CAN INNOVATION BE LEAN?

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Can Innovation Be Lean?

Successfully implementing Lean in complex and novel environments requires some caveats to traditional Lean thinking

Every executive has heard about the importance of Lean. In these competitive times, fat is an unaffordable luxury. But when processes are novel and complex—as in product innovation, research, and new process development—cutting out the fat turns out to be much more challenging. Sometimes managers can confuse fat with muscle, and their efforts at efficiency can lead to an emaciated and uncompetitive organization instead of one that is Lean. So, how can you become efficient without sacrificing effectiveness? How can you cut costs while staying agile? In complex and novel environments, characterized by a need for innovation, is it even possible to be "Lean"? The answer is yes, but the path towards this goal is more challenging in a context of novelty and complexity.

Lean production has been widely viewed as a system of waste reduction and cost control. Pioneered by Toyota, Lean has been implemented in diverse industries, from automotive to construction and healthcare.[1] So often have its virtues been extolled by consultants and experts that many executives believe that merely implementing Lean practices will automatically result in lowered costs. However, Lean practices were pioneered in repetitive production systems characterized by relative stability and certainty, and Toyota made great investments to drive out variation.[2] In contrast, a large number of today's development and production systems, pushed by the need for mass customization and innovation, are characterized by novelty and complexity. Applying Lean in these environments without a deeper understanding creates new problems and tensions and may not deliver expected results. In these environments managers must consider caveats to traditional Lean practices to realize true cost savings.

The Leading Question
How is Lean implementation different for complex, novel, and innovative processes?
Findings:

- Lean does not mean emaciated. Sometimes innovative processes must *add* rather than remove activities to increase the value they provide.
- Value and waste cannot always be attributed to individual activities in a process. Rather, value stems from how activities work together, and waste from how they fail to do so.
- If poorly timed, or taken too far, even Lean practices can be wasteful.
- Rather than trying to reduce novelty and complexity at once, start by focusing on one or the other.

Our research shows that, in contexts with novelty and complexity, a traditional application of Lean practices can lead to the opposite of cost savings. The timing, scale, and extent of Lean implementation become much more critical, and we discuss how. We also show how, in this environment, the value of a complex process differs from the sum of the values provided by its constituent activities. Therefore, the elimination of activities will not guarantee cost reduction, and even greater value may be provided by strategically *adding* activities and buffers instead of reducing them. In the form of five caveats to Lean implementation, we carve out a path that executives and managers can follow to become Lean without compromising innovation.

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About the Research
To understand Lean in an environment characterized by novelty and complexity, we primarily studied the innovative production system for Lockheed Martin's F-22 Raptor.[3] It can be seen as an extreme case of a complex, novel, and innovative product (considering the infrequent occurrence of new military aircraft programs, extremely rigorous requirements, and the integration of cutting-edge technologies) and process design. We interviewed manufacturers, engineers, managers, directors, Lean and Six Sigma experts, and vice-presidents at two locations (Marietta, GA and Fort Worth, TX), as well as the company president. We toured assembly lines and combed through documents and records. Our findings went through several iterations of scrutiny by 30 individuals at all organizational levels of Lockheed Martin, a number of individuals in the U.S. Air Force (USAF), external experts on Lean, and academic peer review.

LIPOSUCTION, OR DIET AND EXERCISE: WHICH PATH TO LEAN WILL YOUR COMPANY TAKE?

> "Classic American business style may be characterized as a collection of projects, going on perpetually, aimed at removing the deficiencies from the operation… But when you remove the things you don't want, you don't necessarily get what you do want."
>
> - Russell Ackoff

To use a physical metaphor, the quest for Lean can be thought of as striving to get an enterprise "in shape" for competition. Of course, getting in shape includes "leanness." But a focus on simply losing weight will not win a race. A competitive athlete has to improve fitness and skills through a combination of diet, exercise, and practice.

Developing the metaphor, there are two general approaches to getting Lean (Exhibit 1).[4] The first, liposuction, entails looking for "non-value-added" activities and removing them from processes. However, much of the lack of value may not be attributable to discrete activities. In many cases, lack of value stems less from doing unnecessary activities and more from doing *necessary* activities with the *wrong inputs* (such as faulty information or bad assumptions) and then having to *redo* them (the "garbage in, garbage out" problem). Truly removing waste ("anti-value") requires a holistic, system perspective. Diet and exercise, the second approach to leanness, focuses on becoming competitive and healthy rather than on short-term, surface appearances. It focuses on maximizing value and recognizes that a truly Lean and agile athlete may actually weigh more than their emaciated counterpart. The same is true of organizations. Applying Lean principles without thought is analogous to following the liposuction path to Lean. The difference between these two paths can be the difference in an organization distinguishing fat from atrophied muscle and becoming emaciated rather than competitive.

