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TRANSPORTATION
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The BRIDGE

LINKING ENGINEERING AND SOCIETY

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THE NATIONAL ACADEMIES

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Editor's Note

George Bugliarello

Infrastructure and Transportation: Our Nation at a Crossroads

From the very beginning of our history, infrastructure has been a foundation of growth and prosperity for our country, and it has become increasingly important as we continue to expand economically and demographically.

Today, however, much of that foundation is inadequate in capacity and performance and in need of maintenance and repair, close surveillance, and assessment. In addition, substantial portions of our infrastructure are vulnerable to environmental disasters, such as earthquakes, floods, hurricanes, and rising sea level, as well as to hostile attacks. Yet, in our desire for greater economic efficiency, we continue to reduce redundancies and increase interdependencies among our infrastructure systems, often doing away with our margins of safety. In addition, a lack of capital is inducing some infrastructure owners in the public sector to sell, lease, or outsource our common infrastructural systems.

The consequences, such as the aftermath of Hurricane Katrina and the dangerous overcrowding of air lanes, are still vivid and hardly bear re-emphasizing. So are the D-minus safety and performance ratings (by the American Society of Civil Engineers) of major elements of the civil engineering infrastructure and the concerns of the Department of Homeland Security about the lack of resilience in our critical infrastructures. Sobering cautionary messages are also implicit in outrageous cost overruns, as in the "Big Dig" in Boston.

The infrastructure problem is enormous in its dimensions; its causes and remedies are complex; and the need to address them is urgent. The nation is at a crossroads—should we continue to make expedient fixes, hoping they will suffice in the short term, or should we rethink fundamentally the role of infrastructure in our future, reconsider our choices and opportunities, and reassess the roadblocks facing us.

Clearly, we need to rethink. The evidence is all around us, whether we look at the tens of thousands of bridges that have raised concerns about their structural integrity or at the crowding of our port facilities or at the inanity of continuing to expand short-range commercial air traffic to make up for our substandard passenger rail system; whether we look at congested, polluting highway traffic, often traveling on deteriorating pavement, or at the lack of efficient, affordable urban and suburban mass transit systems; whether we look at the frequent failures of water, gas, and steam pipes under our older cities or at the risks associated with our overburdened power grids or the growing demands on our water supply and waste-disposal systems.

An efficient infrastructure is essential to a competitive economy. Flight delays at La Guardia Airport propagate to delays in many other airports throughout the United States, with significant economic consequences. Imagine what shutting down New York City as a whole, or Chicago, Los Angeles, or any other major city would do to our nation and the world economy. Cities themselves should be considered critical elements of the infrastructure, mega-infrastructure, if you will. Their dysfunctionalities and poor responses to disaster can affect the entire nation.

It may cost as much as 1 percent of our annual GDP to bring the entire infrastructure to an adequate condition. However, at a time when social demands for health care and education and the needs of the military and homeland defense are making very large, urgent claims on our national budget, even 1 percent would be so onerous as to be deemed politically unrealistic.

But it is even more unrealistic to expect that, with critical components of the infrastructure in substandard condition, obsolete, or in need of repair, the nation can remain globally competitive and secure. We need to determine, with as much confidence as possible, the extent to which the costs of fixing our infrastructure will be offset by increases in productivity, savings in energy, improved security, and a healthier environment.

The creation of an up-to-date infrastructure will require an intense national dialogue and a willingness to stretch our political will, technological creativity, and financial savvy to the limit.

Upgrading the infrastructure presents a host of engineering challenges, ranging from how to increase capacity through intelligent systems to building elements of the infrastructure that can be deconstructed and recycled, self-monitored, self-diagnosed, to some extent self-repaired, and protected against cascading failures of interdependent systems. Creating the infrastructure of the future will certainly require reinvesting in long-range research.

The Bridge has repeatedly addressed aspects of the infrastructure problem. In this issue, we focus on transportation, the logistic lifeline of our economy and our way of life. Robert Skinner, the executive director of the Transportation Research Board of the National Research Council, addresses the challenges in designing and reconstructing highways and provides an overview of prospects for new transportation technologies. Joseph Sussman, professor at MIT and chair of an advisory committee to the U.S. Department of Transportation, makes a strong argument for intelligent transportation systems to improve traffic on our roads and highways. **Ted Galambos**, Emeritus Professor, University of Minnesota, describes the causes of bridge failures and the lessons learned from the collapse of the Minneapolis bridge in August 2007.

John Samuels, former head of Norfolk Southern Railroad, describes the ongoing renaissance of the freight railroad system in the United States and the technologies that are making it possible. Keith Michel, CEO of Herbert Engineering, and Peter Noble, of ConocoPhillips, provide an overview of new technologies in the maritime industry. Finally, Richard de Neufville, chairman of the MIT Technology and Policy Program, argues that we need new strategic thinking and flexible design in building airport systems for the next generation.

The deficiencies in our transportation systems and other components of our infrastructures cannot be addressed piecemeal. They demand that we develop a national plan and a systematic and farsighted approach to financing and technological innovation based on a realistic public understanding of what is at stake.

George Bugliarello

Innovations and advances in research are changing the way highways are built in America.

Highway Design and Construction: The Innovation Challenge

Robert E. Skinner Jr. is executive director of the National Research Council Transportation Research Board.

Robert E. Skinner Jr.

The Egyptians were pouring concrete in 2500 BC, and the Romans used it to construct the Pantheon and the Colosseum. By the mid-1800s, Europeans were building bridges with concrete, and the first "modern" concrete highway pavements appeared in the latter part of the 19th century. Naturally occurring asphalts, which have been used for waterproofing for thousands of years, came into common use in road construction in the 1800s. The first iron bridge was constructed in 1774, but by the end of the 19th century steel had largely replaced iron in bridge construction. These materials—concrete, asphalt, and steel—are now the mainstays of highway and bridge construction throughout the world, as well as of most types of public works infrastructure. Concrete and steel, the most versatile of these materials, are used for bridges and other highway structures; concrete and asphalt are used for roadway pavements.

Everyone is familiar with concrete, asphalt, and steel, and some of us have worked with them, perhaps on home improvement projects. This familiarity, coupled with the long history of their many uses, has led many otherwise technically savvy people to believe that these materials are well understood, that their performance can be easily and reliably predicted, and that the technical challenges in using them for highways were overcome long ago. However, such notions are largely incorrect and misleading.

For example, consider concrete, which is a mixture of portland cement, sand, aggregate (gravel or crushed stone), and water. Its performance characteristics are determined by the proportions and characteristics of the components, as well as by how it is mixed and formed. The underlying chemical reactions of concrete are surprisingly complex, not completely understood, and vary with the type of stone. Steel may be added for tensile strength (reinforced concrete), and a variety of additives have been identified to improve the workability and performance of concrete in particular applications and conditions. Damage and deterioration to concrete can result from excessive loadings and environmental conditions, such as freeze-thaw cycles and chemical reactions with salts used for deicing.

Many factors contribute to the urgent need for innovation in highway construction.

Concrete is the most heavily used substance in the world after water (Sedgwick, 1991). Worldwide, concrete construction annually consumes about 1.6 billion tons of cement, 10 billion tons of sand and crushed stone, and 1 billion tons of water (M.S. Kahn, 2007). Given transportation costs, there is a huge financial incentive to using local sources of stone, even if the properties of that stone are less than ideal. Thus concrete is not a homogenous material. In truth, an unlimited number of combinations and permutations are possible.

Much the same can be said of asphalt—technically, asphaltic concrete—which is also a mixture of aggregate (gravel or crushed stone), sand, and cement (asphalt binder); economics promote the use of locally available materials; and the underlying chemistry is not well understood. The characteristics of asphalt binder, for instance, vary depending on the source of crude oil from which it is derived.

The metallurgy of steel is probably better understood than the chemistry of either asphalt or concrete, but it too is a mixture with virtually limitless combinations. Strength, toughness, corrosion resistance, and weldability are some of the performance characteristics that vary with the type of steel alloy used and the intended applications.

As uses evolve and economic conditions change, we have a continuing need for a more sophisticated understanding of these common materials. Even though they are "mature" products, there is still room for significant incremental improvements in their performance. Because fundamental knowledge is still wanting, there is also considerable potential for breakthroughs in their performance.

Factors That Affect Highway Construction

All other things being equal, stronger, longer lasting, less costly highway materials are desirable and, given the quantities involved, there are plenty of incentives for innovation. In highway transportation, however, all other things are not equal. A number of other factors contribute to the urgent and continuing need for innovation.

First, traffic volume and loadings continue to increase. Every day the U.S. highway network carries more traffic, including heavy trucks that were unimagined when the system was originally conceived and constructed. The 47,000-mile interstate highway system today carries more traffic than the entire U.S. highway system carried in 1956 when the interstates were laid out. The U.S. Department of Transportation (DOT) estimates that in metropolitan areas the annual cost of traffic congestion for businesses and citizens is nearly $170 billion (PB Consult, Inc., 2007). On rural interstates, overall traffic more than doubled between 1970 and 2005; at the same time, the loadings on those highways increased six-fold, mainly due to the increase in the number of trucks and the number of miles they travel. (Truck traffic increased from about 5.7 percent of all vehicle-miles traveled on U.S. highways in 1965 to 7.5 percent in 2000 [FHWA, 2005]).

Second, traffic disruptions must be kept to a minimum during construction. Our overstressed highway system is not very resilient. Thus disruptions of any sort, such as lane and roadway closings, especially in major metropolitan areas and on key Interstate routes, can cause massive traffic snarls. This means that repair and reconstruction operations must often be done at night, which introduces a variety of additional complexities and safety issues. Occasionally, heroic measures must be taken to keep traffic moving during construction. For example, during construction of the "Big Dig" in Boston, the elevated Central Artery was in continuous service while cut-cover tunnels were constructed directly below it.

Third, environmental, community, and safety requirements have become more stringent. For many good reasons, expectations of what a highway should be, how it should operate, and how it should interact with the environment and adjacent communities are constantly evolving. Designs to promote safety, measures to mitigate a growing list of environmental impacts, and attention to aesthetics have fundamentally changed the scope of major highway projects in the United States. For example, on Maryland's $2.4 billion Intercounty Connector project in suburban Washington, D.C., which is now under construction, environmental mitigation accounts for 15 percent of project costs, or about $15 million per mile (AASHTO, 2008).

Fourth, costs continue to rise. Building and maintaining highways cost effectively is an ever-present goal of good engineering. But cost increases in highway construction have been extraordinary due in part to the expanded scope of highway projects and construction in demanding settings. In addition, the costs of the mainstay materials—portland cement, asphalt binder, and steel—have risen dramatically as the world, particularly China, has gone on a construction binge. The Federal Highway Administration's cost indices for portland cement concrete pavement, asphalt pavement, and structural steel increased by 51 percent, 58 percent, and 70 percent respectively between 1995 and 2005 (FHWA, 2006).

Fortunately, research and innovation in construction have never stopped, although they are not always sufficiently funded and they seem to fly beneath the radar of many scientists and engineers. Nevertheless, there have been great successes, which are cumulatively changing how highways are built in America.

The Superpave Design System

In response to widespread concerns about premature failures of hot-mix asphalt pavements in the early 1980s, a well funded, congressionally mandated, crash research program was conducted to improve our understanding of asphalt pavements and their performance. The seven-year Strategic Highway Research Program (SHRP), which was managed by the National Research Council, developed a new system of standard specifications, test methods, and engineering practices for the selection of materials and the mix proportions for hot-mix asphalt pavement.

The new system has improved matches between combinations of asphalt binder and crushed stone and the climatic and traffic conditions on specific highways. State departments of transportation (DOTs) spend more than $10 billion annually on these pavements, so even modest improvements in pavement durability and useful life can lead to substantial cost savings for agencies and time savings for motorists (TRB, 2001).

SHRP rolled out the Superpave system in 1993, but it took years for individual states and their paving contractors to switch to the new system, which represents a significant departure, not only in design, but also in the procedures and equipment used for testing. Each state DOT had to be convinced that the benefits would outweigh the modest additional costs of Superpave mixes, as well as the time and effort to train its staff and acquire necessary equipment.

A survey in 2005 showed that 50 state DOTs (including the District of Columbia and Puerto Rico) were using Superpave (Figure 1). The remaining two states indicated that they would be doing so by the end of 2006. Throughout the implementation period, researchers continued to refine the system (e.g., using recycled asphalt pavements in the mix design [TRB, 2005]).

It may be years before the cost benefits of Superpave can be quantified. A 1997 study by the Texas Transportation Institute projected that, when fully implemented, Superpave's annualized net savings over 20 years would approach $1.8 billion annually—approximately $500 million in direct savings to the public and $1.3 billion to highway users (Little et al., 1997). Moreover, analyses by individual states and cities have found that Superpave has dramatically improved performance with little or no increase in cost. Superpave is not only an

FIGURE 1 Superpave application on Michigan State Route 95, near Iron Mountain. The Superpave system, which matches the combinations of asphalt binder and crushed stone to the climatic and traffic conditions on specific highways, was developed under the National Research Council–managed Strategic Highway Research Program and is in use in every state. (Photo: Larry L. Michael.)

example of a successful research program. It also demonstrates that a vigorous, sustained technology-transfer effort is often required for innovation in a decentralized sector, such as highway transportation.

Prefabricated Components

The offsite manufacturing of steel and other components of reinforced concrete for bridges and tunnels is nothing new. But the need for reconstructing or replacing heavily used highway facilities has increased the use of prefabricated components in startling ways. In some cases components are manufactured thousands of miles from the job site; in others, they are manufactured immediately adjacent to the site. Either way, we are rethinking how design and construction can be integrated.

FIGURE 2 Aerial view of the east span of the San Francisco-Oakland Bay Bridge, Labor Day 2007, with the replacement deck piece newly installed. Demolishing the old viaduct sections and moving the prefabricated section into place was accomplished in 70 hours—11 hours ahead of schedule. (Photo: Barrie Rokeach, Aerial/Terrestrial Photography.)

When the Texas Department of Transportation needed to replace 113 bridge spans on an elevated interstate highway in Houston, it found that the existing columns were reusable, but the bent caps (the horizontal connections between columns) had to be replaced. As an alternative to the conventional, time-consuming, cast-in-place approach, researchers at the University of Texas devised new methods of installing precast concrete bents. In this project, the precast bents cut construction time from 18 months to slightly more than 3 months (TRB, 2001).

As part of a massive project to replace the San Francisco-Oakland Bay Bridge, the California Department of Transportation and the Bay Area Toll Authority had to replace a 350-foot, 10-lane section of a viaduct on Yerba Buena Island. In this case, the contractor, C.C. Myers, prefabricated the section immediately adjacent to the existing viaduct. The entire bridge was then shut down for the 2007 Labor Day weekend, while the existing viaduct was demolished and the new 6,500-ton segment was "rolled" into place (Figure 2). The entire operation was accomplished 11 hours ahead of schedule (B. Kahn, 2007).

Probably the most extensive and stunning collection of prefabricated applications on a single project was on the Central Artery/Tunnel Project ("Big Dig") in Boston. For the Ted Williams Tunnel, a dozen 325-foot-long steel tunnel sections were constructed in Baltimore, shipped to Boston, floated into place, and then submerged. However, for the section of the tunnel that runs beneath the Four Points Channel, which is part of the I-90 extension, bridge restrictions made this approach infeasible. Instead, a huge casting basin was constructed adjacent to the channel where 30- to 50-ton concrete tunnel sections were manufactured (Figure 3). The basin was flooded and the sections winched into position with cables and then submerged.

An even more complicated process was used to build the extension tunnel under existing railroad tracks, which had poor underlying soil conditions. Concrete and steel boxes were built at one end of the tunnel, then gradually pushed into place through soil that had been frozen using a network of brine-filled pipes (Vanderwarker, 2001).

Specialty Portland Cement Concretes

New generations of specialty concretes have improved one or more aspects of performance and allow for greater flexibility in highway design and construction. High-performance concrete typically has compressive strengths of at least 10,000 psi. Today, ultra-high-performance concretes with formulations that include silica fume, quartz flour, water reducers, and steel or organic fibers have even greater durability and compressive strengths up to 30,000 psi. These new concretes can enable construction with thinner sections and longer spans (M.S. Kahn, 2007).

FIGURE 3 Casting basin constructed adjacent to Four Point Channel during Boston's Central Artery-Tunnel project, for manufacturing 30- to 50-ton concrete tunnel sections; when the sections were complete, the basin was flooded, and the sections were floated into position and submerged. The casting basin was 1,000 feet long, 300 feet wide, and 60 feet deep—big enough to hold an aircraft carrier or three *Titanics* side by side. (Photo: Massachusetts Turnpike Authority.)

Latex-modified concrete overlays have been used for many years to extend the life of existing, deteriorating concrete bridge decks by the Virginia DOT, which pioneered the use of very early strength latex-modified concretes for this application. In high-traffic situations, the added costs of the concrete have been more than offset by savings in traffic-control costs and fewer delays for drivers (Sprinkel, 2006).

