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"Engineering Systems: Putting People in the Picture"

2004 Engineering Systems Symposium: Addressing the Challenges of Large-Scale Systems
Government Perspectives on Engineering Systems
Massachusetts Institute of Technology
March 29, 2004

Good afternoon to everyone. I greatly appreciate being invited to take part in this symposium together with my distinguished fellow-panelists and colleagues. NSF is grateful to MIT and the new Engineering Systems Division for hosting this event.

Over the years, MIT has pioneered many innovations in engineering research and education, and we have all benefited. As we formally consider large-scale engineering systems, and how understanding them can contribute to knowledge and to society, we are in the vanguard, exploring fresh synergies in the best of this tradition.

[Slide #1: Title Slide]

My task today is to present some perspectives on engineering systems in the context of the National Science Foundation. I've titled my comments "Engineering Systems: Putting People in the Picture." Above all, I want to emphasize the human dimensions of our complex technological world. Since NSF investments range over the entire frontier of science and engineering research and education, I plan to cast a broad net with some comments about our common enterprise. Then I will provide three seemingly disparate examples of engineering systems research and education from the many supported by NSF.

Francis Bacon once advised that truth is the daughter of time.[1] A goodly number of us participating in this symposium have had the opportunity and privilege to be members of the engineering community over many years and in many roles—as students of engineering, as practicing engineers in industry, as professors and deans of engineering, and in many roles in government.

[Slide #2: The Engineer]

During that time, we've seen some truth emerge. Society's appetite for high performance has expanded exponentially, in every sector. Engineering is no exception. We expect today's engineers to possess a daunting repertoire of skills. We want them to be holistic designers, astute

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[1] Francis Bacon, 1620, *Organon Novum*, Aphorism 84.

makers, trusted innovators, harm avoiders, change agents, master integrators, enterprise enablers, knowledge handlers, and technology stewards.

With these burgeoning talents, we also expect them to help us achieve an equally daunting set of goals: economic and social prosperity, a safe environment, and national and global security.

This requires a very different model of engineering education and practice, a model suitable to a world in which change and complexity are the rule, a world transformed repeatedly by new knowledge and the technology it makes possible, a world linked globally, where differences can engender progress and divisions can destroy it.

[Slide #3: Kresge Auditorium, MIT Campus with Eliel Saarinen quote]

Good design is central to a new vision. Many of you will recognize the architect Eero Saarinen as the designer of Dulles Airport, the TWA terminal at Kennedy Airport, and the Gateway Arch in St. Louis. He designed the Kresge Auditorium on this campus in 1954.

He was fond of quoting[2] the advice of his father Eliel, also an architect of great distinction: "Always design a thing by considering it in its next larger context -- a chair in a room, a room in a house, a house in an environment, an environment in a city plan."

Good design requires this holistic view. As engineers, we will be better designers over time if we also consider the larger context – the chair within the room. This kind of integrative vision gives us a window not only onto *function* but also on expanded effectiveness. We simply can't achieve this view by focusing on a narrow glimpse of the landscape.

It also enables us to find solutions in unlikely places. A hallmark of our current age of cross-boundary discovery and innovation is the ability to shift from one context to another with agility, borrowing concepts and models along the way.

So, for example, in the context of the attack on the World Trade Center, investigators were able to apply knowledge garnered from research on earthquakes and other natural disasters to studies ranging from the structural aspects of building design to the nature of human response to extreme events.

Holistic design is also our window *into* the future. More and more, it is possible – and even necessary—to anticipate and allow for a plethora of outcomes. We need to develop a tolerance for ambiguity and the flexibility to make course corrections, to adapt, along the way to our goal.

Understanding the larger context in which we work – the sector, the society, and even the time in history – gives us a path for *anticipating* the future. This is a subtle skill we all must learn to develop in a world now besieged by fast-paced transformation.

[2] Eliel Saarinen, quoted by his son Eero, Time 2 June 1977

We often speak of new knowledge in science and engineering and innovation without explicitly acknowledging the people who *do it*. This is an expression of our commitment to the cumulative and communal character of our craft, its shared methods and openness.

