WALLACE J. HOPP

Positive Lean: Inspiring Efficiency from Within

By many measures, lean production has been a phenomenal success. Since the early 1980's when the West first became widely aware of the practices of a scrappy car company named Toyota, the methods now called 'lean' have swept first through the auto industry, then through the manufacturing sector and are now moving rapidly into the service sector. Today, a visit to a hospital anywhere in the developed world is likely to find a lean initiative under way. A quick Google search will reveal consulting ads for lean office, lean banking, lean food services (lean cuisine?), lean education and lean just-about-anything-you-care-to-name. It is hard to think of any firm in history that has been emulated more than Toyota. Even the moving assembly line of Henry Ford or the multidivisional firm structure of Alfred P. Sloan and Pierre du Pont did not permeate all the way to hospitals and schools the way the Toyota Production System has.

This deluge of lean activity has produced scores of success stories. Most prominently, Toyota leveraged its production system to grow from a struggling niche player in the wake of WWII, with production below 5,000 vehicles per year, to the largest automaker in the world, with annual production of nearly 10 million vehicles. Examples of smaller success stories range from a reduction in floor space for a chair production line from 6,000 sq ft to 3,500 sq ft at Herman Miller (Drickhamer 2010) to a 95% reduction in slide misidentification in a surgical pathology laboratory at Henry Ford Hospital (Zarbo et al. 2009). For the American manufacturing sector as a whole, Chen, Frank and Wu (2005) found that work-in-process inventories declined from 1981-2000 at an average rate of 6% per year, largely due to lean initiatives.

But along with these undeniable accomplishments, there have been persistent problems. The literature is full of claims of high failure rates among lean implementation efforts. For example, Wall Street analyst Cliff Ransom famously estimated that only 1-2% of firms that implement lean do so effectively enough to see the results financially (Hall 2004). A 2006 survey of nearly 300 manufacturing firms found that 90% reported that they were committed to lean, but less than 20% of them could be considered best in class (Aberdeen Group 2006). In a 2007 Industry Week/Manufacturing Performance Institute survey, 70% of manufacturers reported using lean, but only 2% of them reported having fully achieved their objectives and less than 24% reported achieving significant results (Pay 2008). Rajagopalan and Malhotra (2001) studied the American manufacturing sector from 1961 to 1994 at the industry level and, like Chen, Frank and Wu, found that inventories, particularly raw materials and work-in-process, declined. However, they did not observe acceleration in the rate of decrease from 1981 to 1994, when the lean movement was presumably taking root.

In addition to these concerns about how well or how often lean has achieved its business objectives, there have been claims of negative impacts on the workforce. For example, based on a scholarly study of lean groups in a large vehicle manufacturer, Parker (2001) concluded that, particularly in assembly line settings, lean practices induced negative reactions from employees that included reduced organizational commitment and increased job depression. At a more personal level, Mehri (2006), who worked in a Toyota group company, found lean to create a 'culture of rules' that stifled creativity, neglected safety and created a poor quality of life for workers. Speaking from a decidedly political point of view, Post and Slaughter (2000) described lean as 'management by stress' designed to eliminate waste even when that 'waste includes most things that make life bearable like breaks, or a reasonable pace, or a set work schedule, or a decent pay check, or job security.'

A fair assessment of the evidence is probably that lean can produce spectacular results, but that this is rare. Most lean adopters achieve localized operational improvements without major strategic impact.

Why isn't lean living up to its potential? The response one hears from lean experts is almost always some form of the argument that failures are due to 'not doing it right'. But this begs the question. Of course, by the very definition of 'right', failed implementations or lean programs that harm workers aren't doing it right. A better question is w*hy* aren't they doing it right? The most common reasons cited in the many discussions of failure in the lean literature are:

- Lack of commitment from top leadership
- Resistance to change
- Overreliance on tools, without a deeper understanding of lean thinking

While these may indeed be problems in many lean efforts, they are also excuses. If well-intentioned practitioners are failing to realize the full potential of lean, there must be something missing from the current descriptions and training materials. For some reason, the message is failing to get through. For this, those of us in the lean education and consulting arena must bear part of the blame.

To usher in a new generation of lean, with deeper penetration and broader impact, we need to understand more completely and communicate more clearly the essence and application of lean. The criticisms of lean, particularly those from a worker perspective, offer some clues into how to do this. But to really understand the keys to lean success and articulate these in a transmittable way, we need a bit of history, a bit of science and a bit of vision.

Muda and the History of Efficiency

Most descriptions of lean revolve around the concept of eliminating waste or *muda*.[1] But a concern about waste and methods for avoiding it did not originate at Toyota. These have always been at the heart of an efficiency movement that is as old as human civilization itself. The fundamental focus of this movement was, and still is, to reduce the inputs needed to produce a unit of output (or equivalently, increase the amount of output from a given quantity of inputs).

In antiquity, massive construction projects, such as the Egyptian pyramids, Roman aqueducts, and Mayan temples, simply could not have been built without innovations in technology and organizational methods that increased the efficiency of human labour. In the Middle Ages craft guilds emerged for various production specialties (e.g., smiths, cobblers, weavers, tailors, etc.) and fostered efficiency improvements by promoting training and setting quality standards. In the 17th and 18th centuries, craft guilds in some industries gave way to a new domestic system, in which merchants brought work to artisans working in their homes, typically for lower wages than those of guild members. To enable the lower skilled domestic workers to be at least somewhat competitive in quality with the guilds required efficiency improvements through task simplification. But despite these advances in labour productivity, the pace of efficiency innovation up until the mid-18th century was slow by modern standards.

This changed dramatically in the 1760's with the advent of the First Industrial Revolution, which began in the British textile industry. By leveraging innovations in mechanization (e.g., spinning jenny, water frame and power loom) and power (steam engine) manufacturers achieved vast increases in output per worker relative to traditional manual production. As a consequence, the new factory system progressively replaced the domestic production and craft guild systems, first in textiles and then throughout manufacturing.

The First Industrial Revolution also brought about the first systematic writings on efficiency. Most notably, Adam Smith (1776) captured an essential concept of efficiency in his landmark *Wealth of Nations*, by using a hypothetical pin factory to describe how specialization increases labour efficiency. By viewing production as a sequence of steps (much like an early version of the lean practice of value stream mapping), he argued that the work of making a product could be divided into specialized tasks that could be carried out efficiently by narrowly trained workers.

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[1] Many expositors of lean indulge liberally in Japanese terms, both as an homage to Toyota and to make mundane ideas seem more exciting. For example, 'driving out muda' conjures up images of heroic samurai fighting insidious evil, while 'eliminating waste' sounds like taking out the trash.

Through this lens, the craft guilds represented a step toward specialization as a result of grouping work by function (guild). The domestic system extended this step by dividing work into even smaller units. The factory system, with significant help from technology that mechanized many difficult tasks, led to even further specialization.