When the air temperature dips below 40°F, costly insulation techniques must be used when pouring concrete for highway projects. By using commercially available admixtures that depress the freezing point of water, the U.S. Cold-Weather Research and Engineering Laboratory has developed new concrete formulations that retain their strength and durability at temperatures as low as 23°F. Compared to insulation techniques, this innovation has significantly decreased construction costs and extended the construction season in cold weather regions (Korhonen, 2004).

As useful as these and other specialty concretes are, nanotechnology and nanoengineering techniques, which are still in their infancy, have the potential to make even more dramatic improvements in the performance and cost of concrete.

Waste and Recycled Materials

Highway construction has a long history of using industrial waste and by-product materials. The motivations of the construction industry were simple—to help dispose of materials that are otherwise difficult to manage and to reduce the initial costs of highway construction. The challenge has been to use these materials in ways that do not compromise critical performance properties and that do not introduce substances that are potentially harmful to people or the environment. At the same time, as concerns about sustainability have become more prominent in public thinking, the incentives to use by-product materials have increased. In addition, because the reconstruction and resurfacing of highways create their own waste, recycling these construction materials makes economic and environmental sense.

Research and demonstration projects have generated many successful uses of by-product and recycled materials in ways that simultaneously meet performance, environmental, and economic objectives. For example, "crumb rubber" from old tires is increasingly being used as an additive in certain hot-mix asphalt pavement designs, and a number of patents have been issued related to the production and design of crumb rubber or asphalt rubber pavements (CDOT, 2003; Epps, 1994).

Several states, notably California and Arizona, use asphalt rubber hot mix as an overlay for distressed flexible and rigid pavements and as a means of reducing highway noise. Materials derived from discarded tires have also been successfully used as lightweight fill for highway embankments and backfill for retaining walls, as well as for asphalt-based sealers and membranes (Epps, 1994; TRB, 2001).

Fly ash, a residue from coal-burning power plants, and silica fume, a residue from metal-producing furnaces, are increasingly being used as additives to portland cement concrete. Fly-ash concretes can reduce alkali-silica reactions that lead to the premature deterioration of concrete (Lane, 2001), and silica fume is a component of the ultra-high-performance concrete described above.

After many years of experimentation and trials, reclaimed asphalt pavement (RAP) is now routinely used in virtually all 50 states as a substitute for aggregate and a portion of the asphalt binder in hot-mix asphalt, including Superpave mixes. The reclaimed material typically constitutes 25 to 50 percent of the “new” mix (TFHRC, 1998). The National Asphalt Pavement Association estimates that 90 percent of the asphalt pavement removed each year is recycled and that approximately 125 millions tons of RAP are produced, with an annual savings of $300 million (North Central Superpave Center, 2004).

Visualization, Global Positioning Systems, and Other New Tools

For more than 20 years, highway engineers have used two-dimensional, computer-aided drafting and design (CADD) systems to accelerate the design process and reduce costs. The benefits of CADD systems have derived essentially from automating the conventional design process, with engineers doing more or less what they had done before, although much faster and with greater flexibility.

New generations of three- and four-dimensional systems are introducing new ways of designing roads, as well as building them (Figure 4). For example, three-dimensional visualization techniques are clearly useful for engineers. But, perhaps more importantly, they have improved the communication of potential designs to affected communities and public officials; in fact, they represent an entirely new design paradigm. Four-dimensional systems help engineers and contractors analyze the constructability of proposed designs well in advance of actual construction (Figure 5).

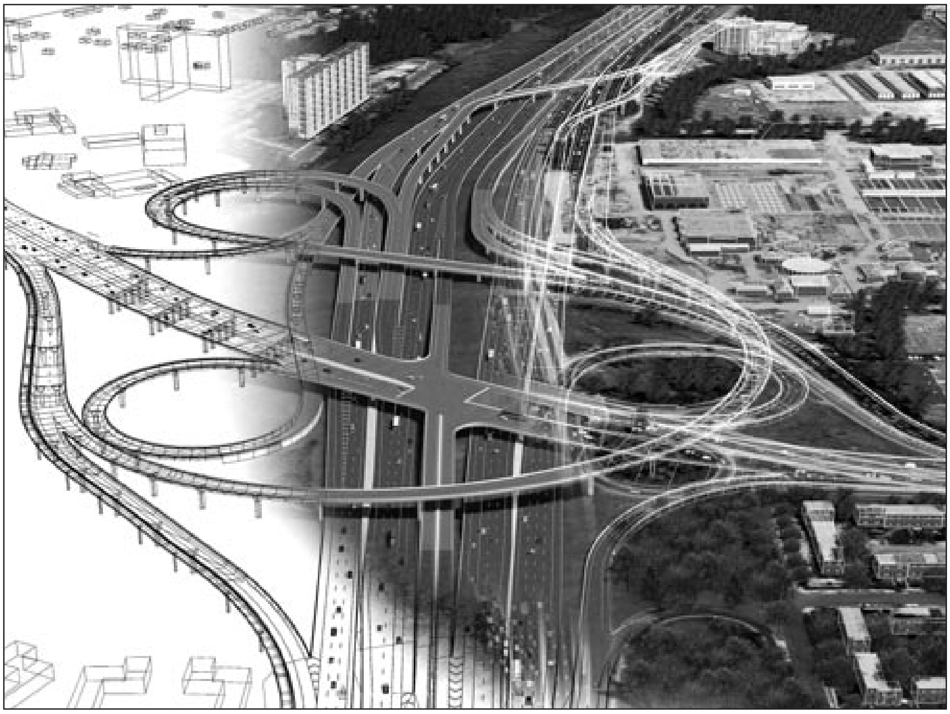

FIGURE 4 Visualization image prepared for a design-build reconstruction of U.S. Highway 52 near Rochester, Minnesota. The image shows the versatility of visualization, incorporating plan views, 3-D rendering, and final projection. (Image: URS Corp.)

Global positioning systems are being used in surveying/layout, in automated guidance systems for earthmoving equipment, and for monitoring quantities. Other innovations include in situ temperature sensors coupled with data storage, transmission, and processing devices that provide onsite information about the maturity and strength of concrete as it cures (Hannon, 2007; Hixson, 2006).

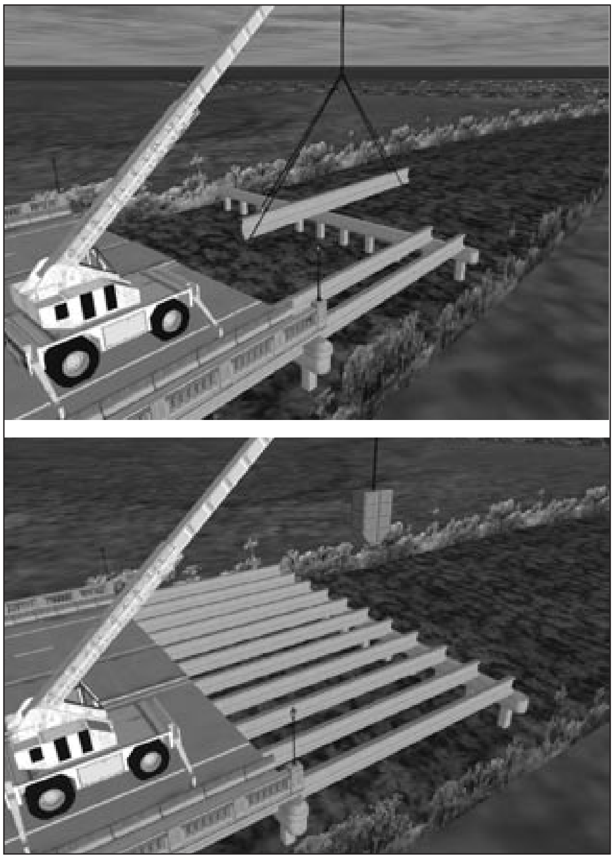

FIGURE 5 Engineers can use visualization to resolve construction sequencing issues and develop cost-efficient approaches. (Images: Charles L. Hixon III, Bergman Associates.)

Conclusion

The examples described above suggest the wide range of exciting innovations in the design and construction of highways. These innovations address materials, roadway and bridge designs, design and construction methods, road safety, and a variety of environmental, community, and aesthetic concerns. Looking to the future, however, challenges to the U.S. highway system will be even more daunting—accommodating more traffic and higher loadings; reducing traffic disruptions during construction; meeting more stringent environmental, community, and safety requirements; and continuing pressure to reduce costs. Addressing these challenges will require a commitment to innovation and the research that supports innovation.

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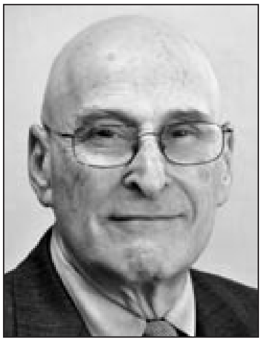
Intelligent transportation systems will change the way we think about surface transportation.

Intelligent Transportation Systems in a Real-Time, Customer-Oriented Society



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Joseph M. Sussman

We live in a "real-time, customer-oriented" society. Since the advent of the Internet and the availability of computational and communications capabilities to large segments of the population, we have become accustomed to responsiveness—for example, buying a book from home with the click of a mouse—in real time. In addition, we have become used to a dynamic market for services and goods, that is, choices that allow us to make trade-offs between price and quality, often measured on multiple dimensions. Surface transportation must also perform in this real-time, customer-oriented environment. Thus the transportation system must meet 21st-century imperatives.

Intelligent transportation systems (ITS) can be defined as systems in which advanced technology operates the surface transportation system by electronically linking vehicles to one another and to infrastructure. But ITS represents not only the innovative use of advanced technology, but also a change in the way we think about surface transportation.

In this article, I describe the potential benefits of ITS for the surface transportation system and how it can serve as an agent of change for that complex system. In addition, I identify organizational and institutional changes that will be necessary for the full benefits of ITS to be realized.

Background

ITS is based on technology that can sense individual vehicles and their characteristics (e.g., speed and location) on the transportation network (Chowdhury and Sadek, 2003). Various technologies are available for doing this, including devices that can sense vehicles using specialized roadside infrastructure (e.g., dedicated short-range communication beacons) or the Global Positioning System or the cellular telephone network. For this information to be of value to more than the drivers of individual vehicles, however, it must be communicated, either from the vehicle to some infrastructure or between vehicles to enable the gathering of data about the overall status of the network.

Collecting these massive amounts of data and reducing them to a form in which they can be used either to provide traveler information to individual drivers or to manage the transportation network as a whole requires computational capabilities and advanced mathematical algorithms to solve complex network problems. So ITS requires sensing, communicating, computing, and advanced mathematical techniques.

The availability of new technologies alone cannot drive the research, development, and deployment of ITS. Work on ITS is also motivated by shortfalls in the performance of the current surface transportation system on several dimensions. *Congestion*, which reflects insufficient capacity on our highways, is a major issue that affects the movement of both travelers and goods. The costs—both financial and environmental—of addressing capacity issues by building or expanding traditional infrastructure can be prohibitive, especially in urban areas where land-use constraints apply. ITS-based concepts can help combat congestion directly in two ways, through (1) information and (2) pricing. In combination with traditional infrastructure, ITS can also directly address the need for more capacity.

In the face of pressures on the highway trust fund, serious concerns have arisen, not only about congestion but also about the *financing* of surface transportation in the future. Another major concern is *safety*, particularly on highways. A fourth, continuing public policy issue is the *environmental impact* of transportation. ITS, as a technology-centric approach, can help address all of these issues (Sussman, 2005).

BOX 1 Privacy Issues

Concerns have been raised about the Big Brother aspects inherent in the real-time tracking of vehicles. Privacy has been an issue since the beginnings of ITS, and research is ongoing to ameliorate some of those concerns. However, in our real-time, customer-oriented society, we have all given up some of our privacy for improved efficiency in many areas. For example, think of the privacy issues inherent in carrying a cell phone, which is in effect a tracking device. ITS is the mobility analog of a cell phone that would make individualized traveler information available, if the individual is willing to give up some personal privacy.

But safeguarding privacy is a legitimate goal. The question is whether people will be willing to forego the convenience and efficiency ITS can provide to protect their privacy. The author suggests the answer is probably not.

Congestion and Insufficient Capacity

The Use of Information

Real-time vehicle tracking and knowledge of the state of the transportation network as a whole would benefit both the traveling public and system operators. Many examples of advanced traveler information systems (ATIS) are either available or in development. ATIS provide drivers with real-time advice on navigating the dynamic transportation network, which can change rapidly many times in the course of a typical day. A system that “knows” where you are and where you want to go (because you have told it) and “knows” the conditions of the network can provide routing assistance that can make your trip faster and more reliable (Box 1).

The information gathered by sensing vehicles on the network in real time can be used by transportation system operators to improve network performance via advanced transportation management systems (ATMS). This information can be used to monitor the network for incidents such as breakdowns or crashes that can cause congestion and to dispatch emergency equipment to remove the disruptions and restore traffic flow.

More generally, operators can integrate current information about the network with historical data, then test a variety of operating alternatives (e.g., adjusting traffic-light cycles or ramp metering rates and changing the information on variable-message signs), predict which alternative will work best for, say, the next 15 minutes, and implement that alternative. Every three minutes or so a new set of alternatives can be considered as network conditions change. Unlike ATIS, which benefit only individual drivers, ATMS takes actions that benefit all drivers.

The relationship between ATMS and ATIS is complex. Because ATIS services would probably not be free, some concerns have been raised about creating two classes of users—those who can afford to pay for ATIS and those who cannot—with deleterious effects for drivers who cannot pay. This concern about equity has some merit and must be addressed. One can imagine, for example, the "haves" receiving information and traveling more quickly and reliably than the "have-nots," who do not have access to that information.

It is generally true that people who buy tailored traveler information will have shorter and more reliable travel times. But some research shows that travel times for most drivers—those who receive information and those who do not—will be reduced as a result of ATIS routing (some) drivers away from points of congestion. Indeed, some experts believe that the best strategy for managing the transportation network is directing individual cars away from congested areas. This strategy, they say, would improve travel for most drivers throughout the network.

Clearly, ATMS and ATIS are linked systems, and this linkage raises the specter of drivers being given information for optimizing the system as a whole that might not be optimal for them in particular. This concern, too, may have some validity and should be addressed. However, it can be argued that this problem would be self-limiting, because if people are given bad advice, they will soon stop accepting it. Thus it would be in the interest of system managers to provide the best information they can. Research on linkages between ATMS and ATIS is ongoing.

Dynamic Pricing of Highways

Another way of dealing with congestion would be through sophisticated pricing. Available technologies, both in the vehicle and on the infrastructure, make it possible to dynamically price transportation services in a way that people willing to pay for a better level of service (e.g., shorter travel times, more reliable trips) will have the opportunity to do so, and will, in fact, receive a better level of service (Pickford and Blythe, 2006).

A straightforward example is high-occupancy toll lanes (HOT lanes), an extension of high-occupancy vehicle lanes (HOV lanes), which have been in operation for decades. HOV lanes are available only to vehicles carrying several people (usually two or three). The idea is that by giving people driving multiple-occupancy cars access to lanes that are less congested than traffic lanes used by people driving single-occupancy vehicles (SOVs), everyone will have an incentive to carpool, thereby reducing traffic.

HOT lanes provide another—and vital—degree of freedom, because a driver of an SOV willing to pay a fee for the privilege will be able to use the HOT lane. Vehicles with multiple occupants (including, for instance, express buses) would continue to use the lane for free. This would give SOV drivers an opportunity to trade off price for quality of service.

To ensure a good level of service, the price could be dynamic, that is, changed by the system operator as traffic conditions changed. If congestion increased in the HOT lanes, the price would be raised, so fewer drivers would be likely to pay to use them. This seemingly simple change is emblematic of how surface transportation could become part of our real-time, customer-oriented society, in which choices for consumers—both travelers and freight carriers—would be front and center.

Sophisticated, dynamic pricing schemes could be used to help address the problem of congestion.

Dynamic pricing is a new concept in surface transportation. Typically, during rush-hour congestion, the highway system currently allocates its limited capacity by requiring people to queue for service, which creates a dead-weight loss because there is no market-clearing mechanism. Everybody queues, even those who would be willing to pay a price to avoid congestion.

Once price enters into the equation, customers can be sorted by their willingness to pay, which could lead to other possibilities. Our highway systems are plagued by recurring congestion during rush hour. Everyone knows that at 8 a.m. on weekdays, when people are traveling to work, which begins at approximately the same time for all of them, certain points in the highway system will be congested.

If operators of highway systems could price their facilities, they could, for example, charge people more for driving during rush hour. This could have the effect of "shaving the peak" by giving people an incentive to travel before or after the peak travel time, if they had that flexibility—a big if, of course. If enough people took that option, however, it would "clear the market," thus creating a more uniform demand for limited highway capacity.

This demand-side approach would count on travelers to change their behavior. A similar incentive is used by energy providers who have implemented time-of-day pricing for energy in an attempt to lower their capital investment costs and entice people, through differential pricing, to use less energy during peak hours.

