A Hospital Is Not Just a Factory, but a Complex Adaptive System—Implications for Perioperative Care

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Many methods used to improve hospital and perioperative services productivity and quality of care have assumed that the hospital is essentially a factory, and therefore, that industrial engineering and manufacturing-derived redesign approaches such as Six Sigma and Lean can be applied to hospitals and perioperative services just as they have been applied in factories. However, a hospital is not merely a factory but also a complex adaptive system (CAS). The hospital CAS has many subsystems, with perioperative care being an important one for which concepts of factory redesign are frequently advocated. In this article, we argue that applying only factory approaches such as lean methodologies or process standardization to complex systems such as perioperative care could account for difficulties and/or failures in improving performance in care delivery. Within perioperative services, only noncomplex/low-variance surgical episodes are amenable to manufacturing-based redesign. On the other hand, complex surgery/high-variance cases and preoperative segmentation (the process of distinguishing between normal and complex cases) can be viewed as CAS-like. These systems tend to self-organize, often resist or react unpredictably to attempts at control, and therefore require application of CAS principles to modify system behavior. We describe 2 examples of perioperative redesign to illustrate the concepts outlined above. These examples present complementary and contrasting cases from 2 leading delivery systems. The Mayo Clinic example illustrates the application of manufacturing-based redesign principles to a factory-like (high-volume, low-risk, and mature practice) clinical program, while the Kaiser Permanente example illustrates the application of both manufacturing-based and self-organization–based approaches to programs and processes that are not factory-like but CAS-like. In this article, we describe how factory-like processes and CAS can coexist within a hospital and how self-organization–based approaches can be used to improve care delivery in many situations where manufacturing-based approaches may not be appropriate. (Anesth Analg 2017;125:333–41)

In 2015, hospitals accounted for 32% of US health care expenditures.[1] The most expensive and complex part of the hospital is perioperative services, which account for about 27% of discharges and 52% of inpatient spending[2] and represent a significant opportunity for productivity improvement. Many methods used to improve hospital and perioperative services productivity and quality of care have assumed that the hospital is essentially a factory,[3] and therefore, that industrial engineering and manufacturing-derived redesign approaches such as Six Sigma and Lean can be applied to hospitals[4] and perioperative services just as they have been applied in factories. However, a hospital is not a factory but a complex adaptive system (CAS)—more like a market or an ecosystem or a community than a factory. The hospital CAS itself has many subsystems, with perioperative care being an important CAS for which concepts of factory redesign are frequently advocated. In this article, we argue that applying only factory approaches such as lean methodologies or process standardization to complex systems such as perioperative care could account for difficulties and/or failures in improving performance in care delivery.

A modern factory typically produces a finite number of finished products (with multiple variations within each production line) using highly specialized fixed assets (machinery, software) and skilled labor specific to the manufacturing of the products it produces. In general, the factory captures economies of scale by serving the largest possible market while keeping the scope and focus of production as narrow as possible. At a given market size, the narrower the scope of activity, the lower the scalable fixed cost base, the more efficient the factory, and the more powerful the economies of scale.

A hospital presents the opposite case. A middle size hospital "produces" on average the equivalent of perhaps 10,000 "independent products" (surgeries and other procedures) using highly flexible, multipurpose assets, and it is limited to serving a market within a 50- to 200-mile radius. The relevant range within which the hospital can exploit scale in any given product is narrow, and the instances in which scale economies are even possible are very limited. While it is reasonable to say that manufacturing-like processes exist inside a hospital, that is not the same thing as saying a hospital is a factory or even that a hospital operates

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like a factory. A hospital is not like a factory in that its scope of activity is too broad, its overhead structure is too multipurpose, and the volume of any single product is too low to enable it to operate like an assembly line or a batch-processing line.

If a hospital is not a factory, or not even like a factory, then what is it? We believe a hospital is a CAS. Whereas a factory can be designed and redesigned "from the top down," a market, an ecosystem, or a community tends to self-organize "from the bottom up." Whereas a factory can generally respond as intended to process mapping and redesign, the market or ecosystem or community can often resist attempts at redesign and can in turn produce unpredictable, unintended, and even perverse responses when external pressure to change is introduced. It is an inherent property of such self-organizing CASs that they cannot be deliberately reengineered using manufacturing-based approaches.