The efficiency gains from labour specialization were not without cost, however. The Luddite Movement in early 19th century Britain led to riots and sabotage of industrial equipment in protest of the low prices and wages wrought by the factory system. Later in the century, extremely repetitive work, coupled with long hours, poor working conditions and low wages, spurred the rise of labour unions across the industrialized world. A fundamental tension between efficiency and gratification of work had emerged.

Nevertheless, the efficiency movement took another leap forward during the Second Industrial Revolution, which began in the 1850's in America. Again, technological innovations played a major role. Communication (telegraph) and transportation (railroad) innovations made mass marketing and mass transportation possible, creating the opportunity for mass production. Process innovations, including the Bessemer process for steel making, pulping processes for making paper, vulcanization for making rubber products, and many more, facilitated mass production of basic materials. Possibly more important than any of these technological innovations was the emergence of interchangeable parts. Evolved by Jean-Baptiste Vaquette de Gribeauval, Honoré Blanc, Eli Whitney and many others, this concept made it possible to manufacture highly complex assembled products via a series of simple, standardized tasks.

The writer who best characterized the efficiency improvements in the Second Industrial Revolution was Frederick W. Taylor (2011). Indeed, he embodied the era's almost fanatic focus on efficiency so completely that he was deemed the 'Apostle of the American Gospel of Efficiency' by Daniel Boorstin (1974: 363). Taylor recognized that, in the complex, large scale facilities of the late 19th and early 20th centuries, dividing production into tasks and mechanizing them was no longer enough to stay on the leading edge of the efficiency curve. Instead, he sought to optimize the tasks themselves and made the revolutionary proposal that scientific methods (e.g., time and motion studies) could be used to achieve this. His framework, Scientific Management, is the ancestor of all systematic efficiency systems that followed, including lean.

Henry Ford borrowed heavily from Taylor and applied the same close scrutiny of auto assembly that Taylor gave to simpler tasks such as ore shovelling. However, while Taylor was concerned primarily with productivity (e.g., tons of ore moved per shift), Ford was obsessed with speed. His celebrated moving assembly line was only one part of a vertically integrated system that he claimed could produce a car from raw iron ore in only 81 hours (Ford 1926).

Taylor and Ford both faced the tension between efficient work and gratifying work head on. Taylor (1911) wrote extensively about the problem of 'soldiering', the practice of systematically slowing down the pace of work. He also experienced opposition from workers who felt his methods created intolerable working conditions.[2] At Ford, the mind numbing monotony of working on the new assembly line resulted in high rates of absenteeism and turnover. Both men responded with financial policies. Taylor used piecework to reward productive workers, but was largely unsuccessful in motivating his workforces. Ford adopted a far more successful policy of paying roughly double the market wage – the legendary '$5 a day' rate – to attract, retain and motivate workers.

Taiichi Ohno, a production engineer at Toyota, picked up the efficiency mantle from Ford. Like Ford, Ohno focused on material flows, but he did so in an even more complex environment. Because Toyota did not have the luxury of high volumes they could not restrict their plants to a single product (and a single colour) as Ford was able to do. So matching, and eventually surpassing, the efficiency of its larger rivals required Ohno and his colleagues to evolve practices beyond anything yet seen. That they were able to do this, through relentless experimentation and attention to detail is a matter of public record.

However, while Ohno was extraordinarily diligent about developing the Toyota Production System, he was less diligent about explaining it. Indeed, in an interview in 1990, Ohno said that Toyota deliberately coined misleading terms and words to describe it because 'If in the beginning, the U.S. had understood what Toyota was doing, it would have been no good for us.' (Meyers 1990). So perhaps it is not surprising that English language writers have taken liberties in interpreting Ohno's writings, particularly his book, *Toyota Production System*, published in Japanese in 1978 but not translated into English until 1988, by which time Toyota's methods were so well-known that they were on the cusp of being given the generic term 'lean' (Womack and Jones 1990).

For example, Ohno (1988) described the Toyota Production System as resting on two pillars:

1. *Just-in-time*, or producing only what is needed.
2. *Autonomation*, or automation with a human touch.

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[2] The most famous of these was the strike at the Watertown Arsenal in 1911, which led to congressional hearings and ultimately a ban on Taylor's methods in federal facilities (Aitken 1985).

But, although just-in-time (JIT) was lionized by Western scholars and practitioners, autonomation was virtually ignored. JIT was so popular that it was given the more generic name 'pull'.[3]

Ohno (1988) also described the key obstacle to ideal performance as waste, which he described with three words:

1. *Muda*, waste or non-value added tasks
2. *Mura*, variability or inconsistency
3. *Muri*, overburden or stress

But, while 'muda' has become possibly the most recognized Japanese word in the West, and the centre of most people's understanding of lean, 'mura' and 'muri' have been almost entirely lost. As we will discuss below, this loss is a serious one.

Ohno (1988) further elaborated by listing seven types of waste:

1. Overproduction
2. Unnecessary transportation
3. Waiting
4. Extra processing
5. Motion
6. Inventory
7. Defects

The lean literature has treated these with near religious respect. They appear with regularity in almost every lean book, paper, course and presentation. Unfortunately, this list is one of the weaker elements of Ohno's description of lean. For one thing, it is incomplete. In the text, Ohno identified unused people and equipment as waste, but he failed to put 'excess capacity' on his list. Other forms of waste, such as waste of natural resources, were not mentioned at all. Because of omissions like these, some people add to Ohno's list, with 'Non-utilized skills' being the most common addition.

In addition to being incomplete, the list is incongruous. For example, overproduction is a cause, while inventory is a consequence. If we produce more product than is needed, we wind up with inventory. As a result, exercises to classify wastes into these categories often dissolve into confusion. Is walking to get a part unnecessary transportation or motion? Such discussions are themselves a waste. Who cares how a waste is labelled as long as we can identify and eliminate it?

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[3] Even JIT was subject to misinterpretation as the term 'pull' wound up being widely interpreted as something entirely different from its original meaning (see Hopp and Spearman (2004) for a discussion).

This cursory overview of the history of efficiency reveals three areas of ongoing challenge:

1. *Complexity:* As production environments become more complex, so do the policies for increasing efficiency. For example, transforming the 18th century textile industry, which used a relatively few steps to convert a single raw material into finished products, was largely a matter of mechanizing two processes, spinning and weaving. Effecting a similar transformation in the automobile industry, which involved thousands of steps to make and assemble hundreds of parts, required mechanization of many processes, a radically new material handling system and decades of detailed process improvements. The reason, clearly, is that systems with more parts, processes and people also have more avenues to explore for improvement.