While they may seem to be cheaper on paper, emaciated processes do not have the critical capability to sense, respond, and adapt to problems, innovations, and changes. In fact, there are numerous examples of problems caused by organizations that focused too heavily on efficiency, from nuclear and naval accidents, to California's energy woes in the 1990s, to the U.S. healthcare system. General Motors' reliance on just-in-time (JIT) deliveries, a key component of many Lean implementations, made its entire North American operations more vulnerable to a labor strike at a single parts plant in 1998 – ultimately resulting in lost production of 576,000 vehicles and an estimated $2.2 billion in lost sales.[5] JIT was also blamed for production stoppages at Japan's automakers following recent earthquakes. Even failures in some of NASA's Mars missions have been attributed to the pressures of focusing on "faster and cheaper."

Exhibit 1. Two Paths to Lean

LIPOSUCTION	DIET AND EXERCISE
• Is effective only when there are large, easy-to find chunks of fat • Can compromise the recipient's overall health • Does not address the system that produced the fat in the first place • Does nothing for the recipient's strength, agility, or flexibility • Is relatively cheap and quick • Focuses on "doing less" • Measures fat removed • Focuses on reducing waste	• Is effective for removing waste throughout • Improves recipient's overall health and fitness • Improves the system that produced the fat in the first place • Improves recipient's strength, agility, and flexibility • Requires ongoing investment and commitment • Sometimes requires "doing more" • Measures fat and muscle (realizing that muscle may "weigh" more) • Focuses on improving value
Examples: • Just seeking out and eliminating "non-value-added activities" • Uninformed cutting of activities or reduction of headcount • Demolishing an old process and jumping to a new, "Lean" process without first verifying that it is feasible and effective in context	**Examples:** • *Adding* activities that increase the likelihood of getting a valued result • Ensuring activities and processes consume and produce the right work products at the right time • Investing in increased understanding of how work really gets done and how value flows

TRADITIONAL LEAN VERSUS NOVELTY & COMPLEXITY

Lean practices assume stable and routine processes, high-volume production, a stable learning curve (costs decrease with repetition of jobs), a stable workforce, and the elimination of buffers such as waiting time and inventory. Unfortunately, the predictability required by traditional Lean systems is not seen in processes of novel and complex environments, particularly in the context of innovation (Exhibit 2). In an age of increasing product functionality, diversification, customization, and change, novel and complex processes are more the norm.

Exhibit 2. Traditional Lean Versus Novel & Complex Environments

ENVIRONMENTAL CHARACTERISTICS

TRADITIONAL LEAN	*NOVEL AND COMPLEX*
- Stable and routine processes	- Dynamic and unfamiliar processes
- High-volume production	- Low-volume production
- Stable workforce	- Workforce turnover
- Traditional learning curve	- Learning curve disruptions
- Eliminated buffers	- Purposeful buffers

Novelty represents a lack of familiarity with a kind of work. For innovative companies, novelty or newness of processes is an ongoing feature. Novelty increases the uncertainty within activities (how to do them). *Complexity*, in turn, is a characteristic of an entity that contains a large number of varied parts that interact in varied ways. Complexity increases uncertainty and instability by making it less clear how one activity might affect other activities. Taken separately, complexity and novelty can each drive uncertainty and instability in a process. Together, they amplify each other's effects. Unfortunately for those seeking to get Lean, they are two of the salient characteristics that define innovative projects and processes. They can also be increased by Lean implementation itself.

Novelty, or lack of familiarity with process activities and their relationships, is reduced through learning. Similarly, learning can help overcome the perceived complexity of process activities and their relationships, although it is a different type of learning process. Learning theorists distinguish between first-order and second-order learning.[6] First-order learning is informal, where the workforce finds smarter ways of doing work through repetition, experience, and experimentation. Second-order learning is where management provides training, invests in new technologies, or changes policies, processes, or product design. First-order learning tends to occur in stable, routine processes, whereas second-order learning is often observed in less well-defined contexts.