Several claims follow:

1. Within hospitals, factory-like processes exist where performance can and must be improved using manufacturing-based redesign approaches such as Lean;
2. Surrounding these factory-like processes are concentric adaptive systems and subsystems that will not respond as intended to manufacturing-based redesign approaches;
3. A different set of approaches, what we might call "self-organization–based" approaches (derived from what we now understand about the behavior of CASs), can be used to improve performance; and
4. To be successful in today's health care market, hospital executives should differentiate between factory-like processes and CASs and apply specific implementation processes accordingly.

The literature has yet to develop a unified theory or consensus on synthesizing the CAS ideas and transferring them to social structures and organizations (such as hospitals). Within health care, the CAS framework has been written about relative to nursing[5]; e-public health information systems, e-home care systems, telemedicine systems, and e-disease management systems[6]; trauma[7]; the emergency department[8]; patients at large[9]; efforts to scale up health care in developing countries[10]; and hospitals.[11]

In this article, our focus is on the distinction between the factory-like process and the CAS as it pertains to perioperative care delivery, because this is where the need to reduce cost is urgent as we are moving toward value-based payment models with payment tied to up to 90 days after surgery, and where the results from applying manufacturing-like process redesign to reduce cost have been inconsistent and sometimes unsatisfactory.[12] First, we discuss the various models of production and factory-like processes and how they apply to the hospital system and more specifically to the perioperative setting. Then, we detail a CAS and self-organizing behavior and describe where and how these concepts coexist in hospitals and in the perioperative setting. Finally, using our own case study examples from Kaiser Permanente and a contrasting, previously described example from the Mayo Clinic, we illustrate how the factory-like processes and CASs coexist within the hospital, and how self-organization–based approaches can improve performance in care delivery.

Why should we anesthesiologists care about these concepts and how they impact the way we implement changes in the perioperative period? The answer is that we are all increasingly engaged in trying to improve efficiency in this setting; understanding factory-like approaches and a CAS thinking will help us move the field forward and will get us involved in these care redesign processes. Concepts such as the Perioperative Surgical Home[13,14] and Enhanced Recovery After Surgery[15,16] models of care have been recently proposed to optimize the way perioperative care is delivered. Integrating concepts such as factory-like and CAS models of production can help clinicians to better understand how each clinical care redesign project could be approached in this setting and how Perioperative Surgical Home or Enhanced Recovery After Surgery can be best implemented.

MODELS OF PRODUCTION AND FACTORY-LIKE PROCESSES IN HOSPITALS

It is important to have a good understanding of the different existing manufacturing models to comprehend how hospitals and perioperative services fit within this construct. Classically, traditional manufacturing models of production include:

1. Job shop
2. Batch process
3. Assembly line
4. Continuous flow process

Many factories that make discrete products include both assembly lines and batch processes operating in series and/or in parallel. Plants that produce steel or refine petroleum or chemicals tend to follow continuous flow models. Hospitals most closely resemble the job shop, since each job is performed individually, case-by-case, with little or no standardization or scalability achievable as seen in many complex clinical cases where there are high variances.

The Focused Factory Model by Wickham Skinner

In 1974, Wickham Skinner[17] from the Harvard Business School introduced the "focused factory" as an optimized production system with the narrowest possible scope focused on its target market:

> A factory that focuses on a narrow product mix for a particular market niche will outperform the conventional plant, which attempts a broader mission. Because its equipment, supporting systems, and procedures can concentrate on a limited task for one set of customers, its costs and especially its overhead are likely to be lower than those of the conventional plant. But, more important, such a plant can become a competitive weapon because its entire apparatus is focused to accomplish the particular manufacturing task demanded by the company's overall strategy and marketing objective.

As we discuss below in the first case study, the Mayo Clinic applied the focused factory model to the standard, high-volume, low-risk cardiac surgery cases as opposed to the complex cardiac surgery cases.