2. *Dissemination:* Propagating improvements between systems becomes more difficult as the systems become more dissimilar. For instance, the new factory methods of the First Industrial Revolution were rapidly adopted by the British textile industry[4] but were slower to be translated to other industries. Similarly, the methods of Toyota were widely being adopted in the automotive industry by the early 1990's, but widespread efforts in the healthcare industry did not appear until nearly 20 years later. The reason is that transmission within the same industry can be achieved by copying practices. But propagation to other industries requires distilling practices into principles, communicating those principles and then translating them into new practices suited to new environments.

3. *Motivation:* The fundamental tension between work efficiency and work gratification has led to gains in efficiency at the expense of gratification, leading to an erosion of employee motivation. The negative impacts of efficiency have flared periodically throughout history into labour protests and critical writings. But more importantly, failures to manage these impacts effectively have undermined the success of efficiency initiatives ranging from the earliest efforts at industrial organization to the most recent lean programs.

To characterize the keys to lean success and formulate a framework for communicating them, we must address these challenges. For this, it is worthwhile

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[4] The new textile manufacturing methods took somewhat longer to migrate to the U.S. because of a British ban on transporting machinery designs abroad. But once Samuel Slater (known as the 'Father of the American Industrial Revolution' in the U.S. and as 'Slater the Traitor' in the U.K.) defied the ban and brought the designs to the U.S., they spread rapidly there as well.

to observe that work is a multifaceted activity that engages humans on many levels. We conceptualize this by appealing to the popular *hands-head-heart* representation of the ways humans engage their world. In this model, the hands symbolize the concrete, physical, action-based orientation. The head symbolizes the conceptual, intellectual, theory-based orientation. The heart symbolizes the emotional, empathic, ethics-based orientation. A human being operates on all three levels, in life and at work.

The hands-head-heart (HHH) model has been invoked in a wide range of contexts. In Religion, hands, heads and hearts appear frequently as symbols in many sects. In the behavioural sciences, which gives the three parts more academic labels—behavioural (hands), cognitive (head), and affective (heart)—the HHH model has been elaborated into the cognitive-affective theory of behaviour. In the American 4H youth organization, a fourth H, for 'health', is added to form the basis for a holistic perspective on personal development.

Hollywood is particularly fond of the HHH model because the interaction of the three elements is a wonderful source of dramatic contrast. For example, in the film *The Wizard of Oz,* the Lion (hands) is unable to act without guidance from the Scarecrow (head) and Tin Man (heart). In the TV show *Star Trek,* Captain Kirk (hands) is prone to rash action (kissing the female aliens and punching the male aliens) when not tempered by Spock (head) and Bones (heart). The moral is always that humans do not function well without all three H's.

When viewed through the HHH lens, it is clear that lean implementation, and lean education, suffer from too much hands and too little head and heart. Some firms are like the Lion, unable to take real action because they lack clear direction. Others are like Kirk, energetically flailing away at actions (e.g., 5S and kanban programs) that have little connection to their ultimate goals.

To rectify this and create a theory of lean that more fully engages humans at all levels, we must better incorporate the missing H's—head and the heart. Interestingly, this is equivalent to bringing back the two M's—mura and muri—that have been lost from Ohno's description of lean.

Mura and the Science of Efficiency

Any system that delivers goods or services is a *production system*. All production systems are comprised of *processes*, in which physical and/or human resources are used to convert a set of inputs (e.g., material, energy, information) into outputs (products or services) that satisfy customer orders. Figure 1 gives a schematic illustration of a process that comprises a single stage of a production system. At the most fundamental level, a process matches supply with demand. Before analyzing the behaviour of this elemental model of a process, we consider two examples that show how the model applies to both manufacturing and service settings.

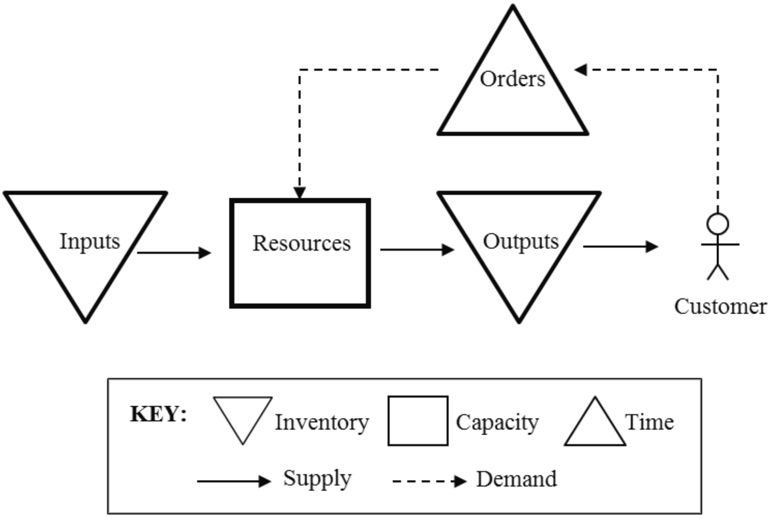

Figure 1: Schematic model of a single process in a production system

As a manufacturing example, consider a system that produces personal computers (PC's). A key component of a PC is the mother board. A step in the production of the mother boards, illustrated in Figure 2, is surface mount assembly, in which electronic components are positioned on the board. The main inputs to the surface mount process are the raw printed circuit boards, components, solder paste and electricity. The resources include one or more pick-and-place machines (chip shooters) and human operators. The outputs are boards with components ('stuffed' boards). The customer is the wave soldering stage, in which a reflow oven is used to solder the components in place. The orders are production triggers, which could be kanban signals in a pull system or order releases in a push (MRP) system. If a demand occurs when there is no inventory of assembled boards available, then the order incurs waiting time.

As a service example, consider a hospital emergency department. An essential step, illustrated in Figure 2, in almost all visits to the ED is an initial examination/consultation with a physician. In this process the inputs vary by patient and can include consumables such as rubber gloves, sanitary wipes, sutures, etc. The resources consist of the physician, the examination room and possibly other equipment and personnel. The patient is the customer in this process and the outputs are the service (e.g., pain relief) and information (e.g., diagnostics) resulting from the examination. If any of the necessary inputs or resources is not available when the patient arrives in the ED, then the patient must wait. Once the patient has completed the examination stage, he/she generally moves to another production stage, such as a diagnostic test or treatment procedure.