First-order learning has been modeled primarily with learning curves that relate cost reductions to increases in the cumulative number of units produced. Increasing production volume gets one "down the learning curve" faster. Conversely, low volume—which often accompanies novel and complex environments—retards first-order learning since activities occur less frequently. Learning curves also assume that the workforce will be relatively stable and thus able to benefit from repetition.

The implementation of Lean practices in a context of novelty and complexity more closely aligns with the definition of second-order learning. While first-order learning seeks to reduce novelty, second-order learning accepts it. Second-order learning can be disruptive, even to the point of causing sizable, if temporary, negative effects on performance. The reason is that there can be downtime while workers become familiar with new activities, tools, technologies, or procedures. That is, putting down an axe to learn how to use a chain saw causes a temporary loss of productivity—and disrupts learning about using the axe. Of course, the expectation is that the changes brought by Lean will more than make up for the temporary loss of productivity, but this may not always be the case, particularly when there are so many disruptions caused by other changes and discoveries as well.

In contexts of low complexity, first-order learning can drive out novelty by revealing knowledge about previously uncertain tasks. The simpler scope permits first-order learning of new tasks and thus creates stability. When complexity is high but novelty low, second-order learning enables Lean implementation when there are few disruptions. This also creates stability. However, when novelty and complexity are both high, first-order learning cannot gain traction because second-order learning creates too many disruptions due to high novelty (Exhibit 3). When stability cannot be maintained, the implementation of traditional Lean is hampered. We also note that the four quadrants shown in Exhibit 3 provide a framework to understand variations of environments relative to novelty and complexity. Although different environments will indeed have differing levels of novelty and complexity, this framework offers a roadmap to better understand the impact of these variables. Later we will suggest strategies for moving from Quadrant 4 towards Quadrant 1, which is best achieved by first moving to Quadrants 2 or 3 rather than by attempting to reach Quadrant 1 directly.

Exhibit 3. Learning Effects in Novel and Complex Environments

NOVELTY	Low COMPLEXITY	High COMPLEXITY
High	**QUADRANT #3** ***First-Order Learning Drives Lean*** • Control of complexity permits first-order learning about new tasks, creating stability • Process stability enables the handling of further novelty as it emerges	**QUADRANT #4** ***Traditional Lean is Hampered by Volatility caused by Novelty and Complexity*** • Lean implementation magnifies novelty and complexity • Unanticipated, emergent effects • First-order learning cannot achieve traction because of instability
Low	**QUADRANT #1** ***Traditional Lean Thrives*** • Stable and repetitive processes • Conventional learning curves	**QUADRANT #2** ***Second-Order Learning Drives Lean*** • Fewer disruptions with lower novelty support stability • Second-order learning enables Lean implementation

PROBLEMS WITH LEAN IN THE F-22 PRODUCTION SYSTEM

To help illuminate some of these issues and challenges, we draw upon the case of the F-22 program, where applying traditional Lean practices in a context of novelty and complexity initially caused numerous problems and then generated many helpful lessons. In response to cost-cutting pressures, the F-22 program embarked on significant, Lean-motivated improvements and brought in world-class experts to point the way. While the program and its stakeholders expected a significant return in variable cost savings from these efforts, unforeseen problems emerged and the savings did not come until much later than anticipated. In fact, the new approaches initially increased costs.

Tight production requirements, complex parts, and new technologies created an extreme case of novelty and complexity. Constant product and process design changes increased novelty and disrupted first-order learning. Ironically, the implementation of Lean practices caused even more disruptions, replacing familiar activities with unfamiliar ones. For example, the new, Lean processes and tools implied new activities, and when these new practices caused unforeseen problems and issues, the corrections implied still more new activities. This chronic novelty caused production process uncertainty and instability and made it difficult to establish a working "baseline" process against which to compare proposed improvements.

THE RIGHT PATH TO LEAN

Considering Lean as meaning competitive, not emaciated—and exploring the sources of the problems on the F-22 program during its Lean implementation, the corrective actions taken, and the lessons learned—leads to five caveats for Lean implementation in innovative environments characterized by novelty and complexity. Although these caveats can also apply to traditional Lean implementations, their application is especially critical in novel and complex environments. As noted earlier, traditional Lean environments have the luxury of being repetitive, stable, and more thoroughly understood. Novel and complex environments do not.

