Management of complex adaptive systems requires leadership rather than power, incentives and inhibitions rather than command and control.

Health Care as a Complex Adaptive System: Implications for Design and Management

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For several years, the National Academies has been engaged in a systemic study of the quality and cost of health care in the United States (IOM, 2000, 2001; National Academy of Engineering and Institute of Medicine, 2005). Clearly, substantial improvements in the delivery of health care are needed and, many have argued, achievable, via value-based competition (e.g., Porter and Teisberg, 2006). Of course, it should be kept in mind that our health care system did not get the way it is overnight (Stevens et al., 2006).

Many studies by the National Academies and others have concluded that a major problem with the health care system is that it is not really a system. In this article, I elaborate on the differences between traditional systems and complex adaptive systems (like health care) and the implications of those differences for system design and management.

Complex Adaptive Systems

Many people think of systems in terms of exemplars, ranging from vehicles (e.g., airplanes) to process plants (e.g., utilities) to infrastructure (e.g., airports) to enterprises (e.g., Wal-Mart). In addition, they often think of improving a system by decomposing the overall system performance and management into component elements (e.g., propulsion, suspension, electronics) and subsequently recomposing it by integrating the designed solution for each element into an overall system design.

This approach of hierarchical decomposition (Rouse, 2003) has worked well for designing automobiles, highways, laptops, cell phones, and retail systems that enable us to buy products from anywhere in the world at attractive prices. The success of traditional systems depends on being able to decompose and recompose the elements of the system and, most important, on someone or some entity having the authority and resources to design the system.

Hierarchical decomposition does not work for complex adaptive systems.

Not all system design and management problems can be addressed through hierarchical decomposition. For example, decomposition may result in the loss of important information about interactions among the phenomena of interest. Another fundamental problem for very complex systems like health care is that no one is "in charge," no one has the authority or resources to design the system. Complex adaptive systems tend to have these design and management limitations.

Complex adaptive systems can be defined in terms of the following characteristics (Rouse, 2000):

- They are *nonlinear and dynamic* and do not inherently reach fixed-equilibrium points. As a result, system behaviors may appear to be random or chaotic.
- They are composed of *independent agents* whose behavior is based on physical, psychological, or social rules rather than the demands of system dynamics.
- 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 or competitions, agents tend to adapt to each other's behaviors.
- Agents are *intelligent*. As they experiment and gain experience, agents learn and change their behaviors accordingly. Thus overall system behavior inherently changes over time.
- Adaptation and learning tend to result in *self-organization*. Behavior patterns emerge rather than being designed into the system. The nature of emergent behaviors may range from valuable innovations to unfortunate accidents.
- There is *no single point(s) of control*. System behaviors are often unpredictable and uncontrollable, and no one is "in charge." Consequently, the behaviors of complex adaptive systems can usually be more easily influenced than controlled.

Before elaborating on these characteristics in the context of health care, it is useful to reflect on an overall implication for systems with these characteristics. One cannot command or force such systems to comply with behavioral and performance dictates using any conventional means. Agents in complex adaptive systems are sufficiently intelligent to game the system, find "workarounds," and creatively identify ways to serve their own interests.

The Health Care Game

Consider the large number of players, or "agents," involved in the health care game (Table 1). It is reasonable to assume that each type of agent attempts to both serve its own interests and provide quality products and services to its customers. However, there are conflicting interests among stakeholders, just as there are different definitions of quality. Thus, even assuming that all agents are well intentioned, the value provided by the health care system is much lower than it might be, in the sense that health outcomes may be compromised and/or the costs of delivering these outcomes may be excessive.

Working with the American Cancer Society, we studied the value chain associated with disease detection (Rouse, 2000). Many people naively believe that new detection technology is the key to successful detection. However, unless we address consumer awareness, consumer education, physician education, and consumer advocacy, to name a few of the other components of the value chain, patients may not experience the benefits of new detection technologies. In general, enormous investments in medical research will not substantially improve health care outcomes unless they are introduced with an understanding of the overall system.