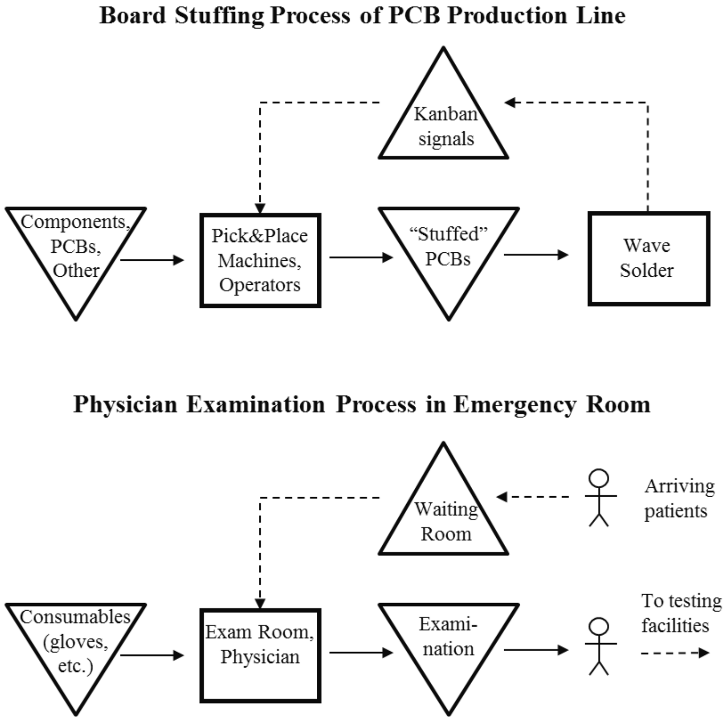

Figure 2: Illustration of processes in a manufacturing (PCB assembly) system and a service (emergency health care) system

A sequence of processes constitutes a *flow*. Note that in a manufacturing system, like the PCB example in Figure 2, the primary flow is of materials through processes. That is, the customer is another process, so that the outputs of one process become inputs of that process. In contrast, the primary flow in a service system, like the emergency room example in Figure 2, is of customers through processes. That is, upon completing service at one process, the customer progresses to another process for service. Real-world production systems often consist of many processes with many different customer and material routings through them. The processes can be geographically distributed and owned by different parties (e.g., as in a supply chain). Coordination of the processes of a production system can be a very complex management challenge. But, ultimately the efficiency of a production system is determined by the efficiency of its individual processes.

The key insight that arises from the process model of Figure 1 is that there are three, and only three, possible types of waste in a production process:

- *Inventory waste*: consists of inputs that are not immediately used by the process and outputs that are not immediately delivered to the customer. In a manufacturing setting, input inventories are labelled raw materials and work-in-process, while output inventories are called finished goods. In a service system there are no output inventories because the outputs are services which cannot be stored.
- *Capacity waste*: results from under-use of capacity human or physical resources. This can be manifested in the form of idle resources or resources that are busy but not producing value for the customer (e.g., making defective products or services).
- *Time waste*: is any delay in delivering a good or service to a customer. This includes both predicted (e.g., time for a patient to get on the surgery schedule) and unpredicted (e.g., time a patient spends in the waiting room waiting to go into surgery).

Inventory and capacity waste represent resources that cost money but do not provide value to the customer. Time waste represents a loss of value to the customer, and hence a loss in potential revenue to the producer.

Note that the seven wastes identified by Ohno map into these three categories:

- Inventory (Inventory)
- Overproduction (Inventory)
- Waiting (Time)
- Transport (Capacity)
- Extra Processing (Capacity)
- Motion (Capacity)
- Defects (Capacity)

The eighth waste, non-utilization of skills, is also a form of capacity waste.

To go beyond mere labelling toward an understanding of the causes of waste, it is useful to apply the common lean practice of envisioning the ideal to the process in Figure 1. In an ideal production process, the following would be the case: (a) customer orders would arrive simultaneously with their associated inputs, (b) processing would start immediately upon arrival of the orders and inputs, (c) resources would be fully utilized at all times, and (d) outputs would be delivered immediately to customers. Any deviation from these will result in inventory, capacity and/or time waste. We label the waste from such deviations *coordination* *waste* because it results from the lack of coordination of orders, inputs, resources and outputs.

But perfect coordination does not by itself guarantee ideal performance. Even if all of the above conditions hold, it is still possible to have capacity waste (e.g., unnecessary processing steps), inventory waste (e.g., work-in-process undergoing non-value-added processing, such as defect creation) and time waste (e.g., delay due to excess processing, such as unnecessary steps or defect creation/correction). We label this *execution waste* because it is a consequence of the individual parts of the process (order processing, input processing, production, output processing), rather than the result of their interaction.

Note, however, that the distinction between coordination waste and execution waste is not sharp. Execution waste can lead to coordination waste. For instance, consider a bank teller who makes a mistake in a customer transaction that takes an extra 5 minutes to correct. The extra time the customer spends in the process is execution waste. But because this delay ties up the teller's capacity, it may result in an inability to provide service when the next customer arrives, causing that person to wait as well. Because the second person's wait is caused by mismatch in timing between capacity and demand, it is coordination waste.

In most production systems, coordination waste comprises the vast majority of waste. This is particularly true for systems in which lean efforts are already under way. Obvious forms of execution waste, such as poorly organized tools that result in excess motion, convoluted layouts that result in excess walking, poor quality control that results in defects and rework, are often amenable to simple remediation (e.g., a 5S system or a rudimentary kaizen event). But once these have been addressed, the remaining coordination waste is much more complex to address.

The essential driver of coordination waste is *variability* or *mura*. In a process like that described in Figure 1, if the rates of order arrival, input arrival or resource processing vary from one another then they will become unsynchronized. Specifically, if an order arrives before the necessary inputs and resources are available, it will wait, causing time waste. If inputs arrive before an order has arrived or resources are ready, it will wait, causing (raw material) inventory waste. If resources finish processing inputs before an order has arrived, the output will wait, causing (finished goods) inventory waste. If the resources are ready before an order and its associated resources are available, then they will be idled, causing capacity waste.

The implication is that if there is variability in the process, there will be waste. But the kind of waste can be managed. To see how, consider the PCB stuffing process of Figure 2. Suppose that pull signals from wave solder (orders) are uneven due to downstream variability in the line (e.g., machine failures, defect correction, operator errors, etc.). Similarly, suppose PCB's and components (inputs) arrive unevenly due to upstream variability. Finally, suppose the processing rate by the chip shooters is uneven due to product variety (i.e., boards with more components take longer to stuff and switching between board types requires changeovers to load different components into the pick-and-place machines). All of these forms of variability will cause mismatches between inputs, orders and resource capacity.

Initially suppose that the work arrives at nearly the maximum processing rate of the process. This implies that the chip shooters will rarely get ahead of the workload and be idle, and hence that there will be very little capacity waste. But there will be time waste because fluctuations in the order rate will cause it to exceed the processing rate periodically, leading to pile ups of waiting kanban cards. Similarly, there will be inventory waste whenever the input arrival rate exceeds the processing rate and causes backups of PCB's and components.