The extension of this idea, universal road pricing, is now a subject of discussion. We might sense all vehicles on the infrastructure everywhere at all times and charge for the use of the roadway as a function of location, time of day, and other parameters, such as congestion level, environmental conditions, and the characteristics of the vehicle (e.g., weight). In some situations, there might be a minimal charge or even no charge at all.

> *"Road charges" could partly replace the traditional gas tax.*

Financing of Surface Transportation

Based on the pricing concept described above, we can rethink how we finance surface transportation. Presumably, "road charges" would replace, at least in part, the traditional gas tax, through which people pay at the pump for access to the highway system.

There are several problems with the gas tax. First, it is a blunt instrument for managing the transportation network. Everyone pays the same gas tax, regardless of when or where he or she uses the system. Second, transportation officials are increasingly concerned about whether the gas tax can provide enough revenue for the continued building and maintenance of our highways *and* for advanced technologies to implement the improvements described above.

Third, raising the gas tax has been politically problematic for some time; see, for example, the recent high-level report by the National Surface Transportation Policy and Revenue Commission (2007), in which the commissioners were split on this very question. Fourth, rapidly advancing new technologies (e.g., hybrids) are making vehicles more fuel efficient. Finally, we must take into account the geopolitical situation surrounding oil.

Road charges would not only provide an alternative revenue stream, but would also be a more sensitive instrument for managing the transportation network strategically. Of course, there would be substantial political barriers to overcome. There was, and is, political opposition to simple congestion charging, and even to simpler cordon-pricing schemes, like the one recently tabled in New York City. Nevertheless, the author believes that, in our real-time, customer-oriented society, road charging is the wave of the future for surface transportation.

Pricing is a good example of how ITS and technologies can not only improve the operation of the transportation system, but can also be a fundamental force for change in the transportation field. Pricing would allow surface transportation to operate as a market, at least partly, and allow the pricing of heretofore un-priced externalities, such as congestion and environmental impacts.

Safety of Surface Transportation

Improving safety is an imperative for the transportation system in the United States. Although fatalities per vehicle-mile traveled (VMT) have decreased continuously over the last several decades, the overall number of VMTs has increased over that period. Thus we have reached a plateau at a still-unacceptable 40,000+ people killed per year on the nation's highways.

Improving safety has long been a primary goal of ITS, which offers a new approach to safety problems. For many years, the watchword of safety programs was crashworthiness, that is, building vehicles that would increase the chances of survival in a variety of crash environments. Of course, we must continue to make vehicles safer, but with ITS, we can also emphasize crash avoidance.

Much recent attention has been focused on an initiative called vehicle-infrastructure integration (VII), the creation of linkages between vehicles and from vehicles to the infrastructure. I have already described how such linkages can provide traveler information and improve network operations, thereby improving mobility. However, the primary goal of VII is to improve safety.

Suppose two vehicles are approaching an intersection, one traveling in the north/south direction, and one in the east/west direction. Suppose also that they are electronically "aware" of each other, either via a vehicle-to-vehicle link or via the linkage of both vehicles to the infrastructure. Given this awareness, there is a smaller probability of a crash at that intersection, even if, for example, one of the drivers runs a red light.

Various ITS technologies, including VII, freeway-management systems (Olmstead, 2001), and in-vehicle autonomous driver aids (e.g., collision-warning sensors, lane-departure warning systems, and electronic braking) are important mechanisms for improving safety.

Environmental Impacts of Surface Transportation

The relationship between transportation (i.e., mobile sources) and air quality, as well as emissions of greenhouse gases related to global climate change, have been understood for decades, and one of the benefits of sensing technologies might be to locate high emitters of pollutants. The more general question, however, is whether ITS would be a plus or a minus for the environment. Here are the competing points of view (in headline form):

> *ITS can smooth traffic flow, thereby reducing stop-and-go driving, which has a deleterious effect on air quality.*
>
> *By adding capacity to the transportation network, ITS will induce demand and therefore "add tailpipes" to the traffic stream.*

In fact, the issue is more nuanced than that. Dodder (2006) notes that investment in ITS has rarely been made strictly for environmental (specifically improving air quality) reasons. She suggests, therefore, that we look for opportunities (as many cities have) to invest in ITS alternatives that deal with congestion (which are relatively easy to fund) and that also have a positive environmental effect. She argues that cities should look beyond the issue of congestion relief and try to leverage a portfolio of ITS investments that would improve mobility for different modes of transportation, including public transportation, in ways that would move us closer to meeting air-quality goals:

> ITS seems to represent a case of potential synergies—or so-called "win-win" outcomes—that could be realized for the dual policy goals of air quality and mobility. If the various public sector organizations responsible for air quality and transportation could cooperate in deploying, assessing and further adapting these new (ITS) technologies to take advantage of these synergies, they could achieve a "sustainable use" of ITS (Dodder, 2006).

She goes on to develop a framework called "Integrated Innovation Deployment and Adaptation of Public Technologies (IIDAPT)," which she applies to Los Angeles, Houston, Boston, Orlando, Tulsa, and Mexico City as case studies of using ITS to address air quality.

Considering that not only technologies, but also institutional issues that influence how those technologies are deployed and adapted must be taken into consideration, the question of whether ITS is good or bad for the environment must be studied at a much more sophisticated level.

Experts disagree about the effects of ITS on the environment.

A Balanced Approach

Because of the need for a customer and market focus in providing surface transportation and because of constraints on building conventional infrastructure, especially highways, the emphasis in modern surface transportation systems must be balanced between infrastructure (which we will continue to build) and operations, using pricing to manage the network. This approach is possible with ITS technologies that can help us manage congestion and improve safety and, perhaps, the environment as well.

ITS requires that we approach surface transportation as a regional system as well as a multimodal/intermodal system, because customers (i.e., travelers and movers of freight) consider their trips not as separate links but as integrated origin-to-destination trips on a large geographic scale that often require several modes of transportation. Communications can be thought of as a "mode" that can make travel more efficient, and sometimes even a substitute for it.

Organizational and Institutional Change

The ambitious change to an operations and customer focus will not be easy to achieve. The focus on operations on a regional scale, along with new technologies and multimodal/intermodal systems, will require changes in transportation organizations, many of which will have to embrace new missions that include information-sharing and responsibility-sharing

BOX 2 Flexible Design

Dealing with uncertainty is a fundamental concern in the design of complex, sociotechnical systems. Simply put, it is imprudent, not to mention ineffective and costly, to think of the future as a deterministic point estimate. One of the benefits of ITS is that it provides flexibility in the face of inevitable uncertainties about the future.

Even when we must make an "inflexible" decision, such as having to commit to a large capital investment before we know what the demand will be, ITS can provide flexibility by enabling us to retain "options" to change the design as future conditions become clearer.[1]

For example, ITS provides a mechanism for deferring conventional capital investment in highway infrastructure until we have a better idea of future demand. In addition, ITS can make investments in conventional infrastructure more flexible by allowing operators to change lane use, say, from HOV to HOT/bus to freight only or to conventional use. These flexible design decisions create an additional value stream over and above the inherent value of ITS technologies.

However, "flexibility" is not cost free. We must develop a method of valuing it so we can compare value with costs. "Real options," analogous to financial options, applied to real systems can be used to compute the value stream that results from flexible design.[2]

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[1] In a companion article in this issue, de Neufville describes flexibility in designing airports (see p. 41).

[2] For a study of flexible transportation systems enabled by ITS technologies in Houston, see McConnell, 2007. For a study of ITS as an alternative investment to major infrastructure improvements in Finland, see Leviäkangas and Lähesmaa, 2002. For a study of flexibility-based value streams in VII, see de Neufville et al., 2008.

(Box 2). These changes, together with new funding patterns that reflect a shift from capital to operations expenditures, will require fundamental changes in the relationships among these organizations.

Institutional changes will be necessary at all levels of government—federal, state, regional, and local, as well as in the private sector—that are involved in operating infrastructure (e.g., through concessions). The organizational and institutional changes, although difficult, will be necessary for the full potential of ITS to be realized (Sussman, 2001).

Conclusion

In this article, I have identified opportunities for improving—and even fundamentally changing—surface transportation in the United States through ITS technology. In the process, I have also uncovered emerging issues that must be addressed, including concerns about equity, privacy, and ambiguities in the impact of ITS on the environment. All in all, I believe that the opportunities for positive change in the transportation system substantially outweigh these concerns.

Nevertheless, we will continue to work on addressing those concerns. In truth, we must address them if we expect to build enough support for the full deployment of ITS technologies. Public acceptance, commercial acceptance, and political acceptance are all preconditions for the widespread deployment of ITS.

Space does not permit a discussion of all of the important aspects of ITS, such as privacy (Kokotovich and Munnich, 2007) and applications of ITS to public transportation (FTA, 2006), commercial vehicle operations (RITA, 2008a,b), homeland security (ITS-America and DOT, 2002; TRB, 2008), and automated highway systems (Bishop, 2005; PATH, 2007).

Success for ITS will be achieved when the new system is so well integrated in transportation decision making that it is routinely considered part of the overall transportation solution.

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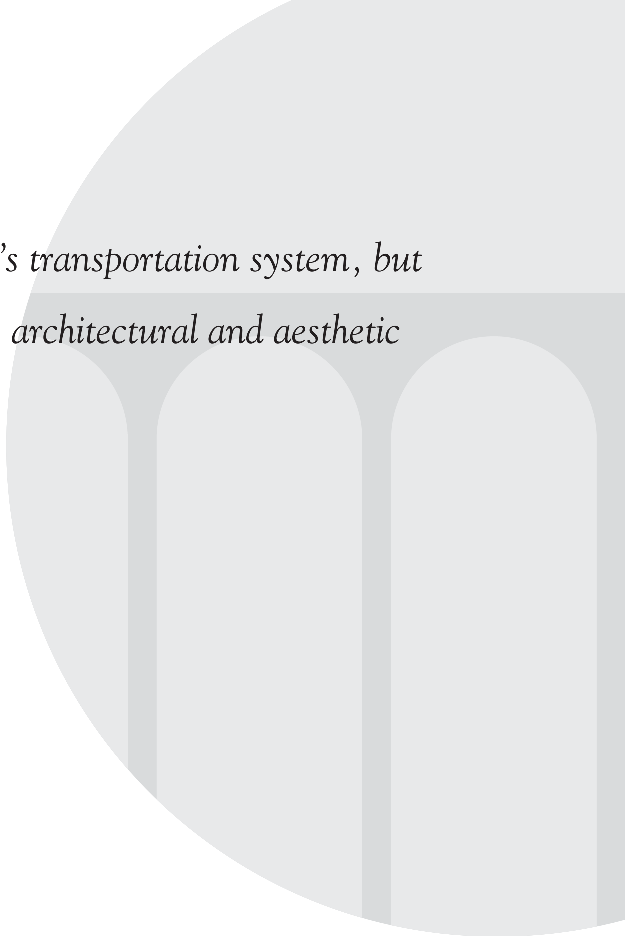
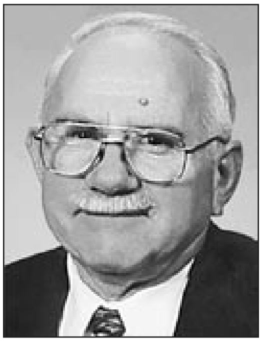


Bridges are part of a city's transportation system, but also part of its distinctive architectural and aesthetic landscape.

The Safety of Bridges

Theodore V. Galambos



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At approximately 6:00 p.m. on August 1, 2007, the bridge carrying Interstate Highway I35W over the Mississippi River in Minneapolis collapsed, plunging rush-hour traffic some 35 meters down with the bridge or into the river. Many of the people in the cars, buses, and trucks survived the unexpected drop; however, 13 were killed and about 80 were injured. Rescue response was almost immediate, and many heroic acts were performed by the surviving passengers, police, and rescue workers, demonstrating that the community was well prepared for an emergency.

The collapse of this bridge was sudden, unexpected, and complete. The structure essentially disintegrated within seconds. Because the demise of the bridge was recorded by traffic management cameras, the whole world witnessed the catastrophe within minutes. The questions on the minds of everybody were how something like this could happen, whether it is safe to drive over any bridge, and who was responsible. These questions are entirely reasonable and must be answered by the bridge-engineering community to reestablish confidence in this part of our infrastructure. This essay is my personal response to the question of why bridges collapse and what we as engineers should do, beyond what is already being done.

Bridges define the character of a city. When I think of New York, San Francisco, London, Paris, Lisbon, or Budapest, it's the bridges that come to mind. City residents are proud of their bridges, which not only provide transportation links, but are also part of their city's architectural and literary heritage and the aesthetic landscape of civilization. A Nobel Prize in literature was once awarded for *The Bridge on the Drina*, a novel of the life of a bridge (Andric, 1977).

There are many thousands of bridges in the world, and there have been thousands more in the past, and it is hardly surprising that there have been partial failures and total collapses. But most of these occurred in the past or in other countries, and so the general American public has not worried about routinely crossing bridges. However, when a failure happens almost next door (the I35W Bridge is a 20-minute walk from my office at the University of Minnesota), we take note!

This is especially so if the failure comes out of the blue on a clear, warm summer day on a bridge that has done its job for half a century. Drivers on the Minneapolis bridge were often not even aware that they were on a bridge. A minute or so, and they were across. No wonder people were upset when this permanent, solid, dependable bridge suddenly gave up the ghost.

People often take great risks. Driving a car, crossing a street, smoking, overeating, even getting married, might have dire consequences. However, individuals voluntarily put themselves into these situations, even though they could have bad outcomes. *The collapse of a bridge, however, is not a voluntary risk.* It is, quite simply, not supposed to happen. Hardly anybody in the world perishes because of the collapse of a bridge.

In a pioneering book on the safety of structures, Pugsley (1966) relates that fighter pilots in WWII went up against the enemy even when there was a high chance they might be shot down. But these same pilots demanded design changes if the structural failure rate of their aircraft was more than 5×10^5 per flying hour. So to the public, the collapse of the Minneapolis bridge is a serious event that must somehow be explained.

Historical Perspective

The collapse and disintegration in a matter of seconds of a bridge that is judged to be sound is almost unheard of. Yet it does happen from time to time, and the memory of such an event lasts the lifetime of the generation that experienced it, even remotely through reports by the media. One such event, which has many similarities to the Minneapolis bridge failure, is described below.

On December 15, 1967, at Point Pleasant, West Virginia, the Point Pleasant Bridge over the Ohio River collapsed. My knowledge of this collapse comes from the final accident report of the National Transportation Safety Board (NTSB, 1970) and from my brother, Charles Galambos, who worked on the investigation. The bridge was constructed in 1929 and had been in service continuously for 38 years when the structure suddenly collapsed during the evening rush hour. Forty-six people died, nine were injured, and scores of vehicles fell into the river. This unfortunate collapse was very like the event in Minneapolis on August 1, 2007.

The Point Pleasant Bridge was a novelty in its time; few such bridges were constructed during its lifetime, and none after its collapse. The sketch in Figure 1 shows the general features of this hybrid structure, somewhere between a truss bridge and a suspension bridge (NTSB, 1970). In the middle of the central span, the tension in the suspension bars is counteracted by the compression in the top chord of the truss. The economic advantage of this type of bridge was that the two forces somewhat cancelled each other out.

The suspension system consisted of sets of two eyebars connected by pins at the junction between adjacent

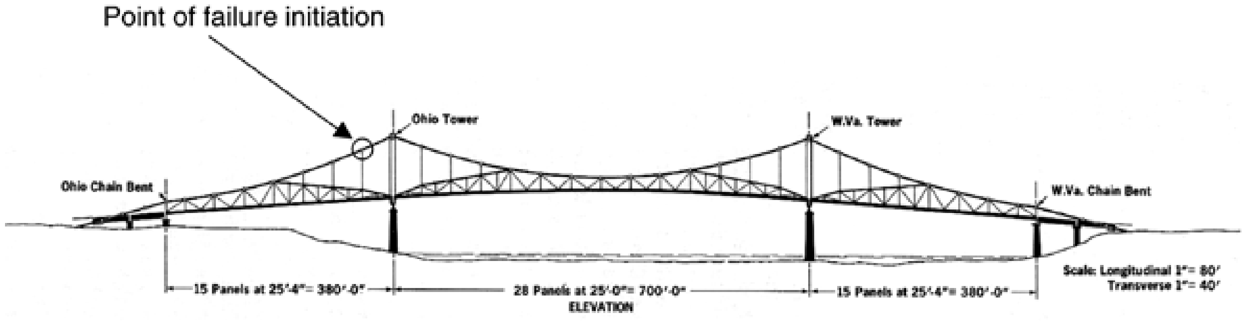

FIGURE 1 Sketch of the Point Pleasant Bridge. Source: NTSB, 1970.