In this context, it is useful to look more closely at the two cells in Table 1 that include physicians. One aspect of the overall health care value chain is the process of education and certification that provides trained, licensed physicians. Physician education and training are currently being reexamined to identify

TABLE 1 Stakeholders and Interests in Health Care

Stakeholder	Risk Management	Prevention	Detection	Treatment
Public	e.g., buy insurance	e.g., stop smoking	e.g., get screened	
Delivery System			Clinicians[a]	Clinicians and providers[b]
Government	Medicare, Medicaid, Congress	NIH, Government CDC, DoD, et al.	NIH, Government CDC, DoD, et al.	NIH, Government CDC, DoD, et al.
Non-Profits		American Cancer Society, American Heart Association, et al.	American Cancer Society, American Heart Association, et al.	American Cancer Society, American Heart Association, et al.
Academia	Business schools	Basic science disciplines	Technology and medical schools	Medical schools
Business	Employers, insurance companies, HMOs		Guidant, Medtronic, et al.	Lilly, Merck, Pfizer, et al.

[a]The category of clinicians includes physicians, nurses, and other health care professionals.
[b]The category of providers includes hospitals, clinics, nursing homes, and many other types of testing and treatment facilities.

future physician competencies and determine the best way to provide them. Some of the many stakeholders in this process are listed below:

- Accreditation Council for Continuing Medical Education
- Accreditation Council for Graduate Medical Education
- American Academy of Family Physicians
- American Board of Medical Specialties
- American Medical Association
- American Osteopathic Association (AOA)
- AOA Council on Postdoctoral Training
- Council of Medical Specialty Societies
- Federation of State Medical Boards
- Joint Commission on Accreditation of Healthcare Organizations
- Liaison Committee on Medical Education

This list is representative, but not exhaustive. In addition, many functions of these organizations are state specific, so there might be 50 instances of these academies, boards, committees, and councils.

Even from this brief description, it is apparent that the system of health care delivery involves what we might call networks of networks or systems of systems that involve an enormous number of independent stakeholders and interests, layered by organization, specialty, state, and so on. If this system is approached in the traditional way, decomposing the elements of the system, designing how each element should function, and recomposing the overall system would be overwhelming. Thus we must address health care in a different way and from a different point of view—as a complex adaptive system.

Modeling Complexity

The first consideration in designing an effective health care system is complexity. Figure 1 provides a high-level view of the overall health care delivery network based on recent studies of service value networks (Basole and Rouse, 2008). Note that each node in the network includes many companies and other types of enterprises.

Assessing the complexity of networks involves defining the state of the network, that is, the identity of the nodes participating in any given consumer (patient) transaction. We then use information theory to calculate the number of binary questions that have to be asked to determine the state of the network. Given estimates of the conditional probabilities of a node being involved in a transaction, complexity can be calculated and expressed in terms of binary digits (bits).

Figure 1 summarizes an assessment of the complexity of five markets. Note that the complexity of health care is assessed to be 27 bits. This means that determining which nodes (i.e., enterprises) are involved in any particular health care transaction would require on the