We should not permit this portrayal of science and engineering to obscure the women and men, young and old, who create and use our shared knowledge and technologies. It merely reinforces the idea that we collaborate in a complex and highly successful human system.

In considering large-scale, technologically enabled engineering systems of any kind, we need to exercise the same vision. In order to understand these systems—from power grids to the Web—we are increasingly compelled to consider humans and our institutions.

I've chosen three examples from the NSF portfolio of activities to illustrate this point. Above all, I want to emphasize that we must go beyond a nod to human and social contexts, to their complete integration in engineering systems.

At the National Science Foundation, we have adopted a strategy of investing in new tools and instruments that are widely shared and broadly accessible. The truly innovative twist, however, is to provide a resource that is greater than the sum of its parts. That means moving beyond incremental improvement to develop an integrated toolkit that gives us the means to do things *in a different way.*

[Slide #4: NEES slide]

Here is an example. The NSF-funded George E. Brown Jr. Network for Earthquake Engineering Simulation—NEES, for short—is a 21st Century model of collaboration, integration, and innovation. It is a distributed, virtual laboratory for earthquake experimentation and simulation. Researchers will share and remotely operate equipment at more than twenty facilities, from shake tables and a tsunami wave basin to field stations.

But that is not the chief innovation that NEES embodies. NEES shifts the emphasis of earthquake engineering research from current reliance on physical testing to *integrated* experimentation, computation, theory, databases, and model-based simulation.

Modeling and simulation give us the ability to investigate phenomena on scales—from the nano to the planetary—that are simply not practical in the physical world. Sophisticated visualization and computation tools add yet other dimensions.

Using NEESgrid—a high-performance Internet network—researchers and students will have a powerful collaborative space for modeling and simulation to study how building design, advanced materials and other measures can minimize earthquake damage and loss of life.

These new distributed tools are also a way to broaden and deepen educational reach – to underserved populations in our own nation and internationally. Providing students with high quality research experiences and access to cutting-edge instruments is absolutely essential to educate the next generation of scientists and engineers.

Over time, NEES will grow, as other sites with innovative research and education resources join the network. NSF envisions NEES as a virtual *international* collaboratory with human, cyber and physical resources distributed around the globe. No doubt it will evolve and organize itself in ways not yet foreseeable. New research and education frontiers will emerge. This is a holistic vision that embraces both tools and the people who create and use them.

Such distributed, large-scale, technology enabled, collaborative *systems* for research and education may one day be ubiquitous. NSF, together with the science and engineering community, is already conceptualizing and designing a national ecological observatory network, and a system of ocean observatories along the same lines.

Likewise, *Cyberinfrastructure* will take research and education to an entirely new plane of discovery. Our new information and communication technologies, together with sensors and satellites, and visualization and simulation tools, have already altered our familiar research, education and innovation landscapes.

We are only at the *beginning* of this great revolution. We know how to *share* information, but we have not yet tapped the full power of these technologies by integrating them into a new system for research, education, and innovation.

[Slide #5: Human and Social Dynamics]

This brings me to my second example. With NSF's newest priority area, Human and Social Dynamics, we intend to jumpstart efforts already underway that will transform understanding of our societies, our institutions, and ourselves. Developments in cognitive and neuroscience, computer science, philosophy, linguistics, mathematics, engineering, psychology, to name only a few—are opening promising new vistas not only in the social sciences but within the physical and natural sciences and engineering as well.

The social sciences are still the poor stepsister of the physical and natural sciences and engineering when it comes to integration and collaboration. They are Cinderellas, only invited to the ball in disguise!

One criterion for our success with Human and Social Dynamics will be that no one needs to be *told* to take humans and our institutions into consideration as we advance the frontiers of knowledge and technology.

Just one example of where this research might take us is understanding "how we learn." Learning is one of our quintessentially human characteristics, as is our ability to communicate what we have learned—not only person to person, but from one generation to the next, and to accumulate and expand knowledge—that's one simple way to describe science and engineering.

Better understanding of human and social dynamics will involve a great deal more than discerning patterns. Because socio-technological systems are generally self-organizing, adaptive, and evolving, we also need to model possible future paths in order to anticipate the direction of change.