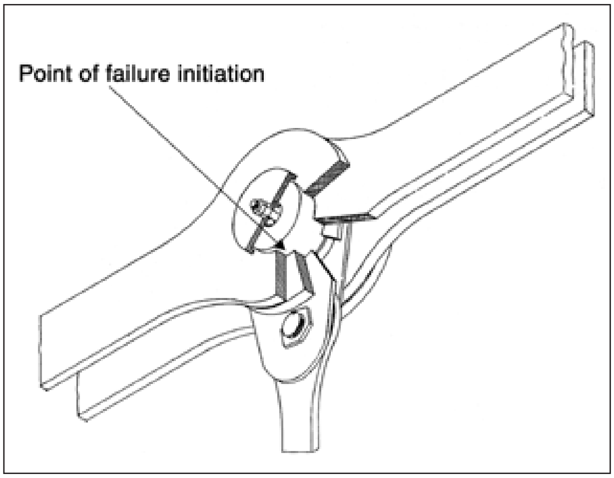

FIGURE 2 Sketch of the eye-bar arrangement of the Point Pleasant Bridge. Source: NTSB, 1970.

segments (Figure 2). The eye-bars were made of a new, tempered, high-strength steel. Failure was initiated by the brittle fracture in the eye-bar material at the first joint to the north of the tower on the Ohio side in the suspension structure, as shown in Figure 1. The causes of the failure were described in the NTSB report:

> . . . the cause of the bridge collapse was the cleavage fracture of the lower limb of the eye of eyebar 330 at joint C13N of the north eyebar suspension chain in the Ohio sidespan. The fracture was caused by the development of a critical sized flaw over the 40 year life of the structure as the result of the joint action of stress corrosion and corrosion fatigue.
>
> Contributing causes are:
>
> 1. In 1927, when the bridge was designed, the phenomena of stress corrosion and corrosion fatigue were not known to occur in the classes of bridge material used under conditions of exposure normally encountered in rural areas.
> 2. The location of the flaw was inaccessible to visual inspection.
> 3. The flaw could not have been detected by any inspection method known in the state of the art today *[1970, emphasis added]* without disassembly of the eye-bar joint.

FIGURE 3 Eye-bars of the Budapest Chain Bridge.

This disaster was a wake-up call for the bridge-engineering community, and the design, construction, inspection, and maintenance of bridges changed radically as a result. Biannual inspections and material fracture toughness requirements were mandated, as well as other changes over the years, especially related to fatigue and brittle fracture. The change of most interest for this essay was the requirement that a bridge be *robust*, that is, that it should not totally collapse when a local joint or member fails. In the jargon of bridge-design standards, the system must not be prone to "progressive collapse." The forces that a failed part is designed to carry must be able to be rerouted to another path. In other words, the structure must be "redundant."

If the Point Pleasant Bridge had been built with many eye-bars in each chain link, like the Budapest Chain Bridge (Figure 3), it would still be in service today, with fractured eye-bars replaced as needed. Thus the cause of failure was not the fracture of the eye-bar per se, but an error in judgment during design.

Causes of Bridge Failures

A bridge is all structure. Unlike a building, which has walls, stairs, elevator shafts, slabs, and other features that usually add uncounted strength and stiffness to the

FIGURE 4 Cable-stayed bridge over the Savannah River.

structural system, bridges have no hidden sources of strength. Every part of a bridge is there for structural purposes of strength and stiffness.

Most bridge failures occur during construction, when the structure is most vulnerable. Also during construction, many problems of undesirable bridge behavior are ironed out. Once a bridge is completed, one can confidently expect that the structure will last for its intended life span and perform its intended job. Although there are rare collapses during the service life of bridges, most of these are partial collapses, and most are discovered in good time and repaired.

The list that follows describes a few of the many possible causes of bridge collapse:

- *Previously unimagined effects of natural forces*, such as the force of the Loma Prieta earthquake that caused the partial collapse of one segment of the traffic lane on the San Francisco-Oakland Bay Bridge. The span collapsed as a result of out-of-phase movements of supports as the seismic wave traveled along the bridge. Design standards now require specific measures to ensure structural continuity between the bridge superstructure and its supports.
- *Deliberate destruction in war.* Most of the bridges in Central Europe were destroyed during the Second World War. In the long run, this was beneficial for the future of bridge engineering, because the reconstruction of those bridges was a veritable renaissance in the art of bridge building. Out of economic necessity, new architectural forms evolved, such as plate-girder bridges, cable-stayed bridges (Figure 4), and prestressed concrete bridges. Since then, this rejuvenation has moved from Europe to America to Japan and presently to China.
- *Carelessness or accidents.* An example of a failure caused by carelessness is the destruction of the original Sunshine Skyway in Tampa, Florida, which was caused by the collision of a ship with one of its piers. Since then, piers in waterways have been surrounded by strong protective barriers.
- *Fatigue and brittle fracture of structural members and connections.* This type of failure is frequently caused by a misunderstanding of the details of connections or by the use of incorrect materials.
- *Decay from cracking or corrosion, often indicating improper maintenance and inspection.* One of the major responsibilities of bridge inspectors is to watch for such deterioration. Although we know how to design to prevent fatigue and brittle fracture, cracking and corrosion are normal consequences of aging and should be constantly watched for and repaired when discovered.
- *Unfamiliarity with new materials, details, and structural systems at the time of design.* This was one of the problems with the Point Pleasant Bridge discussed above.
- *Unseen hazards.* The most recent concern is about scouring at the bases of bridge piers where they interface with the riverbed. This problem is currently thought to be the most common cause of bridge failure and is an area of ongoing research.
- *Unknown hazards, the rarest and most dangerous causes of collapse.* One of the most complex issues is applying the principles of structural engineering to situations for which designers have no previous experience or are not aware of research done elsewhere. For example, the cause of the failure of the Firth of Tay Bridge

in Scotland on December 28, 1979, during a great windstorm was that the designers had not considered the effects of wind forces on the structure (Prebble, 1956). In the case of the collapse during construction of the Quebec Bridge over the St. Lawrence River on August 29, 1907, the designers had neglected one term in a differential equation of column strength; the effect was negligible for columns of solid cross section but significant for the type of latticed, open-section columns used on this bridge (Government Board of Engineers, 1919). The West Gate Bridge in Melbourne, Australia, collapsed on October 15, 1970, for a variety of reasons (Royal Commission, 1971); research by Professor Noel Murray of Monash University in Melbourne showed that the designers had applied the prevailing theory of the behavior of stiffened panels welded from thin steel plates beyond its area of applicability.

Consequences of Bridge Disasters

Every bridge failure has provided builders and engineers with an opportunity to do better next time, to apply the lessons learned to the next design, and to retrofit existing structures. This process is illustrated in the cartoon in Figure 5. When a new configuration of bridge geometry or a new combination of materials is used for a bridge, designers proceed conservatively. If they are successful, they are encouraged to be less and less conservative over time, until they run out of the elbow room provided by the safety factor, which can result in failure of the system.

Society reacts to these failures either by being more conservative in the next design or by judging the type of bridge to be unsuitable. As confidence is regained, the cycle then starts up again, this time buttressed by research, and eventually a good balance is reached between safety and economy.

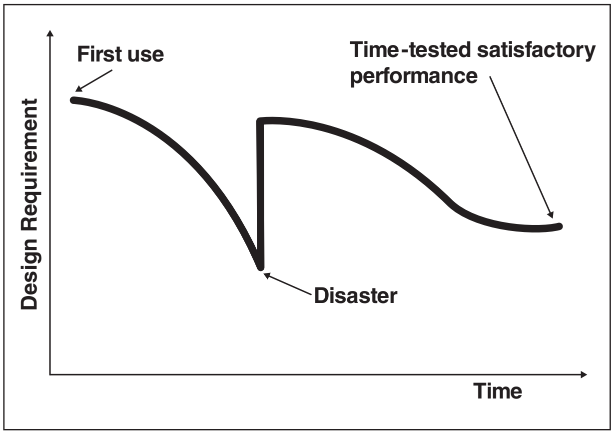

FIGURE 5 Cartoon of the evolution of bridge design.

The classic example is the stiffened roadway on suspension bridges, which became less and less stiff with each new bridge, until the Tacoma Narrows disaster. Research and an understanding of aerodynamic phenomena have now progressed to the stage at which designers all over the world are designing suspension bridges with longer and longer spans.

This scenario has been repeated many times over for other types of bridge structures. Current bridge art is based on the cumulative experience of designers, planners, fabricators, and builders, and on collaboration with researchers in academic, governmental, and industrial organizations and laboratories. Although much has been learned from studying the causes of bridge failures and from research conducted after catastrophes, it would be far better to conduct the research first and avoid the bridge collapses altogether.

Back to Minneapolis

If we have the experience with science, theory, design, and construction techniques, as well as thoroughly researched studies of past failures, why did the bridge in Minneapolis fail? This particular bridge was watched over by inspectors and engineers from the Minnesota Department of Transportation, was thoroughly examined frequently by a consulting firm, and was studied several times in the last decade by graduate students under the guidance of structural engineering professors at the University of Minnesota. To use a medical analogy, the patient died of unknown causes in the hospital with medical specialists standing around the bed studying the symptoms. The precise causes of this collapse are still under investigation by NTSB, and no definitive conclusions have been published at this time (April 2008).

The following is my guess about what happened. It seems now (in April 2008) that the investigators and inspectors somehow missed the fatal points of weakness. A few days after the disaster it was clear from preliminary examinations of the wreckage that one particular node, repeated symmetrically in four places in the trusses of the center span, had been constructed with insufficiently thick “gusset” plates, which are riveted to the members that enter the joint, thus holding them together to form a node in the two trusses. The gusset plates were reported by NTSB to be half as thick as they should have been.

The deck of the bridge was being replaced at the time of collapse, and construction material and equipment were located in the lanes where the replacement work was being done. The resulting extra force on the four presumably half-strength joints could have caused one or more of the gusset plates to fracture, yield, and/or buckle. Although the structure had some redundancy, there was probably no time for the redistribution of forces, or else the critical joints were weakened enough to destabilize the center span. The suddenness of the collapse shows how quickly gravity takes over (think how quickly you find yourself on the ground after slipping on an icy sidewalk). Thus the collapse can be simply explained by the loss of stability caused by overload and under-strength. Gravity took care of the rest! The NTSB report will surely provide specific details and scenarios of other possible contributors to the failure.

Lessons from Minneapolis

As long as there are humans in the world, there will surely be bridge failures in the future, although they will be rarer because of the lessons we have learned. Instructions from government agencies to bridge owners are now being formulated, and the NTSB's recommendations will reduce this tiny probability even more. Nevertheless, whatever we do, there is always a remote chance that we will miss something. Recommendations for the future will certainly include the following measures:

- Older bridges and larger bridges should be under observation by experienced bridge engineers who have years of knowledge with the bridges under their supervision. The original designs of these bridges should be periodically examined and reanalyzed using state-of-the-art computer methods and current design codes.
- The design calculations, drawings, and contract documents for new bridges should be reviewed carefully by experienced bridge engineers who were not involved in the original design. The bridge documents should also be "peer reviewed" by an agency not associated with the original design or the bridge authority that owns the structure.
- Robustness and redundancy should be incorporated into the bridge design as a matter of course to counteract unexpected and unimagined hazards, especially the possibility of progressive collapse.
- The design and construction teams should conduct a "hazard scenario" exercise to reveal possible problems prior to the start of construction.

Many new devices and instruments for monitoring critical parts of bridges, such as accelerators that can reveal changes in the dynamic signature, strain gauges and deflection gauges, and many types of cameras are now available or are being developed. Other, even exotic, high-technology devices may also become available. Data from these instruments can be electronically transmitted, stored, and finally evaluated by inspectors and experienced engineers. No doubt more monitoring schemes will be installed as a consequence of the Minneapolis bridge collapse. However, it will require sustained discipline to store and evaluate data for the life of bridges, for the large majority of which no noteworthy event will ever be observed.

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America's freight railroad system is the envy of the world.

The Freight Railroad Renaissance

John M. Samuels is president of Revenue Variable Engineering LLC and an NAE member.

John M. Samuels

When I mention freight railroads, most people think of steam engines and passenger trains rather than freight trains, and considering Americans' love for passenger trains over the years, this is not surprising. Since the advent of the interstate highway system in the 1950s, freight railroads have had a difficult time competing with highway trucks. In fact, by 1980 many freight railroads were on the verge of bankruptcy. In response to this dire situation, Congress passed the Staggers Rail Act of 1980, which deregulated the railroads and allowed them to compete freely in the marketplace.

As freight railroads learned to compete, they emerged from those difficult times to become an increasingly vital part of America's transportation infrastructure (Figure 1). To compete effectively with other transportation modes, railroads knew they had to not only reduce their costs but also improve their service reliability (Figure 2). With time, as rail freight service became more reliable, the volume of freight transferred from highway trucks and containers back to freight railroads increased dramatically, based on cooperative agreements between trucking companies and railroads.

The general size of the North American freight railroad network is shown in Figure 3. The industry consists primarily of seven major railroads, called Class 1 railroads, and numerous smaller regional and short-line railroads. Freight railroads in the United States operate as a single system based on universally accepted interchange rules maintained by the Association of

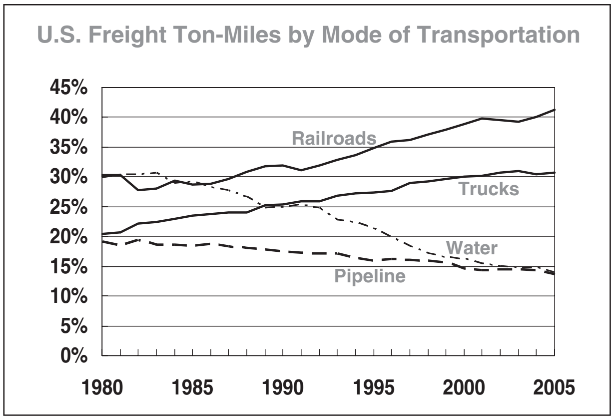


FIGURE 1 Changes in the market share of U.S. railroads from 1980 to 2005. Note: Pipeline does not include natural gas. Source: DOT, 2007.

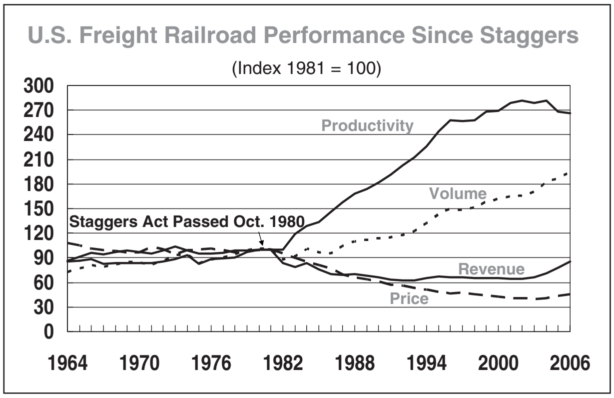


FIGURE 2 Improvements in productivity, volume, revenue, and cost reduction since 1980. Source: AAR, 2008.

American Railroads (AAR) in Washington, D.C. Tracking information on car flow and interchange data are collected by Railinc, a wholly owned subsidiary of AAR.

The successful operation of individual, for-profit, private companies working together in an integrated system has made America's freight railroads the envy of the world. Until the 1990s, freight railroads in most other countries were government owned. Since then, however, following the U.S. model, many countries are privatizing their freight rail operations, driven largely by the realization that railroads must be part of the "green" solution to the growing problems associated with global warming and petroleum dependency. From 1980 to 2006, railroad fuel efficiency in the United States improved by 80 percent. Today railroads are three or more times as fuel efficient as highway trucks, and locomotives emit far fewer greenhouse gases than trucks per ton-mile of freight moved. Another reason for the "greening" of railroads is that a typical freight train can carry several hundred truckloads of freight, which helps reduce both highway congestion and wear and tear on highway infrastructure.

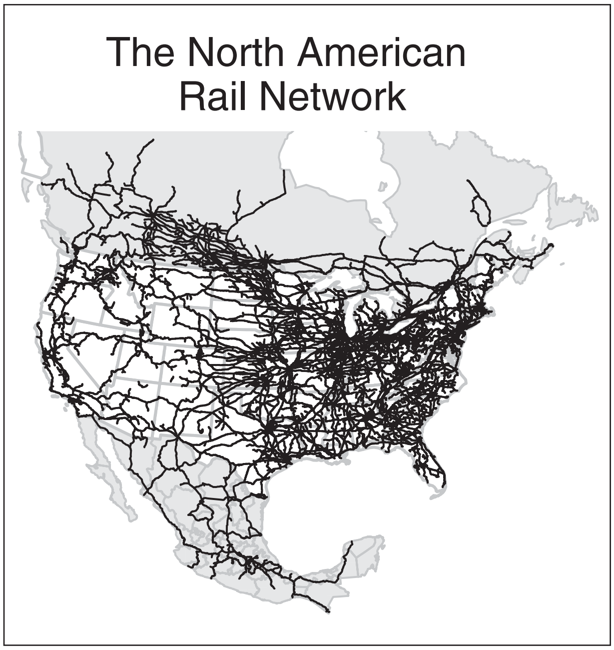


FIGURE 3 Map showing the extent of the freight railroad track network in North America. Source: Reprinted with permission of AAR.

Thus the picture of freight railroading today is very different from the picture in 1980. Freight railroads today are poised for a renaissance, and creative applications of science and engineering will ensure that railroads take their rightful place as a strategic part of America's future.