A "Plant Within a Plant" by Clayton Christensen

More recently, Clayton Christensen et al[18] combined the job shop and the focused factory models when he described the traditional hospital as housing 2 fundamentally different business models simultaneously—a "solution shop" model for diagnostic "jobs" and a "value-adding process" model for treatment "jobs." The "solution shop" operates case-by-case like a professional services firm, with assets and skills specialized in problem solving. The "value-adding process" model operates more like a factory, again, with performance gains associated with scale and focus. Christensen et al[18] posits that no organization can operate successfully under more than one model. The 2 models within the traditional hospital should therefore be embodied in 2 different organizations—a "solution shop" diagnostic delivery organization and a "value-adding process" treatment delivery organization—albeit with the option to create a "plant within a plant."[18]

An Emerging Theory of Manufacturing by Peter Drucker

Peter Drucker[19] proposed an emerging theory of manufacturing consisting of 4 principles and practices emanating from different sources and converging toward a new integrated view of production and business. Those 4 principles and practices include:

1. Statistical quality control
2. Manufacturing cost accounting
3. Modular organization
4. Systems design

Drucker[19] argued that the gradual integration of these components is replacing older, more fragmented notions of manufacturing design and leading to more dynamic, responsive production systems.

These and other conceptual frameworks have been applied in various contexts in hospitals (Lean and Six Sigma), and many have become standard management practice over time.[20]

In care delivery, we believe the factory-like clinical programs that lend themselves to manufacturing-based redesign methods are well suited for low-variance lines and present several common characteristics:

1. High volume of relevant cases—This allows for the realization of the benefits of standardization and reduction in process variation;
2. Homogeneous subset of patients—From the superset of relevant cases, a medically homogeneous subset (few and/or mild comorbidities) can be identified around which a process can be designed allowing for specialization and scalability; and
3. Mature care processes—Knowledge—in the form of evidence-based guidelines, pathways, and protocols—enables standardization of clinical care.

The number of instances in care delivery in which all 3 of these conditions are met is, in most hospitals, modest. The list will vary somewhat depending on the hospital's size, operations, and patient base, but the standard surgical programs such as total joint replacement, hysterectomy, and routine coronary artery bypass graft (CABG) or carotid endarterectomy, without significant comorbidities, among others, are the main candidates for applying manufacturing-based thinking to improve performance.

CASs AND SELF-ORGANIZING BEHAVIOR IN HOSPITALS

With the exception of mathematics, which is common to both, the study of manufacturing processes and the study of complex systems emerged from different sets of disciplines. Manufacturing process was the concern primarily of engineers and cost accountants, and had its origins in the rationalization of manufacturing into mass production in the age of Henry Ford and Frederick Taylor.[21] By contrast, the scientific study of complexity grew out of a gradual convergence of the work of physicists, computer scientists, economists, sociologists, and biologists working in parallel on separate problems and discovering, over time, common patterns in their insights.[22–24] The 2 areas of inquiry yield very different perspectives on the organization and activity of hospitals.

For our purposes, the attributes of CASs pertinent to inpatient care delivery are mostly based on high-variance lines:

- They are composed of independent agents (actors/decision makers in the system) whose behavior is based on physical, psychological, or social rules that are independent of the system in which they operate;
- Because agents' needs or desires, reflected in their rules, are not homogeneous, their goals and behaviors are likely to conflict. In response to these conflicts, agents tend to adapt to each other's behaviors;
- Agents are intelligent. As they experiment and gain experience, agents learn and system behavior changes accordingly over time;
- Adaptation and learning tend to result in self-organization. Behavior patterns emerge rather than being designed into the system; and
- There is no single point of control. The behaviors of CAS can usually be more easily influenced than controlled.[25]

These attributes are common to all CASs and distinguish them from both factory-like processes. A comparison of the characteristics of factory-like processes and those of CASs is shown in Table 1.

The fundamental difference between the 2 models derives from the autonomy of independently acting agents in the system. Factory-like processes can be deliberately designed while CASs tend to self-organize. Factory-like processes can be optimized for efficiency while CASs adapt; therefore, the relevant measure of their performance is their agility defined as the speed and ease with which they adapt and learn as context changes. The structure of a factory is more or less linear—serial or, in some cases, parallel—and, it should be added, hierarchical and, if desired performance is to be achieved, relatively rigid and static. The structure of a CAS is a network—nonlinear, heterarchical, and dynamic. Agents in a factory-like process have little or no autonomy beyond process or organizationally prescribed rules and roles. Agents in a CAS have stubbornly high levels of autonomy, independent of or often in spite of the desire of authorities of one sort or another to impose and exercise

Table 1. Comparison of the Attributes of Factory-Like Processes and Complex Adaptive Systems