Suppose that we add processing capacity by installing another chip shooter. Because of the extra capacity, the processing rate will now exceed the order rate more frequently, resulting in more idle capacity, and hence capacity waste. But the order rate and input rate will outstrip the processing rate less frequently, so there will be less time and inventory waste.

Finally, suppose we use the extra capacity to stuff PCB's ahead of demand. That is, we build up a stock of assembled PCB's when capacity and inputs are available. (We can generate 'early' orders to accomplish this by increasing the number of kanbans between PCB Stuffing and Wave Solder.) The finished PCB's will allow instant fulfilment of some orders, and hence will reduce time waste. But the extra finished PCB's will constitute more inventory waste.

This example illustrates that we can decrease one form of waste at the expense of increasing another. But as long as there is variability in the process, there will be waste. Because the three types of waste represent gaps between perfect coordination of orders, inputs and resources, which are caused by variability, we call them *variability buffers*. Because all buffers are costly, an essential challenge of lean is to drive out the variability that causes them. But because buffers have different costs in different environments, achieving the right mix of buffers is another key lean challenge.

We can formalize this variability buffering model of lean by letting B_I, B_C and B_T denote the fraction of variability buffered by inventory, capacity and time, respectively, in a process like that shown in Figure 1.[5] Since, by definition, all variability in a process is buffered, we must have $B_I + B_C + B_T = 1$. The set of values of B_I, B_C and B_T that satisfy this condition is given by the triangle in Figure

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[5] Hopp and Spearman (2008) give details on how to quantify variability using coefficients of variability and how to characterize the tradeoffs between inventory, capacity and time, but we omit these because they are not central to our discussion.

3. Each point in this triangle represents a different variability buffering strategy, so we call it the *variability buffering triangle.*

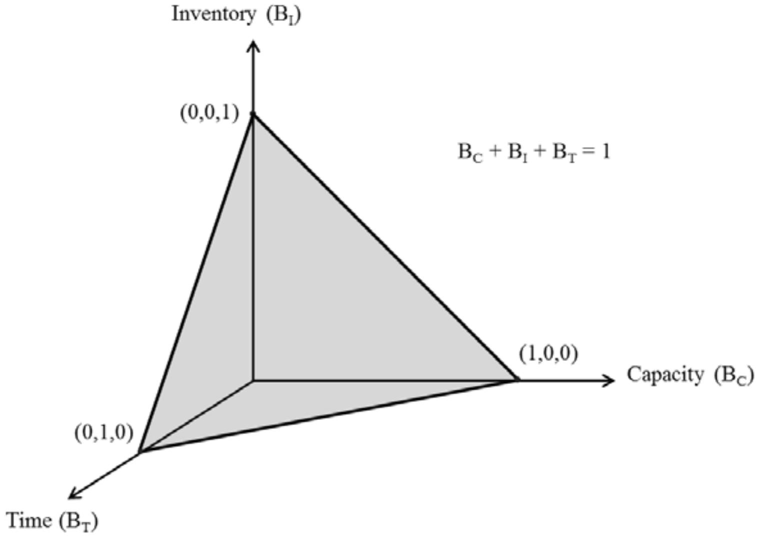

Figure 3: The set of possible variability buffering options

To illustrate how the variability buffering triangle can be used to graphically depict different strategies, we consider three firms in the restaurant industry in Figure 4. (Note that we have dispensed with the three dimensional representation of Figure 3 because we are focusing only on the variability buffering triangle.) McDonald's and Subway are global chains, while Onyx is a high-end, sit down restaurant in Budapest. All three experience variability in customer arrivals (orders), food and supply deliveries (inputs) and rates of preparation and service (resource processing).

Because McDonalds and Subway are fast food restaurants, time buffers (customer waits) must be small. So both restaurants make use of inventory and capacity to buffer the majority of their variability. But they take different approaches to this. McDonalds relies heavily on inventory, particularly during rush periods, by preparing sandwiches and fries ahead of time and holding them on a warming table. Because McDonalds has a higher fraction of its variability buffered by inventory than do the other two restaurants, its strategy is depicted in Figure 4 as lying closest to the inventory vertex of the variability buffering triangle.

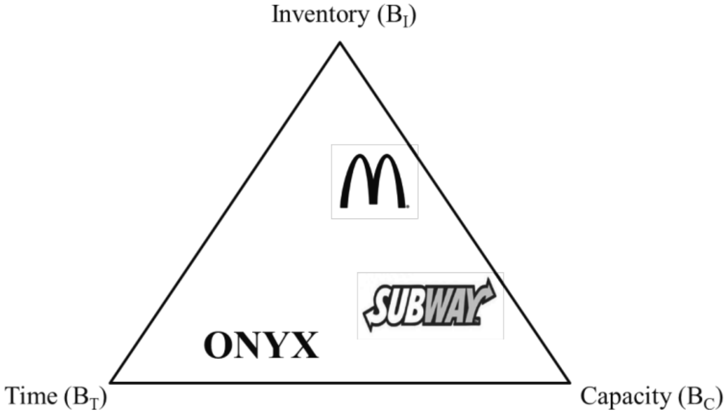

Figure 4: Examples of different variability buffering strategies in the same industry

In contrast, Subway touts customization as a key selling point. To allow customers to choose any combination of ingredients and toppings for their sandwiches, it does not pre-prepare sandwiches. Instead, it holds raw materials and assembles them upon demand. To make this possible without excess waiting time, Subway must have enough capacity (personnel) to respond to spikes in demand. Subway's greater reliance on capacity to buffer its variability is depicted in Figure 4 by its location closer to the capacity vertex than McDonalds.

As a premier (Michelin starred) restaurant, Onyx must offer exceptional quality of food and dining experience to compete in its market segment. Preparing food in advance, as McDonalds does, is inconsistent with the needed quality standard, so an inventory dominated buffering strategy is not appropriate. A capacity dominated strategy, like Subway's, is also not appropriate because highly skilled chefs are too expensive to permit excessive use of them. So Onyx, like all other high-end restaurants, makes use of time as a significant variability buffer, as depicted in Figure 4 by its location closer to the inventory vertex than the fast food restaurants. Customers have to wait, both to get a table and to get served in the restaurant.

Note, however, that in order to be competitive on cost and responsiveness in their respective market segments, restaurants cannot rely on intelligent variability buffering alone. They must also find ways to reduce variability. For example, to facilitate its make-to-stock strategy without excessive inventory, McDonalds reduces variability by limiting its menu and not encouraging customization. To make its assemble-to-order strategy practical without excessive capacity, Subway reduces variability by using an efficient assembly line that standardizes preparation despite customization in the product by allowing customers to specify details of their orders while their sandwiches are being prepared. To support its high quality, high customization strategy without excessive customer waiting, Onyx reduces variability by encouraging customer reservations.

