen now as an extended concept in organizational theory (Salas, Shawn, & Cannon-Bowers, 2000) that involves empowerment, multifunctionality, and coordination. The final step is the implementation of lean techniques. Lean production is not a fixed set of techniques, as has been shown in all the frameworks presented. As part of the implementation, new techniques will emerge at each company. Since businesses share the same interests and join a competitive market, common elements are likely to appear. Based on the previous review, there are three core techniques: the kanban system, production smoothening, and autonomation. The kanban system is the realization of backward or pull requests across all processes and suppliers. In fact, the kanban concept has already been extended as a production control system (Chaouiya, Liberopoulos, & Dallery, 2000). Production smoothening comprises standard operations, machine layout, and setup time reduction. Hormozi (2001) presented agile manufacturing as an emerging system evolving from production leveling and flexible resources. Autonomation involves a quality management and control system that doesn't allow defects to flow through the process. TQM has adopted most of these practices (Ho & Fung, 1994), and TQM is at the core of modern quality systems. These three techniques do not preclude any unique or individual elements that fit a specific company, and core techniques will emerge as they are successfully implemented by leading companies. The workforce capabilities and the lean techniques constitute the subsystems conforming the sociotechnological design of lean production.

6. CONCLUDING REMARKS

In recent years, U.S. manufacturing enterprises have strived to adopt innovative production management methodologies to continually boost their work productivity and quality. In this regard, advancements in technological and human systems are essential to achieve the desired quantum leaps in work quality and productivity. To date, technological advances have been, as depicted in Figure 6, on the cutting edge. On the other hand, advances in human-based systems have been progressing in R&D, but not at the same pace with technology.

For example, lean production has been emerging as an important sociotechnological system that can be used by manufacturing enterprises to achieve and sustain high productivity and high quality (Genaidy & Karwowski, 2003). Indeed, this emerging production system is rich in its technological principles and practices. It also offers several advantages for human-based systems on a conceptual basis in comparison to those embedded in traditional production systems. It is, however, at a disadvantage as to what constitutes the best human performance practices that may balance the technological requirements and resources. Therefore, one should jointly optimize the technological and human systems for the enterprise to meet its objectives.

This article has presented alternative but related models of lean production systems. Lean production is an organizational system, and as a soft system, it can be seen from different perspectives. Most models work on three features of lean production: lean as a new philosophy, lean as a new organization, and lean as a set of human and technological practices. Common elements have been identified based on how they address the essence of the lean system. The lean enterprise is a system that looks for maximizing production performance with minimal resources. The dynamics of lean production start from the goals (zero waste, flow, and pull) and progress to the scope of activities (design, supply, and manufacturing), to workforce involvement, and then to the lean techniques. A framework has been introduced that can support future field studies because it contains the determinants of the degree of implementation of a lean enterprise.

The lean enterprise is a sociotechnological construct since it is based on the combination of human and technological subsystems. The technological system moves around three sets of practices: the kanban system, production smoothening, and autonomation. Each one includes specific techniques that are continuously evolving. The human system consists of the workforce capabilities demanded by lean production: creative thinking, problem-solving focus, and teamwork. There is little effort so far in organizational theory to explain how to achieve such workforce capabilities.

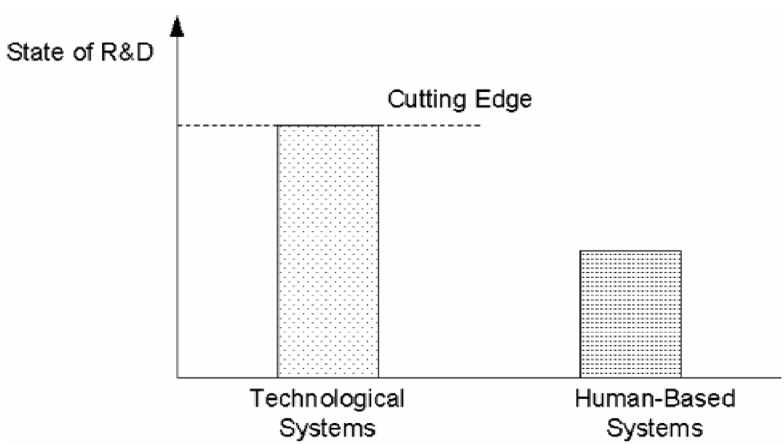

Figure 6 State of R&D in sociotechnological systems.

The lean enterprise is viewed as a dynamic process that translates its goals (zero waste, flow, and pull) into combined techniques that should be implemented throughout the entire organization. A new body of research is required to assess the validity of this construct. First, lean production should be explained based on Cherns's principles. Second, a comprehensive set of human practices that addresses the demands of the technological system should be developed. Then, the impact of all the elements of lean production should be compared to performance outcomes (cost, quality, time, productivity, and safety). Previous research has focused on cross-sectional studies of specific technologies (Genaidy & Karwowski, 2003), but lean production should not be viewed as the addition of isolated techniques. Future research should concentrate on the combined effects of the elements presented, the impact on stakeholders (investors, customers, suppliers, and employees), and the dynamic nature of lean enterprise systems.

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