Caveat #1: Implement Lean at a time of least disruption. The cost-reduction benefits of Lean will vary depending on the timing of its implementation, even to the point where these benefits may actually switch to become costs. The reason is that Lean implementation itself is a disruption, one that increases novelty as well as other disruptive factors. Certainly the timing of Lean implementation is important in all environments, even in traditional Lean. However, in an environment with an already novel and complex product or process, the timing of implementing Lean practices is especially critical, as recovery from this disruption is more difficult in this environment. Therefore, implementation must be planned even more carefully. On the F-22 program, the changes should have occurred either during product and process design or *after* the product and process designs had stabilized—not during production ramp up, while the product design was still changing. The interactions between existing activities and improved (but novel) ones are often dynamic and complex. When activities and their interactions are volatile, attempting to make them Lean, which involves premature standardization, is counter-productive.

While Lean seeks stability, the period during Lean implementation does not provide it to an existing process. In the F-22 program, when a significant change to the process was made, planners mistakenly assumed that the original learning curve would remain intact. However, the improved—yet novel and unproven—processes prevented achievement of the expected learning and cost reductions. Lean practices, the very changes intended to reduce the cost of the process, ironically contributed to its novelty and instability because of their *timing.*

The F-22 program sought to document and standardize work, but did so prematurely. Early emphasis on certain Lean practices, such as 6S (sort, straighten, shine, standardize, safety, and sustain), visual management, and mistake-proofing—before the overall product design and production process had stabilized—turned out to be wasteful. It is not worth optimizing the placement of tools and materials until it is clear that such are the appropriate tools and materials to use. The right work must be determined before mechanisms are instituted to help do the work right. *If implemented at the wrong time, even Lean practices can be wasteful.*

Caveat #2: Understand the complexity of a system before attempting to improve it. In complex processes, a seemingly small change in one area has the possibility of leveraging a much larger change in the whole process (e.g., Lorenz's famous "butterfly effect").[7] Emergence, the phenomenon of certain behaviors arising from the interactions between a system's components, will often perturb a process in unforeseen ways, causing instability. On the F-22 program, the large number of product components, manufacturing activities, people in various organizational groups, tools, and the relationships between them all engendered complexity. As a result, changes—even supposed improvements—to certain activities had unforeseen, emergent effects on other activities and the overall process.

A complex product, organization, and/or tool set will amplify the complexity of an associated process. Complexity has several implications for operations. First, it increases production costs directly through what have been called complexity costs, the costs of performing a heterogeneous rather than a homogeneous set of activities.[8] Second, complexity can increase uncertainty and instability. As activities increase their internal complexity and variety, and as they relate to each other in increasingly complex and varied ways, workers have less certainty about the effects that can emerge from the overall process. Moreover, if activity interactions are difficult to identify – e.g., due to the novelty of the situation – then it becomes even more likely that some important interactions will be overlooked.

Caveat #3: Do not improve a process or activity in isolation. A common but dangerous assumption in many Lean implementations is that a process or activity can be improved in isolation, with its inputs taken for granted. But what works at the activity level may not always work the same way at the process level. Scale matters. And making an individual activity Lean may not even matter to the overall process.

The F-22 program exhibited several cases where Lean practices and results on a local level failed to scale up to the entire production system. For instance, the program assumed a step-function improvement in the learning curve as the result of Lean implementation. This assumption was based on actual savings from an earlier, detailed analysis of individual activities, in which "game film" of workers doing an activity had been used to improve the work sequence. Although the learning curve benefits had been verified at the activity level, the same effects did not materialize for the overall production system. While the earlier Lean implementations had looked at relatively stable activities for which a pattern had already been established, other activities and the overall process were more novel, complex, and dynamic. The pilot implementations had addressed individual activities with relatively stable inputs, whereas the overall process had numerous activities changing within, altering their outputs and thus other activities' inputs. Furthermore, the Lean implementation was conducted by a number of different teams. Each team would make improvements to its own area, but, because of the dependencies among various activities in the process (complexity), many of these improvements caused changes (chronic novelty) for other activities.

Thus, the benefits of specific Lean practices will vary depending on the scale and interconnectedness of the process and activities to which they are applied.