	Factory-Like Processes	Complex Adaptive Systems
Design	Top-down design	Self-organization
Performance imperative	Efficiency	Agility
Relationship structure among agents	Serial and parallel	Network
Autonomy of agents	Minimal or none	Unlimited
Influences on agent behavior	Process- and organization-based rules, command, and control	External and institutional rules unlinked to process and organization; incentives, resources, and constraints
Direction	Management	Leadership
Cost structure	Low variable cost; naturally scalable	High variable cost; hard to scale
Examples	Oil refinery, car manufacturing, large-scale production units	Stock market, political organizations. social networks, Internet

control. Those authorities in a factory-like process can exercise influence through traditional levers of management and formal control. In a CAS, influence over agent behavior may be achieved through leadership. Finally, the cost structure of a factory-like process tends to be characterized by low variable cost of repetitive activity, enabling scalability. In contrast, a CAS will tend to have high variable costs and a low degree of repetition, because it is always changing and adapting. It is therefore difficult to scale.

A confounding issue in endeavoring to differentiate between a factory-like and a CAS-like process is the polysemous property of the term "complex." We refer to complex systems, but also complex procedures and complex patients. The simultaneous use of the term complex in these 3 contexts does not imply that what is "complex" is always CAS-like and what is noncomplex is always factory-like. The differentiating variable, rather, is volume or scale for which a level of predictability and standardization in care can be developed. If a given care process, or a subset thereof that is internally homogeneous, has sufficient volume to practically enable standardization in design, then it can be said to be factory-like. Hence, CABG (without comorbidities), which is a complex procedure by anyone's definition, has become factory-like due to sheer procedure volume (although that volume is now declining steadily each year). By contrast, preoperative evaluation and risk assessment of medically complex patients is necessarily CAS-like because of the inherent heterogeneity of the patient population that makes it difficult to achieve volume and scale for an internally homogeneous group.

The point of this comparison between CAS-like and factory-like systems is not to imply that one form is more or less desirable than the other. Rather, some systems in the hospital are intrinsically factory-like and others are intrinsically CAS-like. Attempts to modify a CAS using manufacturing approaches run a high probability of failure because a CAS cannot be controlled in a top-down manner. Each form requires an appropriate approach to improvement, and the 2 approaches must necessarily be different—manufacturing-based approaches for factory-like processes and self-organization–based approaches for CASs.

We believe perioperative care delivery by its nature possesses the attributes of CAS. It is composed of independent, intelligent agents (eg, surgeons, anesthesiologists, consulting specialists, hospitalists, intensivists) who have different professional norms, guidelines for practice, clinical obligations, and social or professional networks within the institution. The perioperative procedures they perform are diverse, and the combinations of agents involved in any given procedure varies by procedure as well as by the characteristics of the patient. The patient, in turn, can vary widely by demographics, medical history, comorbidities. Additionally, the relationship between physician agents and the hospital/administration can be an important factor in determining the care delivery. In many hospitals, the lines of reporting are not clearly defined or are highly matrixed, and the organizational culture can influence interactions between various agents. The result is a complex system that behaves unpredictably and resists attempts at control by design.

System behavior is determined largely by the balance of competitive or conflicting goals, on the one hand, or collaborative, cooperative, coordinated goals on the other. The overall approach to improving functional behavior in the CAS model is to shift the balance in behavior toward the "generative" (collaboration, cooperation, and coordination) and away from the "adversarial" (competition and conflict). The underlying assumption from a design perspective is that, because actual processes are so complex, varied, and unpredictable, they cannot be anticipated and "designed-in" a priori; instead, the system must rely on the generative behavior of the agents to adapt, improvise, and fill in gaps—that is, to "self-organize" around the tasks that the system exists to perform.

The coexistence of the 2 forms within the hospital is illustrated in the Figure. In general, the structure of organization in the hospital is a complex network, with agents connected across multiple dimensions. In the figure, agents are represented as nodes, or spheres, and the lines connecting them represent the relational links between them. Selected high-volume, scalable surgical programs that are factory-like—for example, total joint replacement, CABG, and carotid endarterectomy—are shown in red and represented as linear processes. These factory-like processes exist in a CAS milieu consisting of many complex adaptive subsystems. Among these are complex surgical cases to the right and medical cases to the left. The top of the figure represents the patient intake subsystems, including the emergency department for many medical and selected surgical cases, and the preoperative assessment and planning subsystem for elective surgical cases. At the bottom of the figure are the discharge planning and postdischarge care subsystems. The Mayo and Kaiser cases discussed below provide evidence