To summarize, implementing lean requires identifying and eliminating both execution waste and coordination waste. Reducing coordination waste requires identifying and eliminating sources of variability, and then finding ways to buffer the remaining variability as efficiently as possible. These improvement efforts must address the many processes that make up a production system, and take into account the interdependencies between them. Hence, to make effective use of lean, an organization must be proficient at both generating ideas for improvements and following through on them.

A failing in many organizations seeking to implement lean, which limits their ability to generate a full range of improvement options, is an over-emphasis on waste reduction and an under-emphasis on variability management. In Ohno's terms, we are not seeing as much muda as we could be because we are not looking for mara. Texts that explain variability in general terms (Hopp and Spearman 2008, Hopp 2008) have been available for some time, and books that discuss it in specialized contexts, such as health care (Jensen et al. 2006, Hopp and Lovejoy 2013) are appearing. But the concept of variability has yet to penetrate lean training materials fully. Until it does, lean education will continue to under prepare practitioners for success.

However, while better training in and application of variability management methods will certainly increase the effectiveness of lean, it cannot by itself close the gap between potential and reality we described earlier. Generating ideas and implementing them successfully also requires the third H (heart), or the third M (muri).

Muri and the Emotion of Efficiency

As used by Ohno, the word 'muri' has a double meaning.[6] First, it means 'overburden' which is important in the physics of flows because highly utilized resources (i.e., resources with very small capacity buffers) are slow to recover from work backups. As a result, highly utilized (or overburdened) resources are particularly sensitive to variability (see Hopp and Spearman 2008: Chapter 8).[7]

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[6] It is not clear whether the dual interpretation of 'muri' as 'overburden' and 'stress' was a deliberate attempt to convey the importance of both to lean, or whether the alliterative appeal of having three 'mu' words—muda, mura, muri—was so strong that it outweighed any potential lack of clarity.

[7] In factory physics terms, we say that 'variability plus utilization causes congestion' to describe the joint impact of variability and utilization on performance. A loose Japanese analog is therefore 'mura plus muri causes muda'.

But muri can also be interpreted as ‘stress’, which conjures up the emotional aspect of work. Viewing stress broadly as a negative reaction to work, it represents the antithesis of ‘heart’, which embodies an emotional engagement with work. So the third H (heart) and the third M (muri) both invoke the human element of lean.

The idea that an emotional connection to work is important to performance is hardly new. Indeed, it is almost definitional that motivation is a prerequisite to good work. In lean, good work means achieving continually improving levels of efficiency. Because people are so manifestly essential to this, the lean literature is replete with references to the human side of performance via terms like ‘respect for people’, ‘eliminating underused talent’, ‘empowerment’, and many others. But as Pfeffer and Sutton (2000) have pointed out, knowing is not doing. In their study of why organizations fail to act on things they know, they noted that many firms substitute talking about a practice for actually using it. Motivational talk is not motivational action.[8]

Motivation has long been a topic of serious research in the fields of human resource management, organizational behaviour and industrial and organizational psychology (see Latham 2007 for a historical overview). While the literature on motivation in work systems is vast and varied, its roots are not far from our crude HHH metaphor. In an early formula, which makes up in simple appeal what it lacks in measurability and nuance, Maier (1955) posited that Job Performance = Ability × Motivation. If ‘hands’ and ‘head’ constitute ability, while ‘heart’ embodies emotion, then this is a version of HHH.

To characterize the role of motivation in a lean system, we make use of the simple diagrams in Figure 5, which indicate: (a) whether the influence of worker motivation on process efficiency is positive, negative or neutral, and (b) whether the reverse effect of efficiency on motivation is positive, negative or neutral. Of the 3×3=9 possible scenarios we lump the six cases in which the impact of motivation on efficiency is either neutral or negative under the heading of *Ignorant Lean*. These cases occur only when the workers lack the ability to improve efficiency, even when highly motivated.[9] But if workers have an understanding of

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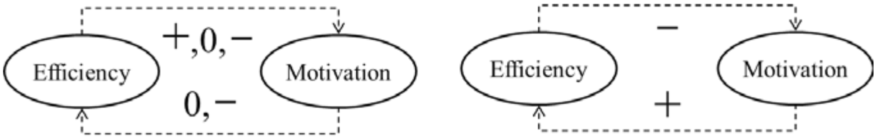
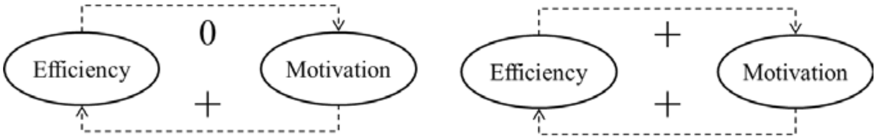
[8] In a comical case of talking in place of doing, a firm for which the author once worked mounted electronic signs flashing motivational messages, such as ‘I love my job’, in a factory that was making little progress on lean.

[9] While it is probably rare that increased motivation can actually make efficiency worse, it is not impossible. Indeed, the author has observed instances where a well-intentioned and motivated workforce instituted a kanban system without any other process improvements, only to find that throughput dropped dramatically. In factory physics terms, the kanban system substituted a capacity buffer (because reduced throughput decreased resource utilization) for an inventory buffer (by regulating work in process via kanban cards). But because the loss of revenue was not made up by savings in inventory costs, this constituted a degradation in efficiency. In these cases, an unmotivated workforce , which did nothing

the levers of lean described earlier, and the tools to address them, they should be able to improve performance if they are motivated to do so. So we will focus on the remaining three cases in which motivation has a positive influence on efficiency.



Ignorant Lean **Negative Lean**



Neutral Lean **Positive Lean**

Figure 5: Interaction between efficiency and motivation in lean systems

Negative Lean represents the classic case of Taylorism gone bad — systems in which improvements in efficiency come at the expense of worker satisfaction. *Neutral Lean* protects workers from the negative effects of efficiency gains, but still does not improve conditions for workers. Finally, *Positive Lean* represents the aspirational situation in which efficiency improvements actually increase worker motivation, which in turn drives further efficiency improvements. Because it will cause business performance and worker quality of life to rise in tandem, Positive Lean has strong economic and ethical appeal.

Since all scenarios in Figure 5 other than Positive Lean are not self-sustaining, improvements in them must be driven from the outside, either by forcing efficiency improvements or by exogenously enhancing motivation. The former can be accomplished by technological improvements or managerial changes effected from beyond the workforce (e.g., by management). The latter can be achieved through heroic hygiene or changes in the workforce itself.[10]

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would have been more effective than the motivated workforce that installed an ill-designed kanban system,

[10] Herzberg et al. (1959) distinguished *motivators* (e.g., interesting work, responsibility, recognition and learning) from *hygiene factors* (e.g., pay, fringe benefits, status, and job security) and argued that the former can increase satisfaction while the latter can only

Henry Ford used both of these approaches in his Highland Park plant. The moving assembly line represented a technological and managerial innovation that dramatically increased efficiency, albeit at the expense of demotivatingly dull work (i.e., Negative Lean). His doubling of wages represented a hygiene tool for incentivising existing workers as well as a recruiting tool for reshaping the workforce.