Furthermore, while it may be attractive, possible, and even seemingly simple to make changes to many low-level activities as part of Lean (the so-called “low hanging fruit”), doing so may not provide any true dividends to the overall process. Unless those low-level activities are on the critical path or in some other way constraining the overall process (e.g., the “bottleneck”), then making them faster may not have a desirable effect on the overall process. (Indeed, it may even have the undesirable effect of allowing them to build up work-in-process inventory more quickly.) It’s analogous to driving a car through a crowded city at rush hour. Upgrading to a formula one race car won’t get you anywhere faster. You’re still stuck in the traffic jam of the overall process. When Lean is implemented by commissioning a bunch of separate teams and sending them off to find improvement opportunities, they usually choose the easy or obvious changes to individual activities rather than stepping back and analyzing the overall process to find high-leverage points. In a novel, complex process, a good model of the overall process may not even exist to help. But getting such a model should precede the “shotgun in the dark” approach of improving individual activities.

Caveat #4: Reconceptualize value and waste. Value and waste (“anti-value”) need to be looked at differently in novel and complex environments. In a context of novelty and complexity, it is much more difficult to pinpoint waste. Much of the waste in a process is attributable to the interactions between activities, not just the activities themselves. Novelty and complexity exacerbate this effect. In other words, value is an emergent property of a complex process that cannot be completely decomposed and allocated to the process’s constituent actions and interactions. Attempting to do so—for example, by labeling some activities as “value-added” and others as “waste”—can cause serious problems.

The hallmark of Lean is the minimization of waste. However, the F-22 program encountered a problem in determining what was in fact wasteful. The large number of interrelationships in a complex process leads to the possibility of a seemingly small change in one area leveraging a much larger, emergent change in the whole. To insulate against such effects, most complex, novel processes contain a variety of time, capacity, and inventory buffers. Diminishing these buffers effectively magnifies the interdependencies by increasing the ability of one activity to affect another. For example, the F-22 program’s complexity and novelty obscured a number of what turned out to be important interrelationships in the product design and manufacturing processes. Many of the changes made to implement Lean practices had unforeseen effects, because many of the buffers that had restrained these problems in the past had been tagged as wasteful and removed. For instance, the elimination of hard tooling and “tool tries” caused problems that the introduction of new tools, such as CAD systems and laser alignment, proved insufficient to prevent. Occurring together, many of these problems took a long time to diagnose and correct, requiring searches through complex webs of interactions. As it turned out, much of the supposed waste in the production process was not really “fat” but rather currently unused muscle.

There were numerous casualties of the efforts to remove supposedly “non-value-adding” activities. One was the elimination of the development of a detailed manufacturing plan, which was also seen as a “waste.” Another was the elimination of safety stock, which existed for use in the event of mistakes, such as drilling in the wrong place, the part not fitting exactly, or the part getting damaged. Since it took at least 6-12 weeks to receive many replacement items, any mistake or misfit—which are common in novel and complex processes—played havoc with the production schedule. The results were unexpected costs and delays.

To further illustrate the point, an activity can switch from being wasteful to valuable simply depending on the quality of inputs it receives. A completely efficient, effective, and value-adding activity will produce bad outputs and fail to add value if it receives bad inputs (such as mistaken data or assumptions)—the "garbage in, garbage out" problem we mentioned earlier. Hence, a process's value is determined by activity interrelationships, which stem from the inputs activities need and the outputs they produce. Value is a function of what is accomplished overall rather than of what is done locally.

In the F-22 production system, some activities were rendered less valuable because their inputs changed, such as when some self-locating parts were eliminated to cut costs. So-called "hard tooling" was seen as a waste without understanding that its output helped specify location and alignment; its elimination therefore created unforeseen chaos. Another problem stemmed from the complexity of putting many novel parts together, where slight deviations from their planned sizes accumulated or "stacked up." As a result, the overall assembly was off, even though each part seemed correct according to its computerized design data. A great deal of time was then spent chasing potential culprits. As it turned out, the fabrication system was not precise enough for complex, contoured, composite parts. While each point on an individual part would fall within its specification limits, this happened only when the other points were at extreme positions. What caused this problem? Essentially, designers and manufacturers had each done their (value-adding) activities with different assumptions. That is, they did the right jobs, but with the wrong inputs. Novelty increased the likelihood that some of their assumptions would be wrong, and complexity made the cascading effects of their faulty assumptions difficult to trace.