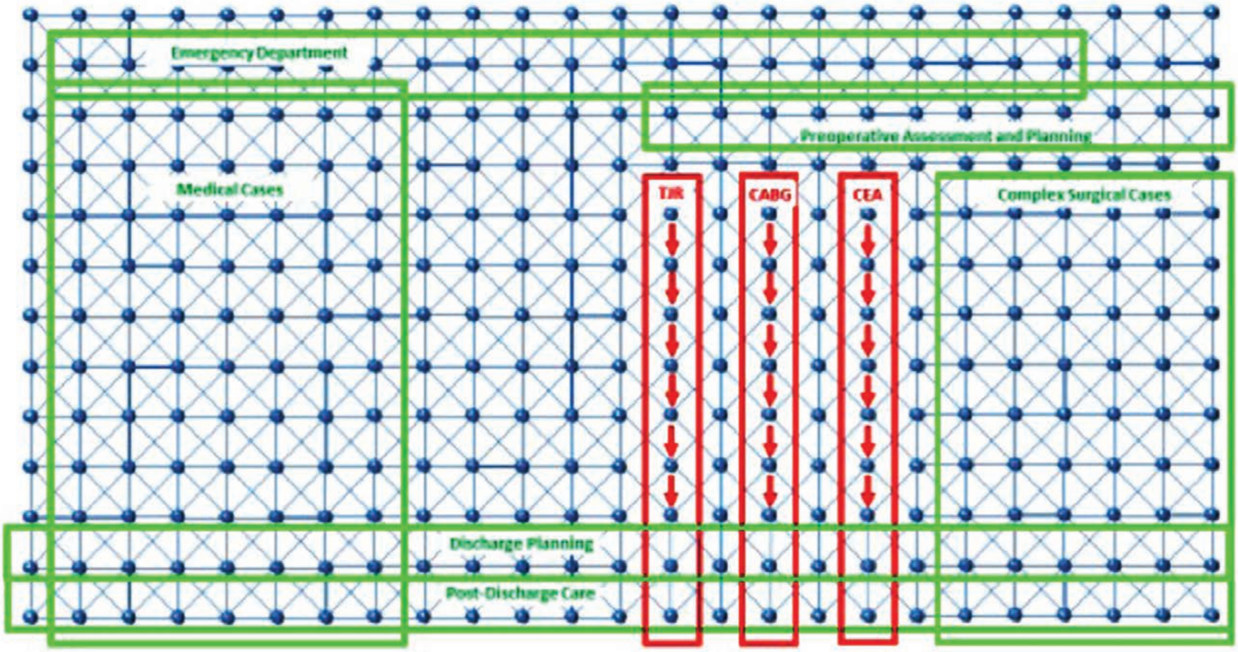

Figure. A conceptual model of the hospital as a complex adaptive system. The coexistence of the 2 forms within the hospital. In general, the structure of organization in the hospital is a complex network, with agents connected across multiple dimensions. In the figure, agents are represented as nodes, or spheres, and the lines connecting them represent the relational links between them. Selected high-volume, scalable surgical programs that are factory-like—for example, TJR, CABG, and CEA—are shown in red and represented as linear processes. These factory-like processes exist in a CAS milieu consisting of many complex adaptive subsystems. Among these are complex surgical cases to the right and medical cases to the left. The top of the figure represents the patient intake subsystems, including the emergency department for many medical and selected surgical cases, and the preoperative assessment and planning subsystem for elective surgical cases. At the bottom of the figure are the discharge planning and postdischarge care subsystems. The Mayo and Kaiser cases discussed below provide evidence as to why we have characterized these subsystems as factory-like or CAS-like. CABG indicates coronary artery bypass graft; CAS, complex adaptive system; CEA, carotid endarterectomy; TJR, total joint replacement.

as to why we have characterized these subsystems as factory-like or CAS-like.