Of course, hygiene factors, like pay and benefits, are only incentives to the extent to that they exceed the market. Once competitors match them, they cease to be distinctive motivators. A more difficult to copy, and hence more sustainable, source of motivational advantage is the work environment itself. This is the target of Positive Lean.

The intrinsic motivating power of work depends on how that work is structured and organized, which is studied in the academic literature under the topic of *job design* (Grant et al. 2011). The classic model of job design is the Job Characteristics Model (JCM) proposed by Hackman and Lawler (1971). In this model, the core dimensions that determine how a worker perceives a job are: *task significance* (ability to have a positive impact on other people), *task identity* (opportunity for individual to complete a distinguishable piece of work in its entirety), *skill variety* (chance to use a range of capabilities), *autonomy* (discretion on how and when to do the work), and *feedback* (clear and direct information on performance).

Although not widely used in the lean literature, the JCM has been invoked by some authors to argue that lean work may be intrinsically motivating. de Treville and Antonaki (2006) and Cullinane et al. (2013) concluded that lean as a general practice can favourably influence some of the JCM dimensions, particularly skill variety and feedback. They conjectured that the net effect of lean on worker motivation can be positive. However, as they concede and as we noted earlier, there is ample evidence that many past and current lean implementations do not have beneficial consequences for workers.

One reason that lean may fail to live up to the motivational possibilities these studies predict is the manner in which it is implemented. For instance, de Treville and Antonaki suggest that a propensity for excessive leanness, achieved through overly aggressive reduction of system slack (buffers), can reduce opportunities for problem-solving activities and thereby erode the skill variety and autonomy benefits. By their reasoning, a system that starts out as Positive Lean may regress to Neutral Lean or even Negative Lean.

Another reason lean may fail to motivate, offered by Vidal (2007), is diversity of individual preferences. Some workers simply do not regard the addition of

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reduce dissatisfaction. Although subsequent research has challenged this distinction (see Grant et al. 2011), the term 'hygiene' has stuck.

problem solving to their duties as an improvement in their situation. Hopp and Spearman (2008: 389) described this diversity as a fundamental distinction between people who ‘want responsibility, challenge and variety in their jobs’ and others who ‘prefer stability, predictability and the ability to leave their work home at the end of the day’. They likened this distinction to the difference between officers and enlisted personnel in the military. Officers have more responsibility and variety in their work, but it is most certainly not the case that all enlisted people wish to become officers.

The above arguments suggest that Positive Lean is possible, but that attaining it in a given implementation requires careful choice of policies that are suited to the environment and people in question. Identifying appropriate policies with which to create the self-feeding loop between efficiency and motivation shown in Figure 5, requires an understanding of the drivers of efficiency and motivation. We have characterized the former with the science of efficiency (factory physics) and the latter with the psychology of work (job characteristics model). Since both of these are largely missing from lean training materials, a key first step toward Positive Lean must be for lean educators to do a better job in conveying these known results. But the key to making Positive Lean a reality will be for practitioners to incorporate these concepts into their lean production systems and thereby systematically encourage management and labour to seek and implement steps that increase both efficiency and gratification.

To illustrate how this convergence of factory physics and work psychology might work, we offer examples for each of the JCM dimensions.

Task Significance: Lean methods are usually seen as having little to do with task significance since they do not generally change the final product or service (de Treville and Antonaki 2006). But this does not mean that lean policies cannot incorporate steps to improve workers understanding of their impact on customers or the world. Grant et al. (2011) described a call centre employing agents who solicited donations to a large public university, and was able to substantially increase fundraising rates by putting agents in contact with students who benefited from scholarships made possible by the donations. Similarly, Spreitzer, Porath and Gibson (2012) described a janitor in the Cancer Centre at the University of Michigan who found ways to assist patients in the course of her normal duties. While the actions in these two examples were not directly part of efficiency improvements, neither were they in conflict efficiency. Since they indirectly improve productivity via motivation, initiatives like these should be fair game in a lean program. Moreover, as we will see below, there can be similar opportunities within efficiency initiatives to increase awareness of the impact of one’s work on the customer.

Task Identity: The tension between efficiency and motivation in work systems is at least as old as the factory system itself. The specialization principle articulated by Adam Smith and refined by Frederick W. Taylor has long been invoked to narrow tasks in the name of efficiency, but to the detriment of motivation. In search of more rewarding work, Volvo famously bucked the specialization trend in the 1990's with team assembly of complete vehicles in their Uddevalla plant. But, while productivity numbers were competitive, and worker satisfaction was very high, Volvo closed Uddevalla after only four years of operation (Sandberg 2007). Whether the motivational advantages of the Uddevalla system would have offset he efficiency disadvantages enough to enable it to keep pace with traditional assembly plants has been a subject of spirited debate ever since. But subsequent Volvo plants have used Toyota style systems.

Certainly vehicle assembly is a difficult environment in which to fight the legacy of Ford and Toyota. But there are other environments whose conditions make it much easier for task consolidation to facilitate lean. For example, the author once worked for a company that did pre-press production of print catalogues and other high volume printing jobs. The system was originally configured as a typical production line with work divided into steps, such as copyediting, mark-up, proofreading, page layout, colour registration, retouching, page assembly, etc., performed at separate process stations staffed by different operators. But high levels of variability in process times caused very uneven workloads at the stations, resulting in frequent and expensive idling of staff. In addition, communication breakdowns between the customer, the client manager and the people doing the work resulted in errors and rework. To address both problems, the company switched to a system in which a single staff member was responsible for all steps in a job (e.g., section of a catalogue) and also served as the client contact. By 'pooling' the variability in the individual steps, this policy eliminated the inefficient capacity buffers inherent in the underutilized staff, as well as much of the variability due to miscommunication errors. It also had the task identity benefit of giving the staff members a much stronger sense of ownership of their portions of the work.

These examples suggest that task aggregation may pit efficiency against motivation in some systems and enhance both in others. To fairly consider the potential of a Volvo-type system we need be able to account for both the variability reduction and motivation enhancement benefits.