Interactions alone will not explain all of the value or waste in a process, any more than just the activities will. Value is an emergent property of a system. Therefore, the elimination of activities will not guarantee cost reduction, and Lean may provide even greater value by incorporating some aspects of Agile production. Agile production, a system for designing processes to enable greater responsiveness to markets and customers, often goes hand-in-hand with Lean. However, Agile often requires adding, rather than eliminating, activities and capacity to enable such responsiveness. In novel and complex environments, greater uncertainty and instability increase the proportion of "just in case" and "sense and respond" activities and resources (that enable agility) in a value-maximizing process. If new activities added to a process serve to catch problems before they cascade through many other activities or increase confidence in the desired result, then they are adding value, despite their characterization as "non-value-adding" by traditional definitions of Lean. *It is essential to measure the value of a process as a whole, rather than merely as the sum of the values provided by its constituent activities, because the value of a system is different than the sum of its parts.*

Caveat #5: Do not push Lean to the point of negative returns. Lean implementation represents an investment, one that is expected to return a reduction of waste. However, an overabundance of Lean practices could potentially fail to recoup the investment. The F-22 program attributed its lack of immediate cost reductions to the unforeseen costs of Lean implementation itself. In hindsight, it is evident that the program carried some Lean practices too far. Ironically, the very Lean practices which had proven helpful in certain areas and to certain extents were sometimes carried to the point of being wasteful themselves.

Executive support, the importance of which has been noted by many researchers and experts on change management, played a surprising part in this. Some executives fail to distinguish between a pragmatic vision of Lean and a romantic one, which entails idealistic goals and slogans such as zero inventories, zero defects, and lot sizes of one.[9] Senior managers without much day-to-day involvement on the shop floor are apt to find "romantic Lean" appealing, envisioning it as a quick fix to problems and cost cutting. Believing Lean to be a relatively simple concept, they expect quick results from lower-level managers and workers. However, the Toyota Production System took decades to develop. Making Lean changes on the shop floor or production line without dealing with the reasons for the supposed waste can quickly lead to chaos, delays, and missed deliveries. Hence, top management support must not be dogmatic and must be qualified by asking tough questions with the overall situation in mind.

The F-22 program exhibited strong support for Lean from top management and other key stakeholders. However, this support was so strong that managers sometimes failed to count the costs of Lean implementation. If making tools, lighting, and other workplace enhancements more available to workers is a good thing, at what point does more of a good thing stop being so good? The F-22 program past this point in several areas, such as in the installation of additional equipment on the production line. Each "Lean team" was incentivized to show improvements in localized metrics, even if this caused issues for other activities and did not ultimately add value to the overall process (see Caveat #3). The lesson here is that implementation of Lean practices will exhibit negative returns past a point, which depends on the prevailing uncertainties and instabilities. Therefore, care must be taken to ensure that Lean practices do not go too far, and that changes really imply improvements to the value of the overall process rather than just the values of specific activities. Even top management support of Lean implementation can contribute to pushing Lean implementation into the region of negative returns.

REPOSITIONING YOUR ORGANIZATION FOR LEAN

While these five caveats (summarized in Exhibit 4) are well supported by ample evidence from the F-22 program, they are also corroborated by our decades of experience and involvement with a number of firms in a variety of industries. As an extreme case of novelty and complexity, the F-22 program made it easier to isolate some of the challenges and observe their effects. However, we find the five caveats to generalize well beyond the production of military aircraft to touch all kinds of processes characterized by novelty and complexity—and even some without as much of either. More research is needed, but the early results are compelling. So what have we learned that will apply to a variety of organizations? And how can it be applied? Considering how to navigate the four quadrants in Exhibit 3 helps.

Organizations characterized by novelty and complexity operate in Quadrant 4 of Exhibit 3, but traditional Lean operates in Quadrant 1. For organizations in Quadrant 4, getting Lean is problematic due to the compounding effects of novelty and complexity, which keep Lean from gaining traction. The ideal environment for Lean implementation is Quadrant 1. However, by definition, highly innovative environments are not positioned there. While the effects of novelty and complexity are intertwined and difficult to isolate, we can still identify two general approaches to helping an innovative organization "get lean" while avoiding some of the problems experienced by the F-22 program and others. Rather than trying to move directly from Quadrant 4 to Quadrant 1, the best bet for these organizations is to first shift toward either Quadrants 2 or 3 (Exhibit 5). Repositioning in one of these quadrants can mitigate the effects of the environment, as only one variable is of high impact, rather than both. Once in either Quadrants 2 or 3, the organization can move to Quadrant 1 through either first or second-order learning.