The Digital Railroad of the Future

Efforts are currently under way to define the railroads of the future. Numerous reports have been issued by AAR and other government agencies involved in planning the U.S. transportation infrastructure, such as the U.S. Department of Transportation and the Federal Railway Administration. In addition, the American Association of State Highway and Transportation Officials (AASHTO) issued a comprehensive report in January 2001 entitled *Transportation Investments in America: Freight Railroad Bottom Line Report*, reiterating the critical need for a strong American freight railroad infrastructure. In September 2007, AAR issued *National Rail Freight Infrastructure Capacity and Investment Study*, in which the authors quantified the need for added rail capacity to handle projected traffic levels for 2035.

All of these reports also identified a need for railroads to continue to improve safety, productivity, and service reliability through the creation of a digital railroad communications infrastructure that would enable railroads to expand the use of computerized control systems related to almost every aspect of railroad operations. Some of the most important of these are described below.

Digital Railcar-Inspection Devices

Wheel-Impact Load Detectors

Railroads deploy wayside detector systems along the railroad right-of-way to assess the dynamic health of railroad cars in transit. These detectors measure the forces created at the wheel/rail interface (Figure 4), which should be kept at a minimum to maximize the useful life of the track structure. Today, approximately 107 digital wheel-impact load detectors (WILDS) are deployed on railroad mainline tracks.

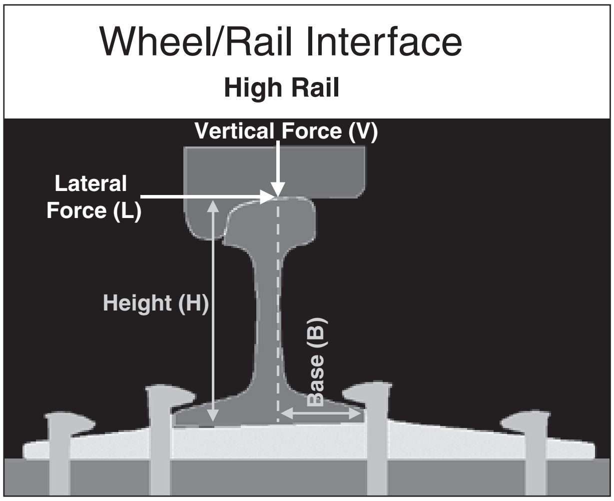


FIGURE 4 Schematic drawing of the critical wheel/rail interface.

As a train passes over the detector at track speed, wheel loads are measured around the circumference of each wheel, and nominal and impact loads are recorded. Wheels that normally have vertical loads of 36,000 pounds per wheel for a loaded railcar can create excessive impact loads, up to approximately 160,000 pounds per wheel, if the wheel running surface is damaged. Wheel-impact data from WILDS are digitally transmitted to InteRRIS, an industry-wide database maintained by Railinc. Railcars with defective wheels are tagged in the computer system and routed to car repair shops.

Truck-Performance Detectors

In-track sensors used in WILDS are placed on curves to measure the lateral forces exerted by railcars as they travel around the curve. These detectors, known as truck-performance detectors (TPDs), measure both vertical and lateral forces exerted on the rail to assess the railcar's ability to negotiate the curve. Data from these detectors are also sent to InteRRIS, and railcars with poor steering are routed to car repair shops before they cause excessive damage to tracks. TPDs are used to measure the stresses exerted by all 1.8 million railcars that transit America. Data are kept for the life of the railcar, so railroads can monitor railcars over their useful lives and send cars that could potentially cause train derailments to repair shops.

Hot-Bearing Detectors

A third type of wayside detector monitors roller bearings on railcar wheels to determine if the bearings are near failure. Hot-bearing detectors (HBDs) use infrared cameras to measure the temperature of roller bearings to ensure that it is within the normal operating range. If an HBD finds a bearing with too high a temperature, the train is stopped, and the bearing is inspected.

Trackside Acoustical Detectors

Recently deployed trackside acoustical detectors (TADs) measure the sounds made by bearings as they pass by the detector at track speed and use digital pattern recognition to identify bearings that are near the end of their useful lives. A TAD detector (Figure 5) usually identifies a bearing long before it is about to fail, so the railcar can continue to its destination and then stop for repairs at the next convenient point in its transit.

Digital Train-Inspection Devices

As part of the Advanced Transportation Safety Initiative (ATSI), the railroad industry research facility in Pueblo, Colorado, known as the Transportation

FIGURE 5 Track-side acoustical detector (TAD). Source: Reprinted with permission of Norfolk Southern.

Technology Center Inc. (TTCI), is developing wayside inspection units that use laser cameras and/or digital machine vision pattern-recognition systems. FRA, industry suppliers, AAR member railroads, and TTCI researchers are working hand-in-hand to solve the industry's most challenging safety problems. Systems positioned on the railroad right-of-way can conduct a complete safety inspection of railcars before they leave the terminal. Thus cars found to have problems can be cut out of the train. This capability will dramatically reduce the probability of in-transit failures.

Digital Track-Inspection Devices

Laser-Acoustic Rail-Flaw Inspection

Railroads have historically used ultrasonic inspection systems to look for internal defects in steel rails. Inspections are carried out by on-track inspection vehicles that move down the track at about 3 miles per hour (mph). Fatigue defects in rail steels develop over time from stress transmitted at the wheel/rail interface. These defects usually grow slowly as a result of repeated stress cycles until they reach a critical size, at which point the rail must be removed.

Current ultrasonic rail-inspection techniques cannot detect defects in the base of a rail, but a new higher powered laser-acoustic system will be able to inspect approximately 98 percent of the rail cross section. With this system, the inspections truck can travel up to about 18 mph along the right-of-way, while computers aboard the car record digitized data from the acoustic signals and process the data into a GIS database. This system will make it significantly easier to find rail flaws before they become a safety concern.

Automated Digital Track-Geometry Cars

All Class 1 railroads in America own one or more track-geometry cars (TGCs). A TGC (Figure 6) is equipped with multiple computer systems that measure the quality of the railroad track structure as the TGC rides over it at speeds of up to 70 mph. Lasers and camera systems record both the quality of track geometry (e.g., gauge, cross-level, and vertical bounce) and wear dimensions. These real-time data-acquisition systems feed the latest track-quality parameters into predictive models that can be used to plan maintenance programs. Real-time track measurements are compared to FRA track standards, and variations are immediately tagged for corrective action.

Another variation of the TGC, which is being used more and more frequently, is the gauge-restraint measuring system (GRMS). This car is similar to a TGC but has a split-axle system in the middle of the car (Figure 7). When activated, the split-axle system puts a lateral load on the inside gauge faces of the rail simulating the lateral forces exerted by a passing train and testing the ability of the track (i.e., the fastening system that holds the rail to the railroad ties) to withstand the load. GRMS vehicles are usually run at about 30 mph to test lateral track strength. Data acquired from GRMS cars is also fed into a GIS database and used for maintenance planning purposes to ensure that weak spots are repaired.

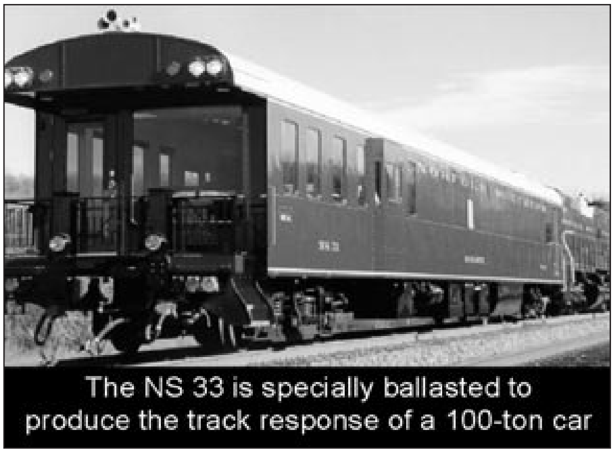


FIGURE 6 Track-geometry car (TGC). Source: Reprinted with permission of Norfolk Southern.

FIGURE 7 Gauge-restraint measuring car (GRMC). The self-contained motorized railcar is on the left; a high-rail inspection vehicle is on the right. Source: Reprinted with permission of Norfolk Southern.

Digital Train-Control Systems

Positive Train-Control Systems

Today the majority of high-tonnage mainline track is equipped with failsafe signal-control systems that work

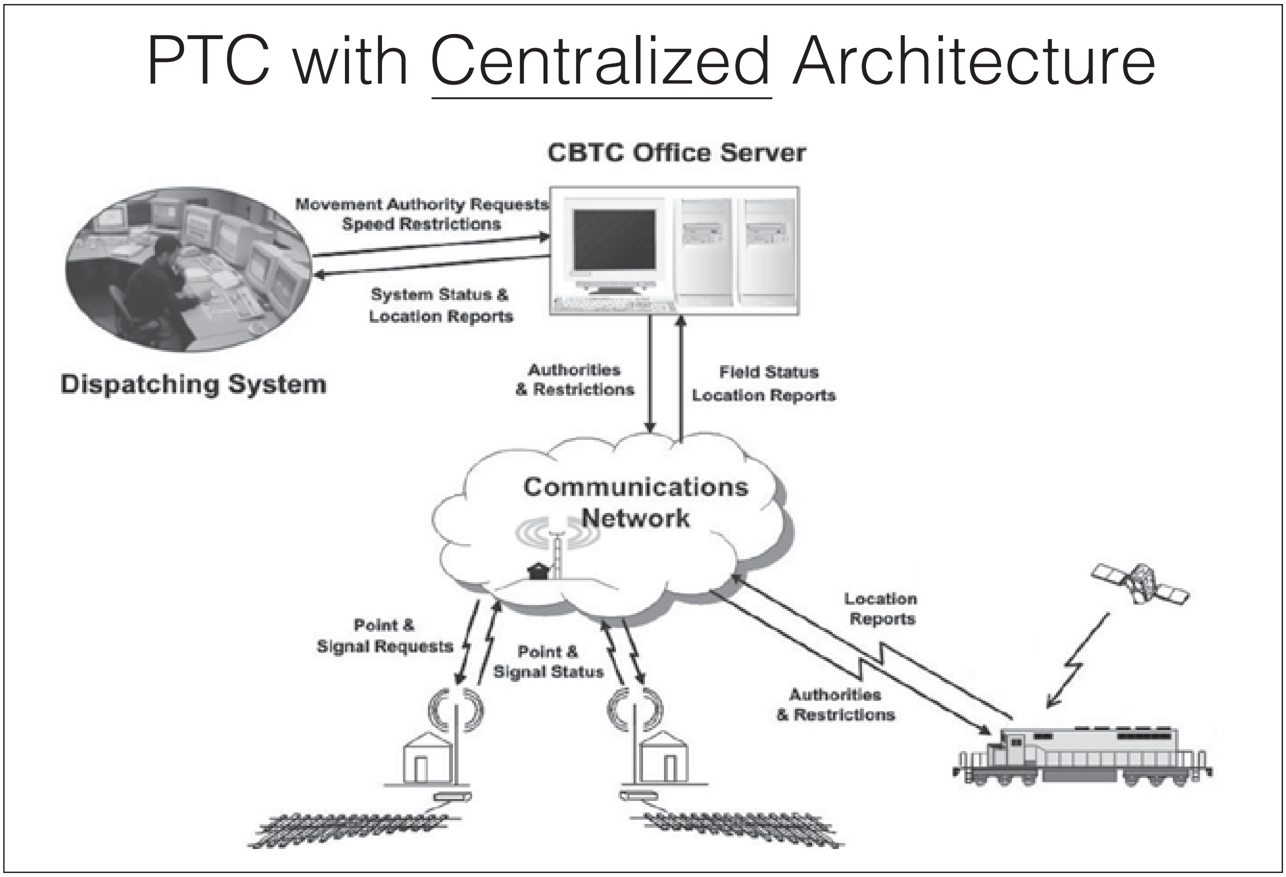


FIGURE 8 General structure of a positive train-control (PTC) system. Source: Reprinted with permission of AAR.

very much like traffic signals on highways. Although there is a wide variety of signal systems, most of them work on the principle that when a locomotive crew receives signal-light indications either from fixed signals on the right-of-way or in the locomotive cab, the crew will obey those signals. Crews also have analog voice radio communications with train dispatchers who control the movement of trains. Dispatchers give train crews permission to proceed, either by changing the signal indications along the right-of-way or by issuing authority verbally (a track warrant) via analog voice radio.

These systems, which have been in place since the early 1900s, have been refined and improved technologically over the past 60 years. However, all of them require a great deal of human voice communication and rely on employees to follow operating rules and signal indications properly. Converting train-control systems to digital communications systems will create endless possibilities for computer-based interventions that can prevent human error.

The generic conceptual structure of the digital systems, called positive train-control (PTC) systems, is shown in Figure 8. Digital authority to proceed is sent to a crew from a central office computer system that tracks all train movements and checks for conflicts. The main office computer also controls all wayside devices, such as switches at the dispatchers' command, but only after all routes have been checked for conflicts. By digitally downloading instructions, PTC systems can fully automate the train-control system.

The component of the system aboard the locomotive, the locomotive-control unit (LCU), consists of computers with software functions that monitor the crew's implementation of movement authorities. An LCU can stop the train if conditions are unsafe.

Once PTC systems are installed, the possibilities for improvement are endless. Several systems currently under development are being tested on several railroads and at the TTCI research facility. As PTC systems become cost effective, they will be widely implemented in the next 15 years.

Real-Time Onboard Train-Performance Simulators

With PTC systems aboard, the automation of real-time train operations will become feasible. PTC systems will be able to optimize acceleration and/or braking to minimize fuel consumption and train-handling forces. To assist crews, these systems can recommend train-handling instructions based on tonnage, track grade and curvature characteristics, allowable speed, and train-dynamic performance. Simulators can optimize operations by calculating several hundred train-handling alternatives per second and forecasting train velocity several miles in advance.

Figure 9 shows a typical coaching screen on a locomotive for a PTC system (right). This screen is from a system called LEADER, manufactured by New York Airbrake Corporation, which is currently being installed on several railroads around the world. The locomotive engineer is shown train position, track grade and curvature, in-train tension and compression forces, and train speed and acceleration. The number in the small blocks at each track milepost location is the predicted train speed at that location, provided that throttle and brake conditions remain unchanged. In the lower right-hand block on the screen, the locomotive engineer is given suggestions for changing throttle or braking conditions.

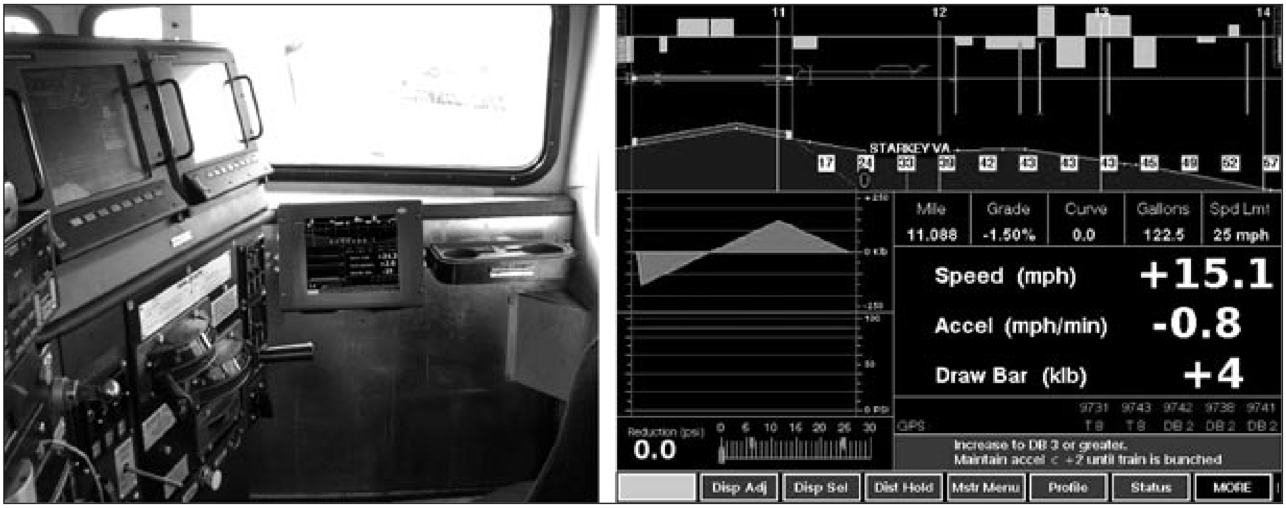
Electronically Controlled Pneumatic Braking Systems

Digital applications can be extended to current braking systems, which have been used for more than 100 years. Designed as failsafe systems, brakes are applied automatically if there is a loss of air pressure in the brake pipe that runs the length of the train. Compressors on the locomotive pump air under pressure through the brake pipe, and airbrake valves on each railcar respond to changes in air pressure in the brake pipe. Currently, it can take several minutes for the air pressure drop to travel from the front of the train to the rear.