Skill Variety: Rotation of cross-trained workers through multiple tasks represents a happy intersection between reducing variability and increasing skill variety. Of course, this intersection is only happy if workers prefer to rotate. A successful example from the author's experience was that of a firm that manufactured circuit boards. Unable to achieve the needed volumes, the firm was contracting additional capacity at a high cost. A utilization analysis revealed that one operation, Expose, was the bottleneck, while another, Inspect, had excess capacity. Unfortunately, because of equipment limitations, it was not practical to move an Inspect operator to Expose to shift capacity. In one of many problem solving sessions with the operators, an Inspect operator suggested an alternative that was adopted. Under her plan, the Inspect operators took their daily lunch break first. When they returned, they took over Expose. The Expose operators then took their lunch break and returned to finish their shift in Inspect. The result was double lunch breaks in Inspect, where capacity was ample, and no lunch breaks in Expose, where capacity was needed. Multiplied over three shifts per day, facilitated a significant amount of additional production.

The happy part of the story was that, because it allowed them to divide their shifts between two different (and repetitive) tasks, many operators found this to be an improvement in their working conditions. But, since there were more Inspect operators than Expose operators, not everyone had to rotate. The occasional operator who preferred to stay solely in Inspect was able to do so.

Another common opportunity for increasing skill variety in lean systems is problem solving. As we noted earlier, however, not everyone finds this to be an appealing activity. So the goal should be a lean system that engages and rewards people who seek the challenge of developing new work methods, but accommodates those who prefer and excel in more narrowly defined work. In the above mentioned circuit board plant, the problem-solving sessions were structured so that the enthusiasts had significant influence but the uninterested were not pressured to perform. In addition, an important recognition of those who developed better ways to carry out their own work was to make them trainers of others. The prestige of instructing their peers was a highly prized distinction.

These examples suggest that skill variety is a dimension that can provide many options that serve both efficiency and motivation.

Autonomy: Autonomy in the sense of ‘everyone for themselves’ is anathema to lean because it implies both execution and coordination waste. Standardized work is a pillar of lean because it ensures that everyone makes use of the same best methods. But the lack of choice implied by adherence to a specified standard would seem to be in direct conflict with autonomy. Indeed this is the case for a job that is so completely understood that an algorithmic best method can be specified for every aspect of the work. But such situations are rare and are candidates for automation. So most human work has some elements that are amenable to standardized best practices and others that are too ill-understood or idiosyncratic to standardize.[11]

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[11] In Hopp and Lovejoy (2013: 517) we describe the appropriate limits on standardization with the maxim ‘Rationalize the repeatable, but only the repeatable.’

For example, in interviews with 19 physicians in Scotland, Fairhurst and May (2006) found that developing and maintaining patient relationships were a much more significant source of physician satisfaction than were the technical elements of diagnosis and treatment. Since the relationship activities are too individualized to permit standardization, while the technical activities are good candidates for data driven rules, it would seem that the standardization needed for waste and variability reduction can be carried out with little reduction in autonomy over the human interactions. Indeed, this is precisely what has been done at MinuteClinic, where a computer provides a script to be followed by a nurse practitioner in diagnosing and prescribing medication for specific maladies. But, to the undoubted relief of the nurses, the script does not extend to patient conversations.

These examples demonstrate that standardization in lean can sometimes be achieved without undermining motivational autonomy.

Feedback: If asked about feedback in a lean system, most people will say that it is necessary if not automatic. Flows with limited buffers (e.g., limited work in process) require close communication to function. But kanban signals of downstream demand or visibility to a customer's production schedule are not the kind of feedback that impact worker satisfaction. What matters to one's sense of well-being is feedback about one's individual performance. This includes feedback, positive and negative, about both work performance and, where applicable, problem solving contributions.

Losada and Heaphy (2004) studied 60 strategic business unit management teams from a large information processing corporation and divided these into high, medium and low performance based on measures of profitability, customer satisfaction and assessments by superiors, peers and subordinates. They also observed team meetings used to develop annual strategic reports and coded the speech in these meetings into positive and negative statements. They found that positive statements outnumbered negative statements by more than 5 to 1 in high performing teams, but in low performing teams negative statements outnumbered positive statements by nearly 3 to 1. Not surprisingly, people find positive speech more motivating than negative speech.

In lean systems, opportunities where communication can be framed in positive or negative terms are everywhere. Feedback on incoming part quality, coordination of conversations among team members, and commentaries on problem solving suggestions are vital information exchanges, as well as critiques of personal performance. Whether these are motivationally demoralizing or affirming depends on the nature of the communication. By incorporating positive communication techniques (see Cameron 2012) into lean feedback mechanisms, the information exchanges needed to promote efficiency can also promote motivation.

These examples are only a hint of the promise that exists at the intersection of factory physics and job design. They show that some work environments permit motivational improvements to be made without impeding efficiency. Others are amenable to practices that simultaneously improve efficiency and motivation. In still others, it may be possible to apply efficiency measures to parts of the work and motivational measures to other parts, and obtain the benefits of both. Finally, there are unquestionably situations where tradeoffs between efficiency and motivation exist. In order to properly evaluate these and make the best choices for the long run, it is important to recognize that investments in motivation may take longer to pay off than investments in efficiency.

Integration and the Path to Positive Lean

Our understanding of the physics of lean systems is admittedly incomplete and our understanding of motivation in lean systems is even more incomplete. But in both areas, we already know much more than we apply. If we make better use of known principles of factory physics and job design, we can improve the impact of lean implementations right now. To equip organizations to do this, lean educators and consultants must incorporate into their lean training materials: (a) a deeper understanding of the impact of variability on flow and (b) an explicit recognition of the impact of job characteristics (task significance, task identity, skill variety, autonomy and feedback) on worker satisfaction and motivation. To make effective use of these concepts in the workplace, organizations must build into their production management systems: (c) a shift in perspective from a restrictive, muda-centric focus on eliminating problems to an expansive, muda-mura-muri-based vision of building capabilities, (d) a long-term planning horizon to allow investments in workforce motivation sufficient time to pay off, and (e) a structured process of exploration and experimentation that facilitates discovery by managers and workers of practical new ways to make work both more efficient and more rewarding. With these organizations can begin to realize the immense benefits Positive Lean offers to investors and employees alike.

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Wallace J. Hopp is Senior Associate Dean for the Faculty Research; Herrick Professor of Business in the Ross School of Business; and Professor of Industrial and Operations Engineering at the University of Michigan. His research focuses on the design, control and management of operations systems, with emphasis on manufacturing and supply chain systems, innovation processes, and health care systems. His work has been recognized with the 1990 Scaife Award (with Mark Spearman, for the paper with the "greatest potential for assisting an advance of manufacturing practice), the 1998 IIE Joint Publishers Book-of-the-Year Award (for the book *Factory Physics*), the 2005 IIE Technical Innovation Award, the 2006 SME Education Award, and the 2011 Ross School of Business Senior Research Award. Hopp is a Fellow of

IIE, INFORMS, MSOM, POMS and SME, and a former President of the Production and Operations Management Society (POMS). He is a former Editor-in-Chief of *Management Science* and is currently a Senior Editor of *Production and Operations Management*.