Among other things, Caveat #1 helps play a role in handling novelty. Hence, it can be especially helpful in getting from Quadrant 4 to Quadrant 2 (as well as in getting from Quadrant 3 to Quadrant 1). In an environment with both high novelty and complexity, timing the Lean implementation at a point of stability, when the basic activities in the process are somewhat stable and better understood, can allow the organization to turn its focus on the overall process and understanding and managing its complexity. Without the disruptions caused by high novelty, second-order learning can help the Lean implementation gain traction and thrive in a complex environment.

Exhibit 4. Summarizing Five Caveats to Lean Implementation

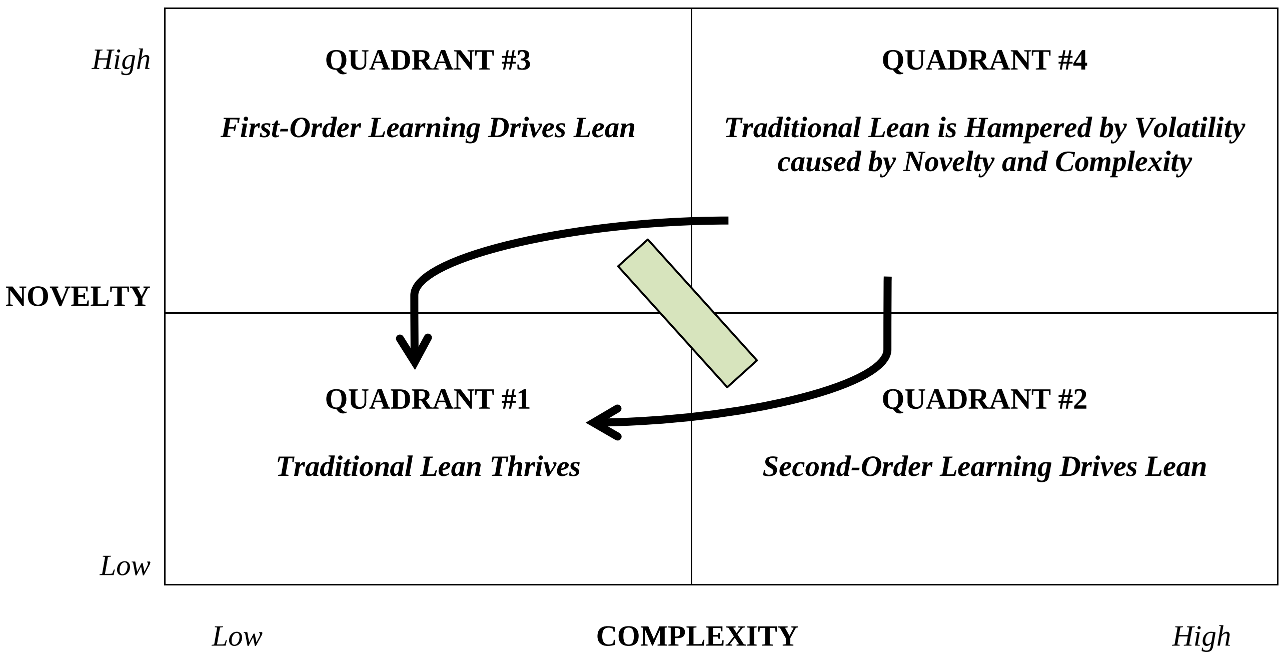
Caveat #1:	**Implement Lean at a time of least disruption**
	Do not add Lean changes to an already fluid situation. Make sure the process works before trying to improve it.
Caveat #2:	**Understand the complexity of a system before attempting to improve it**
	In a complex system, small changes can have large, unanticipated consequences. Make sure the process's activities and interactions are understood before trying to change them. This may involve identifying a few high-leverage opportunities for small changes to have large, positive effects.
Caveat #3:	**Do not improve a process or activity in isolation**
	The things that make a stable, well-understood (not novel), low-level activity Lean will often not work the same way at the process level. Making activities super-efficient (like a formula one race car) is not helpful if they remain stuck in the traffic-jam of the overall process.
Caveat #4:	**Reconceptualize value and waste**
	Measure the value of a process as a whole, rather than merely as the sum of the values provided by its constituent activities, because the value of a system is different than the sum of its parts. Some supposedly "non-value-adding" activities may actually be muscle, not fat.
Caveat #5:	**Do not push Lean to the point of negative returns**
	Too much Lean is not a good thing. When individual teams are incentivized to implement Lean wherever they can, they are prone to passing the optimal point. When managerial support for Lean implementation is strong but uninformed and dogmatic, this situation is even more likely to occur.