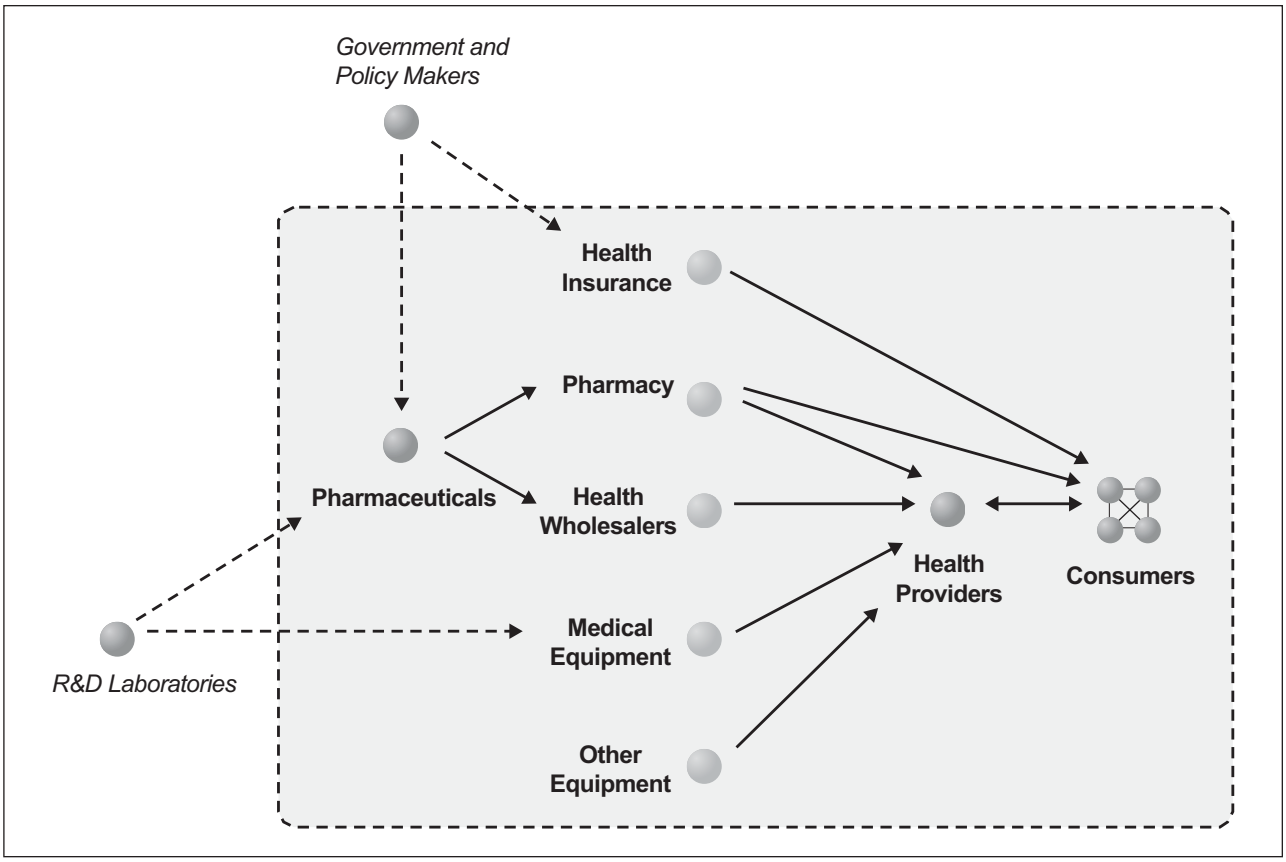

FIGURE 1 A summary of the complexity of five markets in the health care delivery network.

order of 1 billion binary questions. Thus it would be an enormous task to determine the state of the overall health care system.

Notice the ratios of consumer complexity to total complexity in Figure 2. Even though the retail market is the most complex market, the consumer only has to address a small portion of this complexity. The retail industry has been quite successful in managing the complexity of bringing a rich variety of products and services to market without consumers having to be concerned about how this cornucopia arrives on store shelves—or online outlets.

The telecom industry has the worst ratio, as anyone who has tried to call for vendor technical support for a laptop can attest. As a consumer, you need to know much more than you want to know about the hardware and software inside your laptop. A substantial portion of innovations being pursued in this market are aimed at significantly reducing the complexity experienced by consumers. We expect that those who are most successful at reducing consumer complexity will be the winners in this rapidly changing market.

The idea of consumer-directed health care, however, is going in the opposite direction in that it increases complexity for consumers, and possibly for clinicians. Using other markets as benchmarks, we would expect this push to fail, or at least to have limited success. Thus the goal should be to increase the complexity of health care where it can be managed in order to reduce complexity for patients, their families, physicians, nurses, and other clinicians.

The case for decreasing complexity for clinicians is supported in the analyses by Ball and Bierstock (2007), who argue that enabling technologies should support both clinicians' workflow and "thought flow." As long as systems increase clinicians' workload while providing them few if any benefits, the adoption of technology will continue to be difficult.

Design Implications

Our studies of the complexities of markets have led to two propositions for which we have found considerable supporting evidence. Thus we now feel they can be articulated as design principles.