This is necessary and vital knowledge if we intend to shape change. On a large scale, what we mean when we speak of shaping change is simply "policy"—the traditional bailiwick of government.

My third and final example actually spotlights NSF itself as an institution and a large-scale, complex, technology-enabled system.

[Slide #6: NSF Strategic Goals]

NSF's three strategic goals are central to the research, education and innovation enterprise. We refer to them simply as: People, Ideas and Tools – developing a world class science and engineering workforce, fostering discovery at the frontiers of knowledge, and developing the tools to get the job done. Through integration, collaboration and innovation, the people, ideas and tools come together as a holistic and dynamic system.

In NSF's *internal management practices,* people, ideas and tools translate to <u>human resource development</u>, <u>innovative business processes</u> and <u>enabling technology</u>—concepts familiar in the private sector in a management context. NSF has now added a fourth strategic goal to encompass this management triad. We call it Organizational Excellence.

Again, our approach here is holistic. Instead of considering each of these management practices as separate thrusts, we view them as aspects of a single integrated system.

This is not to say that NSF is just a self-contained management unit tasked with spending tax dollars effectively and efficiently to accomplish our goals. We are distinctive in this respect: we cannot function—literally—apart from the science and engineering community with whom we collaborate. Calling the members of this community 'customers' or 'clients' or 'stakeholders' does not adequately capture the extent of their integration into NSF activities. Likewise, my meaning is not *political*! What I want to convey is that the *system* that produces learning, discovery, and innovation *includes*—in a holistic sense—both NSF and the community.
Let me elaborate. The peer review process we use for awarding proposals involves over 50,000 reviewers annually. The competitive nature of the grant process guarantees that investigators and teams of investigators bring us the best ideas. Committees of visitors evaluate programs. Workshop participants delineate research priorities and promising directions for new research and education initiatives. The research and education we fund feeds back into this process to open yet more new frontiers. Over 200,000 students, teachers, and researchers, at all levels and from all sectors, participate in this system annually.

Many of our staff are rotators who bring fresh perspectives to NSF and then return to their institutions with their own perspectives broadened. Our business practices and technology are designed and deployed to *integrate* NSF and the research and education community, not simply to share information, but to accomplish common goals.

From this perspective, our Organizational Excellence goal is itself integrated with the People, Ideas and Tools goals.

These three examples, I hope, portray how the research and education enterprise is itself a kind of engineering system—with a twist. I have emphasized the *human and social* elements, and then added the technology context. This is just the opposite of the usual vision of an engineering system.

Looking at the flip side, we also tend to think of the research, engineering, and innovation enterprise as a human system empowered by technology. But as cyberinfrastructure, sensors, satellites, communications networks, and all the other tools in our technological arsenal become ubiquitous there is really no reason, in principle, to think of these tools as simple adjuncts to human endeavor.

In a nutshell, we humans no longer exist meaningfully in isolation from our technology. Likewise, and here is the moral, <u>if</u> there is one: engineering systems conceived as industries, as civil infrastructure, as information networks, do not exist meaningfully in isolation from our human and social systems.

[Slide #7: Drucker Quote]

I'll conclude with a cautionary perspective from management guru Peter Drucker. "In a few hundred years," he says, "when the history of our time will be written from a long-term perspective, it is likely that the most important event historians will see is not technology, not the Internet, not e-commerce. It is an unprecedented change in the human condition. For the first time - literally - substantial and rapidly growing numbers of people have choices. For the first time, they will have to manage themselves. And society is totally unprepared for it."

Drucker may be far too pessimistic. Gatherings such as this one are pioneering the paths necessary to provide a fully integrated systems framework in which to better understand ourselves, delineate our options, and anticipate the consequences of our choices. That will include the full richness of humans, societies and technology.

Innovative approaches to engineering research, education, and practice, like those we are here to discuss, are part of an ongoing process—evolving along new paths and adapting to the changing societal and global environment—from tweaks to totally new structures. We have already set forth on this exciting journey.

3/30/04: JWS