CAS DESIGN PRINCIPLES

Inducing generative behavior—collaboration, coordination, and cooperation—is achieved by following a set of established principles, what we might call "CAS principles." These have been defined generically in the literature but not, to our knowledge, previously adapted specifically to health care delivery.[26,27] We draw especially on the work of Morieux and Tollman,[26] which we have adapted for the specific applications to health care delivery. Some of the key CAS design principles are as follows:

- Define the system and work context within it. Define the relevant boundaries of the system (or subsystem) and identify the agents operating within those boundaries. This is very important, because adaptive behavior tends to develop in "clusters" within larger organizations, rather than across organizations generally.[28] In the context of managing care across the continuum, Porter and Teisberg[29] introduced the Integrated Practice Unit, defining a system that can self-organize around the management of a specific condition. In inpatient surgical care delivery, the boundaries extend from the beginning to the end of the surgical episode. Relevant agents include at least the primary care physician, surgeon, anesthesiologist, hospitalist, intensivist, radiologist, any consulting specialists, and potentially case manager, discharge planner, and pharmacist. In orthopedics and related procedures, this might also include physiatrist, physical therapy, and pain management. Work context consists of agent goals, resources, and constraints. In the perioperative context, resources include a range of types of data, information and knowledge, training, clinical technology, and support staff. Constraints include but are not limited to organizational and institutional rules and obligations that create organizational rigidity and limit or concentrate power.
- Increase the total quantity of organizational power. Power in an organization, a combination of resources and constraints, is the ability of one agent to solve another agent's problem.[30] Increasing the total quantity of organizational power means distributing the resources necessary to solve problems more broadly and removing constraints that otherwise prevent the application of those resources to problem-solving behavior. Of particular importance are constraints that isolate subsystems from one another or that inhibit interaction between subsystems. In the context of perioperative care delivery, increasing the total quantity of power means expanding the scope and availability of data and analytics, cross-training staff, and removing rules and other constraints that increase the division

of labor or inhibit generative problem-solving across subsystems.

- Reinforce integrators. A particular class of agent in a CAS is the integrator. The integrator is defined not by position, role, title, or credentials but by his or her differential propensity to exercise organizational power to solve the problems borne by other agents. Specific approaches to the management of resources and constraints can be designed to reinforce integrators in those roles as well as elsewhere in the system. These can include financial incentives, to be sure, but also changes in work context (resources and constraints) that increase organizational power, such as administrative or other staff support, information technology (IT) infrastructure, expansion in span of control, promotion, etc.
- Create feedback loops. In general, in a CAS, causes and effects are separated in space and time and interdependencies among participants are hidden, creating unpredictability and uncertainty in the work environment. This principle has been elaborately articulated in the literature on the learning organization.[31] In perioperative care delivery, symptoms of this kind of system behavior include same-day cancellations, high complication rates, and high readmission rates. One way to mitigate this condition is to design ways to expose interdependencies by creating feedback loops within a single team that evaluates patients before surgery and plans and delivers care postsurgically (a consequence of proper definition of the system and work context, above).
- Build and reinforce leadership. Integrating all these principles is leadership, perhaps the most critical component in the successful performance of any CAS.[32] Leadership has a particular meaning in the context of a CAS, and it is not to provide charismatic, transactional, or transformation leadership in the conventional sense. Rather, it is precisely to be able to implement CAS principles to modify system behavior.[33]

LESSONS FROM LEADING PROVIDERS: TOWARD A COMBINED IMPROVEMENT APPROACH

We selected 2 examples of perioperative redesign to illustrate the concepts outlined above. These examples present complementary and contrasting cases from 2 leading delivery systems. The Mayo Clinic example illustrates the application of manufacturing-based redesign principles to a factory-like (high-volume, low-risk, mature practice) clinical program (see Supplemental Digital Content 1, Material 1, http://links.lww.com/AA/B773).[34] The Kaiser Permanente example, which describes work led by one of the authors of this article (Islam), illustrates the application of both manufacturing-based and self-organization–based approaches to programs and processes that are not factory-like but CAS-like (see Supplemental Digital Content 2, Material 2, http://links.lww.com/AA/B774). We believe the 2 examples together capture the range of perioperative activities, processes, and programs likely to be encountered in any delivery system.

A general conclusion suggested by these examples is that the "system" in perioperative services appears to consist of at least 3 subsystems:

- Subsystem 1—"Routine" surgical episodes consisting of high-volume, low-complexity procedures performed on otherwise healthy patients where care could be made predictable.
- Subsystem 2—"Complex" surgical episodes consisting of low-volume, complex procedures and/or cases involving complex patients with severe and/or multiple comorbidities and much higher risk compared to routine surgical episodes.
- Subsystem 3—Segmentation of cases into "routine" or "complex."