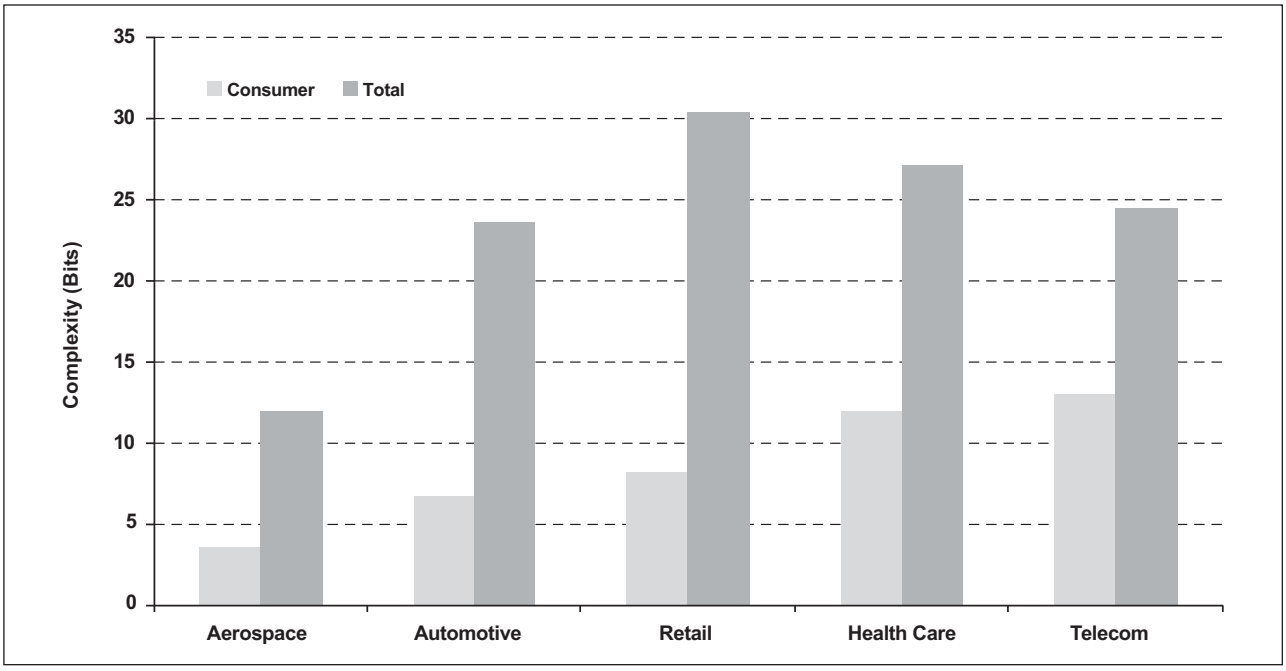

FIGURE 2 Comparative levels of complexity for five markets.

Design Principles

First, the nature and extent of business-to-consumer service value determines business-to-business service value, as well as the value of products and other value enablers. In the context of health care, the value provided to consumers and the payment received for this value determine the financial potential for all of the other players in the network. For example, if consumers do not value and will not pay for a particular test or treatment, none of the participants in this network will be rewarded, no matter how far upstream they are from patients and physicians. This is complicated, of course, when third parties pay for products and services.

The second principle involves the ratio of business-to-consumer complexity to total-market complexity. This ratio tends to decrease as markets mature. The most successful players in a market are those who contribute most to this decrease. To accomplish this, they usually have to increase business-to-business complexity, which often increases total-market complexity. However, this is done in ways that decrease the ratio of consumer complexity to total complexity. This is the strategy that health care should pursue.

As much as possible, complex systems should be designed and not just emerge. Design should begin with the recognition that the health care enterprise—as a system—includes all stakeholder organizations, whether they are customers, partners, collaborators, channels, competitors, or regulators. Starting with this model of the enterprise, the overarching strategy should focus on increasing complexity where it can be managed best and decreasing complexity for end users.

Designing Agile Complex Systems

Most mature enterprises can manage design, development, manufacturing, and sustainment of products and services. Few enterprises can manage economies, markets, competitors, and end users. Put simply, because one cannot control the state of health, education, or preferences of those who seek health care, one cannot assume that they will be able and willing to manage the complexity of the system. Consequently, the design should be focused on managing complexity by providing ways of monitoring and influencing system state, performance, and stakeholders, as elaborated below.

This strategy for managing complexity can be facilitated by also designing an agile enterprise that can readily make decisions to redeploy resources to address opportunities and problems (Rouse, 2006). Achieving agility requires trading off optimization to create the leanest possible enterprise while maintaining flexible resources that can respond to contingencies. The lowest cost health care system would be quite fragile if these

contingencies have characteristics outside of the design assumptions for which the system has been optimized. Recent research indicates that the best way to address this trade-off is to use the construct of system architectures (Rouse, 2007a).

Management Implications

Complex adaptive systems can be designed, but only to a certain degree. For instance, as outlined above, one can design an enterprise-wide information system for such systems (Zammuto et al., 2007). However, these systems cannot be designed in the same sense that a vehicle or industrial process can be designed. This is because complex adaptive systems have strong tendencies to learn, adapt, and self-organize.