With an electronically controlled pneumatic (ECP) braking system, the brakes on all cars are activated at the same time by electrically activated valves, providing a much smoother braking action that can stop a train in approximately half the distance it takes for a conventional braking system. With ECP, a wire extends power to each car in the train. The wire also has circuits for digital communications from each car to the locomotive. Thus it will be feasible to power a monitoring system of the performance of each railcar in the train in real time. Railcars in the future may have low-power, wireless monitoring systems that report unsafe conditions to the crew even as the train is moving.

Conclusions

As the descriptions of digital applications described in this article show, the railroad renaissance is alive and well. Railroads today offer the safest, most energy-efficient mode of handling long-haul freight, and operations will only get better in the future. Conversion of railroad communications systems from an analog infrastructure to a digital infrastructure will facilitate the rapid deployment of computer-based applications that will accelerate improvements in safety, productivity, and reliability. The benefits of the digital railroad to the future of the U.S. transportation infrastructure will rival the benefits of railroads in the 1800s to the western United States. It will be a true renaissance.



Mile	Grade	Curve	Gallons	Spd Lmt
11.088	-1.50%	0.0	122.5	25 mph

Speed (mph) +15.1
Accel (mph/min) -0.8
Draw Bar (klb) +4
Reduction (psi) 0.0

Increase to DB 3 or greater.
Maintain accel < +2 until train is bunched

FIGURE 9 A typical coaching screen for real-time train-performance simulation. Source: Reprinted with permission of Norfolk Southern.

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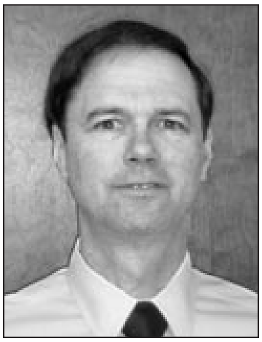
The maritime commercial shipping industry has achieved an extremely high level of efficiency.

Technological Advances in Maritime Transportation

Keith Michel and
Peter Noble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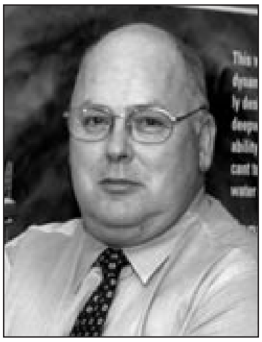
Peter Noble

More than 90 percent of world trade is moved by the maritime commercial shipping industry. Subject to free market forces, this industry has achieved a high level of efficiency, which has contributed to the expanding global economy by enabling the low-cost movement of goods around the world. Worldwide seaborne trade has more than quadrupled in the last 40 years and now exceeds 6 billion tonnes per annum, with an annual growth rate of about 4 percent. Currently some 10,000 shipping companies flying the flags of 150 different countries operate a commercial shipping fleet of roughly 50,000 vessels.

The liberalization of trade in the last few decades has led to specialization among regions around the world. Asian countries have become the leading providers of manufactured goods, for which container ships are the preferred form of transport to overseas markets. In the United States, the demand for petroleum products remains strong while domestic production continues to decline. Thus we can anticipate significant increases in the importation by sea of crude oil and liquefied natural gas (LNG). The growing demand for resources and continuing climate change are expected to create new opportunities for resource exploration, production, and shipping in the

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FIGURE 1 Types of ships in the merchant fleet. 1a. Roll on-roll off (Ro-Ro) vessel. 1b. Bulk carrier. 1c. Crude-oil tanker. 1d. Container ship. Sources: Totem Ocean Trailer Express Inc.; EastWind Maritime; General Dynamics NASSCO and BP Shipping; American President Lines. All photos reprinted with permission.

Arctic region. More than ever before, the economic and societal well-being of the United States is dependent on efficient, safe, and environmentally friendly deep-sea shipping.

Overview of the Shipping Industry

The merchant fleet consists of a variety of ship types and sizes (Figure 1):

- **Tankers** carry liquid cargoes. The world tanker fleet consists of oil tankers (crude-oil tankers and product tankers), chemical carriers, LNG carriers, and liquefied petroleum gas carriers. Tankers vary in size from small coastal vessels to very large and ultra-large crude-oil carriers with cargo capacities in excess of 350,000 cubic meters (m^3).
- **Bulk carriers** are vessels designed to carry dry cargoes, such as ore and grain, in bulk. These ships range in size up to capsize bulk carriers, which are capable of carrying more than 200,000 tonnes of cargo.
- **Container ships** are vessels designed to carry manufactured goods and unitized products in standard-sized freight containers. There are more than 4,000 container ships, ranging in size from small feeder ships to large post-Panamax container ships that can carry more than 12,000 20-foot equivalent containers (TEUs).
- **Other cargo ships and barges** include general cargo ships, reefer ships, roll on-roll off (Ro-Ro) vessels, car carriers, forest-product carriers, barge carriers, heavy-lift ships, dry and tank barges, and articulated tug and barge units. Many of these are specialized vessels designed to carry specific types of cargoes.

Remarkable improvements in the efficiency of maritime transportation have been made in the last 50 years. The costs of bulk shipping have increased only about one-tenth of the overall inflation rate, not even double what they were 50 years ago. This translates into lower costs to the consumer. For example, in the United States seaborne transportation adds only about 2 cents to the price of a gallon of gasoline, $10 to the cost of a television, and a few hundred dollars to the cost of a car.

New concepts, such as container ships, LNG carriers, open-hatch forest-product ships, and car carriers have revolutionized the way products are moved. Other improvements have been in the productivity of shipbuilding, the efficiency of hulls and propulsion systems, reductions in manpower requirements through automation, and economies of scale brought about by larger and larger ships.

As shown in Figure 2, compared to other transportation modes, shipping is a very efficient means of moving cargo over long distances. The high level of efficiency has not only lowered transportation costs, but also significantly reduced greenhouse gas emissions per tonne-mile of cargo moved.

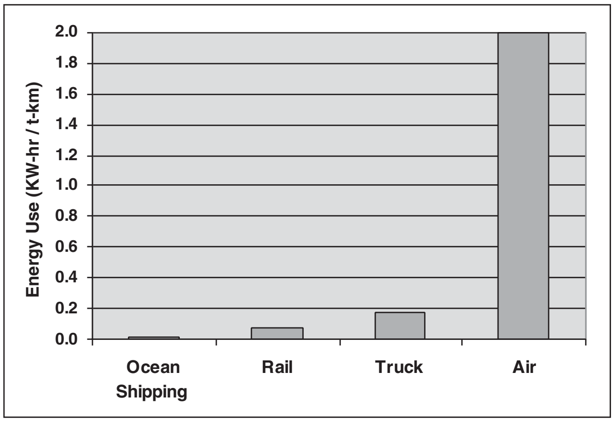


FIGURE 2 Comparative efficiencies of transportation modes.

Marine transportation systems have many components that must interact efficiently to provide overall system efficiency. These include ships, marine infrastructure, tugs, navigations aids, search and rescue facilities, salvage and firefighting support, port security systems, pilotage, bunkering facilities, ports and terminal infrastructure, multi-modal interfaces, environmental incident-response systems, and so on. In addition, the U.S. marine transportation system is multifaceted, including ocean-freight transport, Great Lakes and great river navigation and coastal cabotage, and major passenger ferry operations.

Although both domestic and international waterborne transportation are essential elements in the economic life of the United States, this article is focused on three specific sectors that are undergoing particularly rapid change: container shipping, LNG transportation, and Arctic navigation. In all three of these sectors, U.S. designers, shipbuilders, and owner/operators have played key roles in developing technologies that have led to major innovations and successful implementations.

Container Shipping

Container shipping began modestly in 1956 when Malcolm McLean moved 58 containers from New York to Houston. In the late 1950s and 1960s, McLean's Sea-Land Services and Matson Navigation Company were pioneers in the design of cellular container ships, containers and the means to secure them, container cranes, and other port infrastructure. Within a short time, containerization had revolutionized the transportation industry, and intermodal movements by ship, truck, and rail had become the preferred method of moving manufactured goods and other unitized products.

During the early and mid-1980s, the size of container ships stabilized at about 4,500 TEUs, and the largest container ships had a beam of 32.2 m, the limiting dimension of the Panama Canal. In 1988, America President Lines (APL) took delivery of the first post-Panamax container ship (Figure 1d), which had a beam of 39.4 m and an overall length of about 275 m. Post-Panamax ships are specifically designed for trans-Pacific service. Arranged with a single 41,900 kilowatt (kW) slow-speed diesel directly connected to a single propeller, these vessels are capable of service speeds of more than 24 knots.

The APL post-Panamax design incorporated many innovative features, including lashing bridges for securing on-deck containers, which significantly increased the number of containers that could be carried. Coincident with the introduction of these larger ships, APL developed stack-train technology, which makes it possible to load containers two high on flat railcars. These technological advances provided marked competitive advantages, and in time, post-Panamax container ships became the de facto standard for moving containers in the trans-Pacific and Far East-to-Europe trades.

Although there are diminishing economies of scale for further increases in ship size, the rising price of fuel oil has encouraged the construction of increasingly large container ships. The largest container ships that can transit the Panama Canal have slot capacities up to 5,000 TEUs, but the canal is being enlarged to accommodate container ships of about 12,000 TEUs. The Suez Canal size limit is about 14,000 TEUs, and the Straits of Malacca limit is about 18,000 TEUs.

At this time, the *Emma Maersk* is the largest container ship, with a length of 398 m, a beam of 56.4 m, and an estimated capacity of more than 12,000 TEUs. Samsung Heavy Industries of Korea is now offering a design with a slot capacity of 16,000 TEUs.

The designers and builders of these mega container ships face many technical challenges. The main deck of a container ship has large hatchways so containers can be efficiently loaded into the holds. This open section leads to significant torsional deformation of the hull girder. Great care must be taken to ensure the watertightness and structural integrity of the hatches and to prevent fatigue cracking at the hatch corners and structural transitions. Sophisticated finite element models are used to evaluate design strength, and loads are developed from linear and nonlinear sea-keeping programs and model tests (Figure 3).

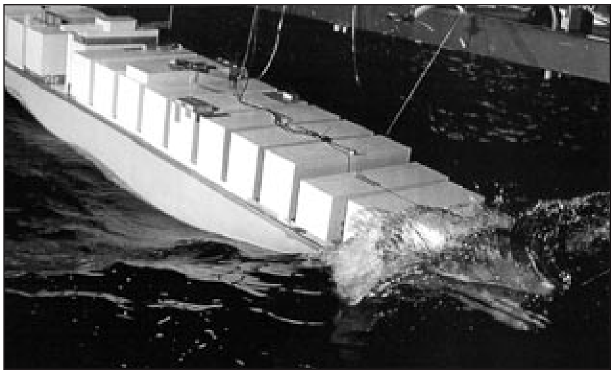


FIGURE 3 Test of a container ship model in extreme head seas. Source: American President Lines. Reprinted with permission.

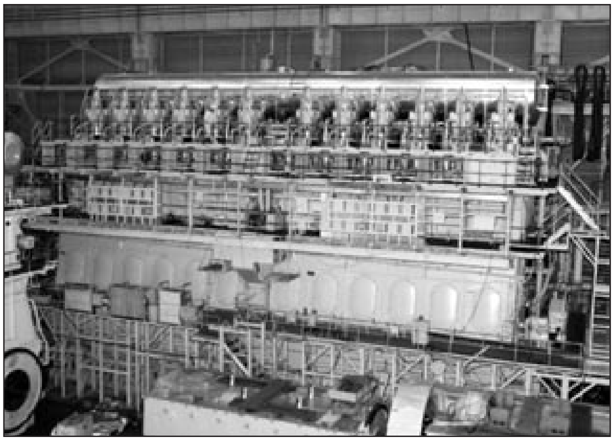


FIGURE 4 A MAN B&W 12K98ME diesel engine (68,000 kW). Source: MAN Diesel. Reprinted with permission.

The rating of main engines (Figure 4) that drive mega container ships now approach 100,000 kW, heavy loading for a single propeller. Although twin propellers are an option, single-screw designs are more efficient. Thus the propeller must be designed to deliver high efficiency and maintain adequate structural strength while minimizing cavitation and propeller-induced vibration.

Another concern on large vessels is shaft alignment. Computational fluid dynamics (CFD) tools and model testing are used to optimize the propeller design, and finite element analysis is used to evaluate interactions among the hull structure, main engine, shafting, and propeller.

Port infrastructure is being continuously adapted to increases in ship size. Port planning is driven by pressures to increase productivity and throughput and reduce air emissions from the terminal equipment, as well as from the ships, trains, and trucks entering and leaving the port. The ports of Los Angeles and Long Beach, the largest container ports in the United States, have been in the forefront of these changes. For example, new cranes with greater vertical clearance and outreach that require less power are highly automated to improve productivity.

Both ports have embarked on a five-year project to reduce harmful air emissions by nearly 50 percent. This aggressive, multifaceted plan includes financing the replacement or retrofitting of "dirty" diesel trucks that move containers to and from terminals, the acquisition of all-electric cargo-handling vehicles, and the use of pollution-based impact fees to encourage good practices and provide financial support for pollution-mitigation initiatives. Facilities for "cold ironing," (ships plugging into the port's power grid rather than using their own diesel-driven generators) have been fitted at many of the berths.

Transportation of Liquefied Natural Gas

On January 25, 1959, the first ocean cargo of LNG was transported from Louisiana, bound for the United Kingdom, by a small U.S. cargo vessel that had been converted to the world's first LNG tanker, the *M.V. Methane Pioneer* (Figure 5). Following delivery of the initial cargo, the ship continued to make periodic deliveries, but the first regular trade in LNG in purpose-built carriers was established between Algeria and the United Kingdom in the mid-1960s. In 1969, Phillips Petroleum (now ConocoPhillips) opened an LNG plant in Kenai, Alaska, and began to export U.S. gas to Japan. Almost 40 years later, this trade is still in place.

FIGURE 5 The *M.V. Methane Pioneer* at a loading berth in Louisiana. Source: ConocoPhillips. Reprinted with permission.

LNG cargo is lightweight and cryogenic, with a specific gravity of approximately 0.45 and temperature of −163°C. Because liquid gas slowly boils as it is transported, LNG carriers must have cargo-containment and cargo-handling systems capable of safely handling this cold cargo. Two types of cargo tank systems have been developed: independent tank systems and membrane tank systems.

Independent tank systems have stainless steel or aluminum tanks (both perform well at low temperatures) that are installed into a ship and are supported independently of the main ship structure. The most common independent tank system has spherical tanks that stick up through the deck, giving the ship a distinctive profile (Figure 6).

Membrane tank systems have a cryogenic metallic membrane that is installed against the inner hull of a

FIGURE 6 LNG ship with spherical tanks. Source: ConocoPhillips. Reprinted with permission.

double-hulled ship to protect the ship's steel from low-temperature effects. Membrane-type LNG carriers have a less distinctive profile, although they are relatively high freeboard ships (Figure 7). These ships require high-volume tanks because of the low specific gravity of LNG (approximately half the specific gravity of oil products).

FIGURE 7 Typical LNG ship with membrane tanks. Source: ConocoPhillips. Reprinted with permission.

Most new LNG ships have membrane tanks with a typical capacity of about 40,000 m^3. Special techniques and equipment are required to manufacture and install membrane tank systems, and only a few shipbuilders, mostly in Korea, are constructing LNG ships. Figure 8 shows a typical membrane tank; the person in the background provides a sense of the enormous size of these tanks.

Until a few years ago, the largest LNG carriers had capacities of less than 160,000 m^3. However, large gas developments in Qatar led to a major new building program of more than 40 new LNG carriers, ranging in size from the *QFlex* design (capacity of about 212,000 m^3) to the *QMax* design (capacity of about 266,000 m^3). This was a quantum jump in size for an industry that prefers to mitigate risk by making incremental changes. The designs were a collaborative effort of major oil companies and Korean shipyards.

To ensure safety and reliability, extensive design and risk evaluations were carried out during the design process. One of the principal concerns was the development of rational design parameters for scaling up the membrane-containment system. A single tank on a *QMax* LNG carrier measures about 48 m wide × 28 m high × 58 m long and can hold about 58,000 m^3 of LNG, nearly twice the size of the tank shown in Figure 8. A variety of techniques were used to design these tanks, including CFD analysis and tank tests to evaluate the sloshing modes, first-principle structural analysis, and full-scale destructive testing of the membrane elements.

This new generation of LNG carriers has many unique characteristics, such as twin-screw, redundant propulsion and steering systems. The hull form is highly optimized, with a gondola-type stern that directs the flow into the propellers. Whereas most existing LNG carriers burn boil-off gas in steam plants, these ships have highly efficient diesel engines. Instead of burning the boil-off gas, it is re-liquefied and returned to the cargo tanks, enabling the delivery of the full cargo payload to market.

The current trend in LNG propulsion is dual-fuel engines that burn both boil-off gas and fuel oil. Designs are available for both medium-speed diesel engines and slow-speed diesel engines. Gas turbines are also being considered.

FIGURE 8 Main cargo tank of an LNG ship. Source: ConocoPhillips. Reprinted with permission.

FIGURE 9 Double hulled, twin screw tanker. Source: ConocoPhillips. Reprinted with permission.