These are consistent with the scheme presented in the Figure, in which subsystem 1, the only 1 of the 3 that is factory-like, is represented in red, and subsystems 2 and 3, being CAS-like, are represented in green.

Case Study 1—The Mayo Clinic Focused Factory Model

Implementation of the focused factory model at the Mayo Clinic improved performance and reduced cost for the "routine" surgical episodes for which it was designed (subsystem 1).[34] This subsystem comprises two-thirds of cardiac surgery patients at the Mayo Clinic carefully selected using predetermined criteria similar to those in subsystem 1.[34] It is not clear what the impact of implementing the focused factory was on the care of the remaining third of "complex" surgical episodes (subsystem 2) because they were excluded from the factory model. In addition, the focused factory approach depends on reliable patient segmentation (subsystem 3), but the focused factory itself could not design a reliable segmentation process. The focused factory delivered reductions in length of stay in the hospital overall as well as individually in the intensive care unit, postoperative care unit, and operating rooms.[34] This approach was associated with better 30-day outcomes, including reductions in pneumonia, sepsis, and renal failure. Further, it was associated with a 15% reduction in mean cost of care for the patients.[34] The team concluded that "creating a focused-factory model within a solution shop," by applying industrial engineering principles and health IT tools and changing the model of work, was very effective in both improving quality and reducing costs.[34]

In our view, and as seen in the Mayo Clinic example, the focused factory model was successful within subsystem 1—the domain of high-volume, homogenous, and clinically mature, knowledge-rich programs—but it is not an approach that can be widely applied to all patients or the other subsystems. Such focused factory-suitable programs exist in the hospital within a larger milieu that is not factory-like but seemingly unmanageably complex. And our argument here is that the reason for this opacity is that most care delivery in the hospital is not factory-like, and viewing it through a manufacturing lens will always render it obscure, mysterious, and unresponsive to improvement efforts. The right way to look at what happens in the hospital outside of and surrounding the focused factory is as a self-organizing CAS. For details, see Supplemental Digital Content 1, Material 1, http://links.lww.com/AA/B773.

Case Study 2—The Kaiser Permanente CAS Approach

At Kaiser Permanente, both the preoperative segmentation of patients (subsystem 3) and the care of complex patients (subsystem 2) incorporated principles of self-organization that sharply contrast with the manufacturing-based approach of Mayo's focused factory. Their primary goal was to reduce its surgical cancellation rate and avoid delays in scheduling of surgeries. In its analysis of work context, the Kaiser Permanente team identified a key resource that limited performance to be information on managing comorbidities. Access to this resource had generally been limited, from a practical perspective, to the relevant specialists (eg, only endocrinologists consistently had ready access to the most up-to-date knowledge about managing surgical patients with diabetes mellitus). Information asymmetry with respect to guidelines and the information contained within them was reinforced by the professional and institutional origins of the guidelines and, therefore, the barriers between these institutional "silos" in the system. "Insider" specialists were members of the professional societies that produced the guidelines. In practice, this meant that only those "insider" specialists had the power to manage such patients optimally—a problem borne by the surgeon, anesthesiologist, or hospitalist.

The Kaiser Permanente system adapted to a change in resource availability—to wit, increased availability of information, and the consequent expansion in the quantity of power—and self-organized. Application of the guidelines was not mandated, but barriers to their appropriate use were lowered through the thoughtful development of order sets in the electronic medical record. This minimized the cost of adjustment to the new guideline system. The net effect was to reduce the information asymmetry among specialists and perioperative medicine (POM) hospitalists, increasing the total power in the system to solve problems associated with the management of comorbidities.

The Kaiser Permanente redesign reinforced at least 3 sets of integrators:

- One set was the surgeons, who were designated to make the initial patient complexity segmentation decisions. While POM staff could revise the segmentation if needed, the surgeon was empowered to use his or her professional judgment, developed through years of training and experience, to make segmentation decisions—as a superior alternative to the failed algorithm-based engineering approach used initially.
- A second set of integrators reinforced in the redesign were the anesthesiologists, who were placed at the center of all surgical patient care, but especially the care of complex patients. A key role of the anesthesiologist in this context was to ensure that all elements of patient evaluation and preparation were thorough and complete, in particular, ensuring that avoidable cancellations were prevented.
- A third set were POM hospitalists, a subset of Permanente hospitalists who were specially trained to evaluate and prepare surgical patients. Traditionally, hospitalists managed medical patients and surgeons managed surgical patients. Through the creation and application of POM clinical guidelines, POM hospitalists were effectively cross-trained to manage medical problems for surgical patients, thus increasing the total power in the system.