Meanwhile, Caveats #2 and #3 serve to help temper complexity through efforts to understand the overall process and the improvements that make sense in light of it, even though individual activities remain novel and perhaps dynamic. Hence, these caveats are especially useful on the path from Quadrant 4 to Quadrant 3 (as well as from Quadrant 2 to Quadrant 1). With fewer compounding effects of complexity, novelty can then be addressed more directly through first-order learning. First-order learning will drive out novelty, enhance stability, and expose the most appropriate targets for Lean implementation.

Caveats #4 and #5 mitigate ill-advised attempts to move directly from Quadrant 4 to Quadrant 1. Caveat #4 refocuses the value metrics on the process as a whole rather than on its individual parts. Lean is not about just minimizing cost, lead time, or waste. Lean is about maximizing value of the entire system. In complex systems, the whole is greater than the sum of its parts, and simply looking for parts to remove can cause unforeseen problems. Caveat #5, in turn, calibrates executive priorities and expectations, permitting management to become an asset in the Lean implementation process rather than a liability that dogmatically pushes implementation to the point of negative returns.

Essentially, an organization must decide which path to take from Quadrant 4 to Quadrant 1. Attempting to move from Quadrant 4 to Quadrant 1 directly—i.e., trying to scale the barrier shown in Exhibit 5—is a bad idea in most situations. Although not impossible, such an attempt will likely create inefficiencies and compounding effects of novelty and complexity, as seen with the F-22. However, by tackling novelty and complexity one at a time, an organization can better focus its efforts and temper its expectations.

Exhibit 5. Repositioning Your Organization for Lean



So we have two basic paths from Quadrant 4 to Quadrant 1. Which path is better, travelling via Quadrant 2 or Quadrant 3? This depends on several factors, such as stability of the product design and stage of product life cycle, the skills and capabilities of the workforce, and the expectations of management. Most importantly, however, it depends on the degree of novelty and complexity present in the environment. A wise prioritization of paths may be driven by which of the two variables is least dominant, and therefore, easier to overcome. As we noted earlier, the Quadrants provide a representational framework intended to help managers navigate implementation of Lean in this environment, however, in actuality these are continuous variables. Identifying what constitutes a high degree of novelty and complexity, and which of the two is easier to overcome, is a key to prioritizing paths to move from Quadrant 4 to either Quadrant 2 or Quadrant 3. Once in Quadrants 2 or 3, a company can move much more efficiently to Quadrant 1 via first- and second-order learning.

The F-22 program probably would have been better off with the path through Quadrant 2 because of the timing. Most of the F-22's Lean implementation occurred well into the production process, right at the point where workers were trying to get the hang of the novel activities. It would have been better to wait until these individual activities were stable before changing the process. On the other hand, if the F-22 had thought about it earlier, they might have had an opportunity to take the path through Quadrant 3 to understand the overall complexity of the process and set that up correctly. Then the workers would have been able to focus on stabilizing and learning about the individual activities.

Toyota essentially alternates approaches by either producing a new product design in a proven production system (proceeding via Quadrant 3, learning about novel tasks within an already understood process) or making major changes to a production system while it operates on a proven product design (changing the overall process complexity while maintaining well-understood individual activities). They do not want to do both at once, because then the complexity and novelty are compounded and isolating problems becomes too difficult.

The five caveats affect and apply to executive leadership, management, engineers, and production workers. They are also applicable to all environments, including traditional Lean. They are not the only things that matter in Lean implementation. However, ignoring them in a context of novelty and complexity—and probably in other contexts as well—is especially likely to result in surprising problems and a failure to achieve desired results.

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Should an organization implement traditional Lean practices blindly in innovative processes and operations characterized by novelty and complexity? We believe that is a foolish strategy. In novel and complex environments it is easy to confuse "fat" with "muscle" and to become emaciated rather than Lean. Applying Lean practices with these caveats can get the best out of an established philosophy while maintaining your organization's innovation capabilities.

NOTES

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