Consequently, the task of managing complex adaptive systems becomes a challenge because, in effect, the system keeps redesigning itself. In fact, the construct of "management" has to be viewed differently for complex adaptive systems than for other types of systems. Consider the management philosophy. Traditional systems are managed to minimize cost. Health care must be managed to maximize value.

Value Philosophy

Recent attempts at health care reform have tended, in effect, to pursue the lowest cost acceptable health care for our population. In contrast, we should be pursuing the highest value health care. Value focuses on organizational outputs (or outcomes), rather than inputs. Thus we should emphasize the health states (outputs) of patients rather than the revenues (inputs) of providers.

Value relates to the benefits of outcomes, rather than the outcomes themselves. From this perspective, we should be very interested in productivity improvements attributable to wellness, rather than simply the absence of sickness. In an increasingly knowledge-based economy, the intellectual assets embodied in people are central to global competitiveness and economic growth. A recent report from the Milken Institute shows that the costs of lost productivity are often four to five times greater than the costs of health care (DeVol et al., 2007).

Finally, value implies relevant, usable, and useful outcomes, which require that stakeholders understand and appreciate the management philosophy of the system and its implications. In a complex adaptive system, a lack of understanding and/or appreciation tends to result in "dysfunctional" behaviors by one or more stakeholder groups, although these behaviors may be well intended and even reasonable according to the stakeholders' understanding of the ends being sought and the means appropriate to achieving them.

Organizational Behaviors

The best way to approach the management of complex adaptive systems is with organizational behaviors that differ from the usual behaviors, such as adopting a human-centered perspective that addresses the abilities, limitations, and inclinations of all stakeholders (Table 2) (Rouse, 2007b).

Given that no one is in charge of a complex adaptive system, the management approach should emphasize leadership rather than traditional management techniques—influence rather than power. Because none, or very few, of the stakeholder groups in the health care system are employees, command and control has to be replaced with incentives and inhibitions. No one can require that stakeholders comply with organizational dictates. They must have incentives to behave appropriately.

Not only are most stakeholders in health care independent agents, they are also beyond direct observation. Thus one cannot manage their activities but can only assess the value of their outcomes. In a traditional system, one might attempt to optimize efficiency. However, the learning and adaptive characteristics of a complex adaptive system should be leveraged to

TABLE 2 Comparison of Organizational Behaviors

	Traditional System	Complex Adaptive System
Roles	Management	Leadership
Methods	Command and control	Incentives and inhibitions
Measurement	Activities	Outcomes
Focus	Efficiency	Agility
Relationships	Contractual	Personal commitments
Network	Hierarchy	Heterarchy
Design	Organizational design	Self-organization

encourage agility rather than throttled by optimization focused on out-of-date requirements.

Of course, there are contractual commitments in complex systems, but because of the nature of these systems, stakeholders can easily change allegiances, at least at the end of their current contracts. Personal commitments, which can greatly diminish the risks of such behaviors, imply close relationships rather than arm's-length relationships among stakeholder groups and transparent organizational policies, practices, and outcomes.

Work is done by heterarchies, whereas permissions are granted and resources provided by hierarchies. To the extent that the heterarchy has to stop and ask the hierarchy for permission or resources, the efficiency and effectiveness of the system is undermined. Decision-making authority and resources should be delegated to the heterarchy with, of course, the right incentives and inhibitions.

Finally, as noted throughout this article, because complex adaptive systems self-organize, no one can impose an organizational design. Even if a design were imposed, it would inevitably be morphed by stakeholders as they learn and adapt to changing conditions. In that case, the organization that management would think it was running would not really exist. To the extent that everyone agrees to pretend that it still exists, or ever existed, value will be undermined.

Information Systems

Based on the organizational behaviors for complex adaptive systems described above, information to oversee the system should include the following elements:

- Measurements and projections of system state in terms of current and projected value flows, as well as current and projected problems.
- Measurements and projections of system performance in terms of current and projected value, costs, and metrics (e.g., value divided by cost), as well as current and projected options for contingencies.
- Observations of system stakeholders in terms of the involvement and performance of each stakeholder group.
- Capabilities for measurement, modeling, and display of system state, including agile "What If?" experimentation and adaptation.