Arctic Navigation

For centuries, people searched for navigable routes from Europe to Asia along the Northwest Passage (North America) and the Northern Sea Route (Russia). Today these routes can be navigated, with some difficulty, allowing ships to pass from the Atlantic to the Pacific and vice versa. But experts generally agree that the main use of these northern sea-lanes is likely to remain voyages to specific destinations rather than transpolar voyages; access to Arctic resources and tourism are the main reasons for sailing north.

The Arctic, which is rich in natural resources, has historically provided both biological and mineral resources, such as fishing and whaling (Greenland, Alaska, Canada, and Russia), lead and zinc ore (Greenland, Canada, and Alaska), nickel ore (Russia), iron ore (Canada), coal (Norway), and oil and gas (Alaska, Canada, and Russia).

Global climate change over the past few years has reduced the Arctic Ocean sea-ice cover in the summer months, and some predictions are that the summer ice cover will disappear totally by mid-century. Winter ice cover will, however, remain, although predictions are that the thickness of the ice will decrease some. Nevertheless, navigation will still be challenging.

In the United States, major oil, gas, and mineral reserves have already been developed in Arctic Alaska. In the late 1960s, oil was discovered on the North Slope of Alaska near Prudhoe Bay, and production began in 1977. During the development planning for the North Slope, some consideration was given to exporting oil directly from the Arctic to the U.S. east coast via the Northwest Passage, and a specially converted tanker, the *SS Manhattan*, did in fact make two voyages in 1969 and 1970 to test out this possibility. In the final analysis, however, a pipeline was built across Alaska, and the crude oil was transported to the U.S. west coast in purpose-built tankers (Figure 9).

In parallel with oil and gas development, there has been some significant mining development in Alaska. In 1989, the largest zinc/lead mine in the world, the Red Dog Mine, started production about 80 miles north of Kotzebue. Today this mine produces about 600,000 tonnes of zinc concentrate per annum and about 100,000 tonnes of lead concentrate per annum.

The ore is stockpiled throughout the winter and exported by ship during the short summer open-water season. Because of the very shallow water near shore, which is typical of the U.S. Arctic, and the total absence of ports and other marine infrastructure, the mine has built a marine terminal for loading shallow-water barges with ore concentrate. Barges carry the ore from the terminal to bulk carriers anchored in deeper water, and the cargo is trans-shipped at sea.

Recent oil and gas lease sales by the U.S. government drew record-high bids. In February 2008, more than $2.5 billion was put up for leases in the Chukchi Sea. Development of these sites will require special marine assets, including drilling rigs, ships, semi-submersible or jack-up units, and supporting resupply and ice-management vessels. Similar arctic offshore exploration was successfully carried out in the Canadian Beaufort Sea in the early 1980s, and current and future exploration will build on that experience.

To date, development in the U.S. Arctic offshore has been mostly in very shallow water in the Prudhoe Bay area and has relied on traditional pipeline export systems to connect to the trans-Alaska pipeline. In the future, oil and gas discoveries in the Arctic may very well be in deeper water and farther from land, which will involve major shipping activities.

ConocoPhillips, with its Russian partner LukOil, is currently developing an arctic crude-oil export system that may be a prototype for the future. The system consists of a pipeline from short-term storage tanks to a fixed, offshore, ice-resistant off-take terminal (Figure 10), and three purpose-built ice-breaking oil tankers equipped with diesel electric propulsion and azimuthing electric drives (Figure 11). These tankers will shuttle oil out of the ice zone to Murmansk, where it will be trans-shipped into open-water tankers for delivery to markets in Europe and North America. In addition, two ice-breaking support vessels are being built to support activities around the terminal during loading (Figure 12).

FIGURE 10 Fixed offshore ice-resistent offtake structure. Source: ConocoPhillips. Reprinted with permission.

FIGURE 11 Arctic Ice breaking tanker. Source: ConocoPhillips. Reprinted with permission.

The Changing Environment and Future Ship Design

Public expectations for improved safety and environmental performance will have a major influence on ship design in the next decade. Although oil spillage from ships has significantly decreased in the past 30 years, further reductions are expected by a concerned public.

International regulations now require that bunker tanks on new ships be double-hulled or provided with equivalent protection. Thus newly built ships can no longer carry fuel oil in wing tanks outboard of the cargo holds to maximize carrying capacity. To minimize the negative impacts of these changes on efficiency and capacity, new designs are being developed that allocate fuel in protected locations in superstructures and between holds.

Another environmental concern is the introduction of non-indigenous species from ballast water. Currently, ballast water is exchanged in the open ocean, and ballast-water treatment systems are used to reduce the likelihood of introducing invasive species. Eliminating ballast-water discharge completely is the failsafe solution. This is a practical option for large container ships and Ro-Ro vessels, which generally move cargo on every leg of the voyage. However, it would not be practical for tankers and LNG carriers, which typically deliver their cargo and return empty. A few recently built ships have internal freshwater ballast-transfer systems (for example, the Ro-Ro shown in Figure 1a), which not only enable the control of the vessel's trim and heel but also eliminate the need for saltwater ballast with its corrosion-inducing properties.

The large diesel engines on oceangoing ships are well suited for burning residual oils, and the lower cost of heavy fuel oil (compared to the cost of distillates) has contributed to the efficiency of the marine transportation system. Unfortunately, because of the high sulfur content of residual oils, shipping is a major emitter of sulfur oxides ($\mathrm{SO_x}$), and pressure to reduce emissions

PARTICULARS

Length	81.6m
Beam	18.5m
Depth	11.2m
Power	12,960kW
Continuous Level Ice Capability	1.5m

FIGURE 12 Multi-purpose icebreaking supply vessel. Source: ConocoPhillips. Reprinted with permission.

of SO_x, nitrogen oxides, and particulate matter is increasing. Full-scale tests are being conducted on various pre-treatment (e.g., water emulsion) and post-treatment (e.g., scrubbers and selective catalytic reduction) systems.

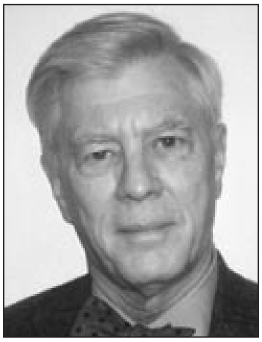
International regulations now under consideration will require that ships burn increasingly cleaner fuels. By 2020, it is likely that ships will only be permitted to burn low-sulfur diesel oil or marine-gas oil or to install treatment technologies that reduce emissions to equivalent levels. The shift toward these higher cost distillates, as well as the dramatic rise in fuel prices, will encourage further efforts to improve the efficiencies of the hull and propulsion systems.

Significant fuel savings can be realized by reducing ship speed, which would decrease wave-making resistance, which is magnified at higher speeds. With the rise in fuel costs, the optimal service speed for minimizing freight rates is now much lower than the typical container ship speed of 22–25 knots, LNG ship speed of 19–21 knots, and oil tanker speed of 14–16 knots. Market willingness to pay for faster delivery will surely be tested in the coming years.

In this rapidly changing environment, adaptability will be the key to success. Although U.S. shipyards are no longer internationally competitive in the labor-intensive business of shipbuilding, U.S. owners and designers will have significant influence on future ship designs. In the coming years, naval architects and marine engineers will have ample opportunity to explore creative options, because new markets such as mineral and petroleum production in the Arctic will require innovative concepts and techniques. In addition, existing markets will require continuous improvements in efficiency, safety, and environmental performance.

Dealing with uncertainties will require a systems perspective and a paradigm shift in airport development.

Building the Next Generation of Airport Systems



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Richard de Neufville

Airports worldwide are struggling to keep up with demand, and many major cities are making do with collections of more or less inadequate and obsolete runways and passenger buildings. Most travelers know from experience the frequency of aircraft delays, missed connections, misdirected baggage, and uncomfortable crowding. We clearly need to rebuild and enhance our airport systems.

Defining the Problem

Lack of money is not a fundamental obstacle to creating better airports. In fact, the air transport industry is committing huge sums to capital investments. To put the matter in perspective, airlines worldwide have ordered more than 900 new Boeing Dreamliners (B787s), which list for about $150 million each. The total value of this order must be more than $100 billion. Airlines have also ordered about 200 new double-decked Airbus A380s, recently listed at about $375 million each. This order is worth about $75 billion. In short, the industry has access to huge pools of money.

In addition, large amounts of money are going into airport development. For example, Chicago's plan for modernizing O'Hare could cost as much as $10 billion; Terminal 5 at London/Heathrow cost about $8.5 billion; and the Toronto airport recently underwent a $4 billion rehabilitation.

In the United States, billion-dollar projects are contemplated, under way, or have recently been completed at Atlanta, Boston, Dallas/Fort Worth, Las Vegas, Miami International, New York/Kennedy, Orlando International, Philadelphia, Washington/Dulles, and elsewhere. Brand-new or thoroughly reworked airports are also emerging in China and India—in addition to a string of ambitious airports along the Persian Gulf.

For further evidence of the availability of resources, one need only look at the private consortia lining up to invest in the privatization of airports; the most likely candidate in the United States is Chicago/Midway. Worldwide, investors are prepared to spend billions on airport deals in India and many other locations, such as Portugal. There is no doubt that money is available globally for the development of the closely coupled airline/airport industry.

We need a new paradigm for designing and implementing airport infrastructure.

So, if we recognize the need and we know the money is available, then why do airport delays, congestion, and aggravations seem to be getting worse? With so many skilled and smart people doing their best to make things better, why aren't we getting reasonable results?

More specifically, why is this happening now? Neither air travel nor air traffic is growing faster than it was a generation ago. In fact, in the United States, growth is slower than it was. The technological advances brought about by larger, carbon-fiber aircraft are no more momentous than the shift from propeller to jet aircraft or the introduction of the Boeing 747. So why do matters keep getting worse? Why aren't we succeeding as we did before?

The answer is almost surely that we are not working effectively in the current circumstances. Since we have the money and the technological know-how, by process of elimination we must conclude that something is wrong in the context, in the system around us.

Neither the institutional framework that defines the way we tackle issues nor the professional traditions that shape the way we think about possible solutions seem to be working. The political and personal approaches that worked reasonably well in the past are simply not up to the problems of today.

Deregulation of the Airline/Airport Industry

The airline/airport industry is a profoundly different industry from what it was a generation ago. To be successful in these new circumstances, engineering practice must be adapted to the new reality. Traditional, historically successful ways of dealing with airport needs have to be refashioned. In short, we need a new paradigm for the way we design and implement our airport infrastructure.

Remarkably, the deep changes in the airline/airport industrial system have little to do with technology. Technologically, airlines and airports are functionally equivalent to what they have been for 50 years or more. Now, as then, passengers queue up for check-in procedures and walk onto a plane; meanwhile, their bags are tagged, sorted, and loaded onto carts and the aircraft; then pilots and flight attendants care for them during the flight. Interesting, cost-effective technologies have found their way into various phases of the process—in the form of automatic check-in procedures, laser reading of bag tags, electronic instrumentation in cockpits, more efficient, quieter engines, and so on.

But none of these technological advances has changed the essential functions of or requirements for airport buildings, runways, or controls. From the overall perspective of airport performance, the technological advances are relatively minor adjustments that have not significantly impacted the structure of the engineering problem.

However, unlike airports, which have not changed greatly in terms of engineering system, the air transport industry of today is fundamentally different from what it was a generation ago. This is because economic deregulation (in 1978 in the United States, and at various dates in Australia, Canada, the European Union, and the United Kingdom) radically altered the conditions in which airlines operate. In fact, what used to be a very stable environment is now a highly uncertain environment.

Economic deregulation of the airlines removed the bureaucratic processes that had guaranteed a highly stable environment for airlines and, in turn, for investment in their facilities at airports. Before deregulation, highly legalistic regulatory processes, which entailed much time and expense and took years to process requests, controlled the way the airlines operated. For example, airlines would fight for years for the right to offer new service to a popular city, while airlines that already provided service to that city fought hard to prevent the new competition. This highly contentious process often took years to resolve. Sheltered by regulations that prevented sudden major changes, airline executives could reliably anticipate that the next year would be essentially the same as the last year.

Deregulation destroyed this stable world, and, in so doing, it created the conditions for innovation, low-cost airlines, cheaper fares, and what many consider overall economic benefits. However, deregulating the industry was like taking the shock absorbers out of a car—it turned what used to be a smooth ride into a chaotic experience. Along with greater economic efficiency, deregulation led to instability and uncertainty in the airline/airport industry.

Economic deregulation has given the airlines much more freedom (Table 1). They can decide to provide service to an airport whenever they want, and they can do so as quickly as they can organize themselves to set up shop. Aggressive airlines such as Southwest and jetBlue (in the United States) and Ryanair and easyJet (in the European Union) have routinely opened dozens of new routes each year, a tempo that was unimaginable before deregulation. Conversely, airlines can also abandon an airport or facility and shift their operations elsewhere, as US Airways did when it shifted its domestic hub from Pittsburgh and its international hub from Baltimore/Washington to Philadelphia.

Airports, which are closely coupled with the airlines and thus face the same kinds of uncertainties, are affected by deregulation the most. When Southwest, for example, moves into an airport and triples its traffic—a phenomenon popularly known as the “Southwest effect”—the entire airport infrastructure—runways, passenger buildings, parking facilities, and so on—is affected.

Deregulation especially impacts airport developers, who necessarily have large fixed assets. When US Airways moved its hub out of Pittsburgh, the airline was able to redeploy its fleet, but the airport and investors in its stores were stuck with under-used facilities. When Pittsburgh lost its main tenant, it lost much of its ability to repay the mortgage on the property—the bonds it had issued to finance the development of the facilities to serve US Airways.

Similar stories are common throughout the industry. Cincinnati built attractive facilities to serve Delta when the airline created a hub there and then was stuck with those facilities when Delta went bankrupt and dropped the hub. Raleigh/Durham became an international hub for American Airlines, serving traffic from Paris to Mexico, and then lost this traffic when American Airlines rerouted its services. Kansas City was left with empty, obsolete facilities when TWA moved its hub to St. Louis, which, in turn, later spent more than a billion dollars to build and open a new runway to serve this client. Yet after declaring bankruptcy for the third time, TWA disappeared, and traffic in St. Louis dropped from 30 to 15 million passengers annually (Masek, 2007). Nothing like this could have happened before deregulation. Airport investments have become very risky!

A Highly Uncertain Future

In the current climate, long-term forecasts cannot be developed with any degree of confidence. On the contrary, as has been extensively documented, forecasts of airport traffic today are “always wrong.” For example, half of the time, five-year forecasts for individual airports in the United States have been off by 10 percent (Friedman, 2004). The track record is worse for longer term forecasts (Flyvbjerg et al., 2005).

Trend breakers, such as bankruptcies or mergers,

TABLE 1 Freedom of Action for Airlines before and after Deregulation

Choice	Before Deregulation	After Deregulation	Implications of Deregulation
Routes	Strictly controlled	Freedom to change	Loss of secure tenure
Prices	Set by formula	Freedom to change	Price wars
Frequency of flights	Controlled	Freedom to set schedules	Capacity wars
Aircraft type	Often controlled	Freedom to choose	Capacity wars

cause immediate shock and realignments of the industry, further disrupting projections. The disappearance of TWA and Swissair totally scrambled the forecasts for St. Louis and Zürich. Trend breakers might be catastrophic events, such as 9/11, which led to new security requirements and disrupted the designs of airport passenger buildings everywhere, or they may be new political arrangements, such as the "Open Skies" agreement between the United States and the European Union (EU), which came into effect in March 2008.

The Open Skies agreement represents a major new phase of deregulation—and uncertainty. It eliminates the bilateral agreements, which had specified traffic rights between the United States and the EU countries and which had been very difficult to change. The new agreement permits any carrier from the United States to serve any point in the EU, and vice versa. Thus it offers many new opportunities and challenges. Who knows how this will change traditional gateways for European traffic? Who knows what new markets will open up?

A good design must address the performance of the overall system.

Deregulation always makes the future more volatile (de Neufville and Barber, 1991). By enabling airlines to redirect their traffic, both massively (as by creating or abandoning hub airports) and in the short term (for a year or less, a tiny fraction of the life span of an airport facility), deregulation adds great uncertainty—and thus great risk—to airport development.

A New Design Paradigm

The traditional engineering paradigm for planning and designing airports and airport facilities is not suitable in a deregulated environment. The airline/airport system has changed fundamentally, from a stable environment with marginal changes to a fast-paced environment subject to repeated disruptive shocks. The design processes suitable for a stable, predictable system—the traditional paradigm of airport development—was based on the premise that we could correctly anticipate the future, which is no longer the case.

The standard approach was based on "master planning," which had two main phases: (1) the determination of the correct forecast; and (2) the selection of a single (i.e., master) plan that best suited this forecast (de Neufville and Odoni, 2003; FAA, 1985; ICAO, 1987).

This approach was plausible when designers could assume that a forecast adequately represented the system. Such an approximation generally provided a reasonable working basis for planning and design when traffic patterns changed slowly. Based on past successes, master planning became the established framework for airport development.