Finally, the Kaiser Permanente redesign created numerous beneficial feedback loops. Perhaps, the most important of these is the preassignment of anesthesiologists to each case with enough lead time to oversee the entire episode following patient segmentation—preoperative, intraoperative, and postoperative. This design feature ensures that the anesthesiologist takes responsibility for any deficiencies or errors in the perioperative process from admission before surgery through recovery until discharge. In this case, it is noteworthy that no formal process mapping took place nor were any "hand-offs" designed in. Instead, the "system" was defined, including not only primary care physicians, surgeons, anesthesiologists, and POM hospitalists but also all consulting specialists (eg, cardiology, nephrology, endocrinology, pulmonology) as well as an array of physician extenders and other allied health professionals. The rate of surgical cancellations for medical reasons was approximately 5% before redesign. Now it is about 1.3%, and most of these cancellations are due to acute illness and other unforeseeable causes. A streamlined preoperative process with reduction in the multiple touch points before surgery has reduced wait times and improved patient satisfaction (and also reduced their out-of-pocket costs for copayments for each visit or test). While nearly a 100% of patients were referred to the preoperative clinic previously, this number was reduced to 60% after redesign, allowing timely scheduling of surgeries. These results have not been analyzed statistically and are used for illustrating the process.

The distinction between manufacturing-based approaches and self-organizing–based approaches and their applicability in factory-like processes and CASs is summarized in Table 2. The columns summarize the classification of the 3 perioperative subsystems, the 2 case examples, and the objectives of any performance improvement effort appropriate to the nature and behavior of the perioperative subsystem. Below that the main principles of the 2 improvement approaches are summarized. While each improvement approach falls primarily under the appropriate column, there is some overlap across columns—an acknowledgment that each improvement approach has some applicability broadly and that the 2 approaches are complementary rather than competitive. For details, see Supplemental Digital Content 2, Material 2, http://links.lww.com/AA/B774.

CONCLUSIONS

A hospital is not merely a factory, but it is composed of multiple subsystems that function as self-organizing CAS. Perioperative care is one such subsystem that has features of CAS and factory-like processes. For health system executives seeking to improve the performance of care delivery in

Table 2. Comparison of Improvement Approaches and Process Type

	Factory-Like Processes	Complex Adaptive Systems
Perioperative subsystems	• #1: “Normal” surgical episodes (high-volume, low-complexity procedures and healthy patients)	• #2: “Complex” surgical episodes (low-volume, complex procedures, and/or complex patients) • #3: Segmentation of cases into “normal” or “complex”
Case example	Mayo cardiac surgery	Kaiser Permanente perioperative services
Improvement design objectives	• Minimize process variation • Eliminate waste • Expedite care advancement	• Maximize generative behavior (cooperation, coordination, collaboration) • Break down barriers and silos and expose interdependencies
Manufacturing-based improvement approaches	• Map all processes and subprocesses (eg, vent management, fluid management, central line removal) • Create dedicated focused factory units (ff-ICU, ff-PCU) • Design protocols for each subprocess and unit and bundle them into tiers of meta-orders • Design IT to embody and enforce adherence to protocols and meta-orders	• N/A
Self-organization–based improvement approaches	• N/A	• Increase the total quantity of power (liberalize and systematize information on management of comorbidities, define guidelines for specialist consults) • Identify and reinforce “integrators” (surgeons manage segmentation, anesthesiologists manage episode, POM hospitalists manage comorbidities) • Create feedback loops (assign anesthesiologist at time of scheduling to manage entire episode) • Design IT to maximize access to and “actionability” of information

Abbreviations: ff-ICU, focused-factory-intensive care unit; ff-PCU, focused-factory-progressive care unit; IT, information technology; N/A, not applicable; POM, perioperative medicine.

hospitals, it is essential to recognize the fundamental difference between CAS and factory-like processes. For each, there is an appropriate approach to redesign—self-organization–based approaches for the former and manufacturing-based approaches for the latter. Using either one or the other will render a redesign effort only to be partially effective; to be fully effective, any redesign should utilize both approaches. ■

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