The question arises about who would be looking at and using the information for the whole health care system. If we were discussing the banking system, the answer would be the Federal Reserve Bank. The Fed does not tell banks what to do, but it sets the prime interest rate and determines each bank's reserve requirements. Banks and investors then decide how they want to adapt to any changes.

The health care system has no overseer,[1] although some have argued that there should be one, considering the importance of the health of the country's human capital to competitiveness and economic growth. The question is which variables an overseer might adjust. Perhaps it would adjust reimbursement rates in relation to the value of health outcomes. Admittedly, outcomes can be difficult to characterize and calibrate, and determining attribution of causes of outcomes can be difficult because multiple actors are involved and outcomes only emerge over time. Nevertheless, at the very least, we should be able to characterize and assess bad outcomes (IOM, 2000).

Because complex adaptive systems self-organize, no one can impose an organizational design.

More controversially, an oversight organization might adjust tax rates so that (risk-adjusted) high-value providers would pay lower taxes, perhaps reflecting the economic benefits of high-value health care. I know this idea is controversial because I have presented it to various groups of thought leaders in health care. Beyond the philosophical objection to using the tax system to improve the public good, the most frequent criticism is that providers cannot fully affect health outcomes because patient behaviors are also essential to success. However, this is also true of markets of all kinds. The enterprises that succeed are the ones that convince and incentivize consumer behaviors that co-create

[1] Some have argued that the Centers for Medicare and Medicaid Services (CMS), an element of the U.S. Department of Health and Human Services, plays a dominant role in setting reimbursement levels for patients enrolled in these programs via the Medicare Payment Advisory Commission. However, CMS does not oversee the whole health care system or address the overall health outcomes and economic impacts discussed in this article.

high-value outcomes. Success for the health care model depends on providers seeing themselves as ensuring high-value outcomes, rather than being reimbursed for the costs of their services.

Conclusions

The models and analyses discussed in this article can be summarized in just two words—information and incentives. Substantial improvement in the system of health care in the United States will require that stakeholders have easy access to information on the state and performance of the whole system, or any subsystem, as well as information on best practices at all levels. This information would be used to assess current and emerging situations in this complex adaptive system, which would lead to adjustments of incentives and inhibitions to motivate stakeholders to change their behaviors to continually increase value.

In general, incentives are essential to complex adaptive systems. Outcomes, as well as activities, must be incentivized. Payments to providers should reflect the (risk-adjusted) value of the outcomes achieved regardless of the cost incurred to achieve them. Poorly informed and/or out-of-date practices should be disincentivized. High-performing providers should reap substantial rewards, and poorly performing providers will go out of business. In this way, the average performance level will continually rise.

Wellness, which contributes to productivity, should also be incentivized. Building on the recent report of the Milken Institute (DeVol et al., 2007), an economic model could be developed of the relationship between wellness and productivity to provide a basis for determining how much should be invested in public awareness and education. The model would also be a basis for designing tax incentives for employers who offer wellness programs and whose employees participate in them.

These are "big" ideas that need much refinement, analysis, and debate, and we must keep in mind the inertial power of the status quo. A few years ago, *The Economist* (2004) published a long survey article on health care financing, which admonished would-be reformers to remember that every health care dollar saved is somebody's income. Aspinall and Hamermesh (2007) reinforced that idea in a recent assessment of the promise of personalized health care.

Thus we clearly need incentives for key stakeholders to change. One incentive might be a crisis. For example, when the percentage of GDP devoted to health care approaches 100 percent, many things would certainly change, and health care might be rationed at that point. However, by acting long before we reach such a crisis point, we can engineer much better solutions to providing high-value health care.

Systems engineering for health care can operate on multiple time scales. Several of the ambitious ideas outlined here will take several years, or more, to be fully realized. However, in the process of pursuing these ideas, we will gain in understanding, which will inevitably result in our identifying much low-hanging fruit, that is, short-term opportunities that can be pursued much faster than the overarching vision. These short-term pursuits will undoubtedly improve the health care system, even as we work on the long-term vision to transform the overall system.

We need to analyze and design the systemic nature of health care delivery and not continue to let it evolve and see whether one idea or another works. Complex adaptive systems require sophisticated and sometimes subtle analyses and designs, which will no doubt require experts in a wide range of disciplines beyond engineering. However, a strong competency for analysis and design of complex adaptive systems will serve us well.

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