But historical inertia is no reason to continue to accept past practice now that circumstances have changed. In today's highly uncertain environment, it is unreasonable to design for a single set of requirements, as was done in the traditional master planning process. A responsible design must deal with reality—particularly with the uncertainties in forecasts. In an uncertain environment, the right thing to do is to anticipate a range of scenarios and define a strategy for dealing with these scenarios as they might unfold over time.

Another reason for the inadequacy of the traditional process for developing airport infrastructure is that it focuses on components of systems. Indeed, the entire structure for financing and approving new projects required that airport owners operate only a few airports. Moreover, the old system could operate in metropolitan areas in which airports are run by competing organizations. For example, three distinct authorities run the three commercial airports that serve the San Francisco Bay area. Three authorities—in different states—operate the three major airports that serve Boston. The five London airports are managed by three different groups. Two different authorities operate the three commercial airports for Washington, D.C. The current, historically driven engineering practice concentrates on the components of each system, on individual nodes, rather than on the architecture of the nodes and their interrelationships.

In the deregulated environment, a good design must address the entire system, including upgrading and creating components that are in the best interest of overall performance. But this is not how we approach the development of airport infrastructure today. We are still repeating the historical pattern that focuses on fixing the "squeaky wheels" and trying to improve them.

Thus improving the Philadelphia airport has become a fast-track national priority because it is very congested, largely as a result of US Airways' decision to locate a hub there. If we consider airports as an engineering system, however, the focus on improving Philadelphia may not make sense. First, there is great capacity available close by, in Pittsburgh, and US Airways could decide to move again or might even disappear in another wave of airline consolidations.

In the current institutional and governmental context, however, the systems-level approach is not feasible. Thus we continue to design for one airport in a region, rather than dealing with all of the airports in the region at once—let alone the national airport system. In fact, the focus of investment in infrastructure in general has been on specific projects rather than on regional or national systems.

The current paradigm of airport planning and design is too narrowly focused and misses opportunities in the new environment. It does not see the forest for the trees. We need a different approach.

Strategic Thinking and Flexible Design

We must begin to think strategically about developing the system of airports. We must also anticipate and design for a variety of possible scenarios. A fixed plan, built around a single prediction of the future is invariably ineffective. Excellent performance requires that designers think through the possible consequences of decisions, develop contingency plans, and commit to making only one move at a time.

Thinking strategically about designing the overall system of airport infrastructure represents a change in engineering practice. This shift in thinking is absolutely necessary to confront the realities of the new situation, but there is no doubt that the transition will be difficult. Old patterns of thought, however obsolete, are hard to change once they have been imprinted through practice.

The shift to a new strategic approach will require not only changes in the engineering paradigm, but also changes in procedures. Current research is being conducted to determine the best approaches to these changes. Procedurally, we must calculate the possible consequences of different developments under different scenarios associated with future uncertainties. In doing so, we will be able to identify unfavorable outcomes that we must protect against, as well as opportunities we must be ready to exploit. As in good financial management, we need the equivalent of options—"puts" against the possible downside outcomes and "calls" on the upside opportunities; technically, these are "real options in the system."[1] There are many ways to develop real options in engineering systems, particularly in airports (de Neufville, 2007).

The essence of new strategic thinking about the development of infrastructure is flexible design, which involves components that system managers can adapt to future conditions as they unfold. For example, the design for the new passenger building at the Toronto airport includes a number of interior passageways that make it possible to use given gates for different kinds of traffic (such as international and domestic) that must be handled separately.[2] This arrangement will enable airport operators to adapt their facilities to handle a wide range of possible short- and long-term variations in traffic.

A new strategic approach will require changes in the engineering paradigm.

To design for the airport system as a whole, we can no longer simply repair the components that "squeak the loudest" or are the most politically expedient. We must develop a process for identifying what will be best for the system as a whole and then investing in those areas. Inevitably, this will mean investing in system components that do not currently have a large amount of traffic or support.

For example, a systems perspective on the development of additional airport capacity around Chicago would have considered the relative values of two alternatives: (1) building a brand new airport on a green-field

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[1] "Real" options concern the actual development of physical entities, in distinction to financial options on the price of an asset. Real options are "in" the design, because they are embedded in physical features that designers have created. For example, designing a bridge with sufficient strength so that it can be double-decked if necessary (as was done for the George Washington Bridge in New York and the Ponte de 25 Abril in Lisbon) is a way of embedding a real "call" option on the opportunity to expand the system.

[2] Canadian airports handle three types of traffic: domestic, transborder to the United States (passengers technically enter the United States while still in Canada), and international. EU airports also handle three types of traffic: international, *Schengen* (from specific EU countries), and non-*Schengen* (from other EU countries).

site; and (2) modernizing Chicago/O'Hare (the second-busiest airport in the world) while keeping it operational. In the current institutional framework, the first option could not be given serious consideration because the mayor of Chicago (traditionally a Democrat) would not allow the governor of Illinois (frequently a Republican) to control the process. Furthermore, statutes largely obligate the federal government to allocate airport funds to facilities in proportion to their traffic volume (by definition non-existent at a new airport).

Designing for the system as a whole will constitute a fundamental paradigm shift, which may be particularly difficult to achieve in the United States and EU, which both consist of separate states with their own entitlements. This circumstance may represent a grand challenge for the development of airport infrastructure—and, more generally, of rapid intercity transportation, which can be supplied by rail systems, such as the Japanese Shinkansen or the French TGV.

Conclusion

Designing for a range of possible scenarios will require flexible components that system managers can adapt to new conditions as they unfold. Specifically, this will mean designing "options" into the system. We must design for the airport system as a whole, rather than continuing to misallocate resources by patching up component parts. In short, we need a new kind of strategic thinking that takes into account the great uncertainties in the deregulated environment.

Further Reading

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NAE News and Notes

NAE Newsmakers

Anjan Bose, Regents Professor/Distinguished Professor of Electrical Power Engineering, School of Electrical Engineering and Computer Science, Washington State University, has been named the winner of the annual **Eminent Faculty Award**, the highest honor the university bestows on a faculty member. The award is bestowed on a faculty member who has changed the thinking in his or her field and made lasting contributions through teaching, research, creative scholarship, and service. Dr. Bose was honored during a luncheon on March 28, 2008.

The Association for Computing Machinery (ACM) has named NAE member **Edmund M. Clarke**, FORE Systems Professor of Computer Science, Carnegie Mellon University; E. Allen Emerson, University of Texas at Austin; and Joseph Sifakis, Centre National de la Recherche Scientifique, the winners of the 2007 **A.M. Turing Award** for their original and continuing research on a quality-assurance process known as model checking. This fully automated process, which enables computer hardware and software engineers to find errors efficiently in complex system designs, is the most widely used verification method in the hardware and software industries. The Turing Award, named for British mathematician Alan M. Turing, carries a $250,000 prize and is funded by Intel Corporation and Google Inc.

On May 7, 2007, the American Association of Engineering Societies (AAES) bestowed the **2007 National Engineering Award** on **W. Gene Corley**, senior vice president, CTLGroup, for his leadership, his devotion to improving engineering education and advancing the profession, and his contributions as an engineer-statesman to the development of sound public policies. AAES also honored **William A. Wulf**, former NAE president, with the **Chair's Award** "for his continuous advocacy that engineers learn today the tools they will need tomorrow, his wise counsel that the profession needs to consider views from all perspectives in designing engineering solutions, and his efforts to advance the dialog between the engineering community, public policy makers, and society."

The Association for Computing Machinery Committee on Women in Computing (ACM-W) has named **Shafrira Goldwasser**, professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, the **2008–2009 Athena Lecturer** for her outstanding research in cryptography, complexity theory, and number theory. Her contributions have provided the underpinnings for secure transmission of information over the Internet. The award, which includes a $10,000 honorarium, is given to a woman whose research has made fundamental contributions to computer science.

On February 22, 2008, the **2008 Washington Award** was presented to **Dean Kamen**, president, DEKA Research and Development Corporation, by the Western Society of Engineers at a banquet at the University Club of Chicago. The Washington Award, one of the oldest and most prestigious engineering awards in the country, was created in 1916 to recognize "devoted, unselfish, and preeminent service in advancing human progress." Named after George Washington, the award is a reminder that the nation's first president was an engineer whose achievements advanced the welfare of humanity.

Takeo Kanade, U.A. and Helen Whitaker University Professor of Computer Science and Robotics, Carnegie Mellon University, is the 2008 recipient of the **Bower Award and Prize for Achievement in Science** from the Franklin Institute in Philadelphia. Dr. Kanade was honored for his "visionary leadership and scientific accomplishments in the design of perceptual robotic algorithms and systems that function in the physical world." The Bower Award and Prize includes a gold medal and a cash prize of $250,000.

Alan R. Mulally, president and CEO, Ford Motor Company, received the Society of Automotive Engineers (SAE) **SAE Foundation Manufacturing Leadership Award** at the 2008 SAE Foundation Banquet in Detroit, Michigan, on May 22, 2008. The award is given to an individual who has contributed to the development of the automotive industry, as well as to educational, philanthropic, or government activities.

David A. Patterson, professor of computer science, University of California, Berkeley, received the

2007 Distinguished Service Award from the Association for Computing Machinery (ACM). This award is given to an individual for outstanding service to the computing community, including activities in other computing organizations. The award was presented at the ACM Awards Banquet on June 21, 2008, in San Francisco.

Gavriel Salvendy received the American Society of Engineering Education (ASEE) **2008 John L. Imhoff Global Excellence Award for Industrial Engineering Education**. Gavriel Salvendy is professor of industrial engineering at Purdue University and Chair Professor and head of the Department of Industrial Engineering at Tsinghua University, Beijing, China.

Henry Samueli, chairman and chief technology officer, Broadcom Corporation, and his wife Susan, were presented with the **2007 "Engineering the Future"** Award by the Henry Samueli School of Engineering, University of California, Irvine, "for their continued leadership in the advancement of education and research."

On April 30, 2008, the American Society of Civil Engineers (ASCE) held its Annual OPAL (Outstanding Projects and Leaders) Awards Gala in Arlington, Virginia. Three OPAL awards this year went to NAE members. **Ernest T. Smerdon**, Dean of Engineering Emeritus, University of Arizona, received the **OPAL Lifetime Achievement Award for Education**. **Gerald E. Galloway**, Glenn L. Martin Institute Professor of Engineering, University of Maryland, received the **OPAL Lifetime Achievement Award for Government**. And **Clyde N. Baker Jr.**, senior principal engineer, STS Consultants Ltd., was awarded the **OPAL Lifetime Achievement Award for Design**.

James S. Thorp, Hugh P. and Ethel C. Kelly Professor and department head, Bradley Department of Electrical and Computer Engineering, and **Arun G. Phadke**, research professor and University Distinguished Professor Emeritus, Department of Electrical and Computer Engineering, both of Virginia Polytechnic Institute and State University, were awarded the **2008 Benjamin Franklin Medal in Electrical Engineering** for their combined contributions over a period of more than 60 years to the power industry. Their advances greatly improved the industry's ability to prevent blackouts and/or to make them less intense. Drs. Thorp and Phadke have been added to the Franklin Institute's list of the greatest men and women of science, engineering, and technology.

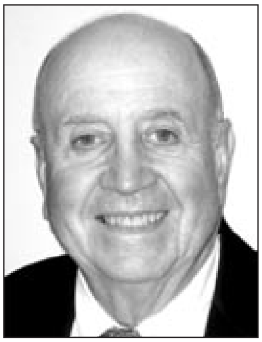
Rao R. Tummala, Joseph M. Petit Chair in Electronics Packaging and director of NSF-ERC in SOP Technology, Georgia Institute of Technology, received the **2007 David Feldman Outstanding Contributions Award** from the IEEE Components, Packaging, and Manufacturing Technology (CPMT) Society. Dr. Tummala was recognized for his far-reaching contributions to IEEE/CPMT during his unprecedented two terms as CPMT president.

Dr. Albert R.C. Westwood, former chairman/chief executive, Council for the Central Laboratory of the Research Councils of the United Kingdom, and Vice President Emeritus, Research and Technology, Sandia National Laboratories, was elected a **Foreign Member (academician) of the Georgian Academy of Engineering** in recognition of his work to rebuild the research capabilities of Georgia (FSU) and develop its next generation of research and development managers.

On April 29, 2008, NAE members **Frances H. Arnold**, Dick and Barbara Dickinson Professor of Chemical Engineering and Biochemistry, California Institute of Technology, and **Evelyn L. Hu**, professor, Electrical and Computer Engineering Department, University of California, Santa Barbara, were elected **members of the National Academy of Sciences**.

Chair, Home Secretary, and Councillors Elected

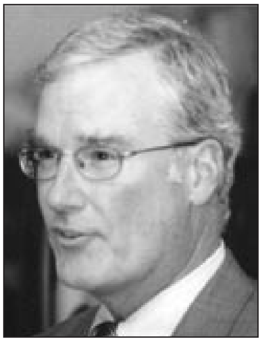
Irwin M. Jacobs



Thomas F. Budinger

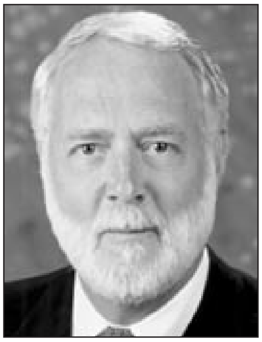
Bradford W. Parkinson

Alice M. Agogino

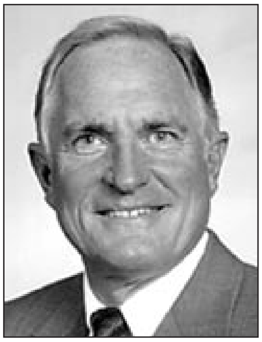


Paul R. Gray

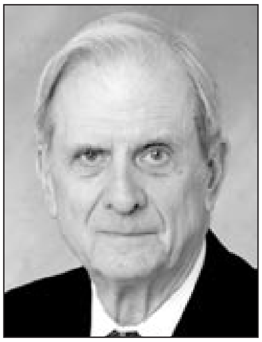
Julia M. Phillips



G. Wayne Clough

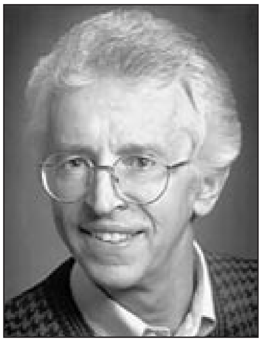


Craig R. Barrett

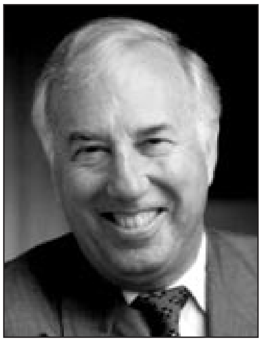


W. Dale Compton

Elsa M. Garmire



Siegfried S. Hecker



C. Dan Mote, Jr.

This spring, NAE elected a new chair, a new home secretary, and one incumbent and four new councillors. All terms begin July 1, 2008.

The new NAE chair is **Irwin M. Jacobs**, chairman of Qualcomm, Inc.; he was elected to a two-year term. **Thomas F. Budinger** was elected to a four-year term as home secretary. Budinger is a professor at the University of California, Berkeley, and faculty senior scientist at the E.O. Lawrence Berkeley National Laboratory.

Four councillors were also elected to three-year terms. They are: incumbent councillor **Bradford W. Parkinson**, Edward C. Wells Professor of Aeronautics and Astronautics Emeritus, Stanford University; **Alice M. Agogino**, professor of mechanical engineering, University of California, Berkeley; **Paul R. Gray**, Executive Vice Chancellor and Provost, Emeritus, University of California, Berkeley; and **Julia M. Phillips**, director of the Physical, Chemical, and Nano Sciences Center, Sandia National Laboratories. In addition, **G. Wayne Clough**, secretary designate of the Smithsonian Institution and president of the Georgia Institute of Technology, was elected by the NAE Council to a one-year term to complete the term of council member Tom Budinger when he assumes the duties of home secretary.

On June 30, 2008, **Craig R. Barrett**, chair of Intel Corporation, completed two terms of service as NAE chair, the maximum allowed under the academy's bylaws. **W. Dale Compton**, Lillian M. Gilbreth Distinguished Professor of Industrial Engineering, Emeritus, at Purdue University completed two terms of service as home secretary, the maximum allowed under the academy's bylaws. **Elsa M. Garmire**, Sydney E. Junkins Professor of Engineering at Dartmouth College; **Siegfried S. Hecker**, Director Emeritus of Los Alamos National Laboratory, and co-director of the Center for International Security and Cooperation and professor (research) at Stanford University; and **C. Dan Mote Jr.**, president and Glenn Martin Institute Professor of Engineering at the University of Maryland, completed six continuous years of service as councillors, the maximum allowed under the academy's bylaws. Dr. Barrett, Dr. Compton, Dr. Garmire, Dr. Hecker, and Dr. Mote were recognized for their distinguished service and other contributions to the NAE during a luncheon in May attended by NAE Council members and staff.

NAE Honors Winners of the 2008 Draper and Gordon Prizes

The 2008 winners of the Charles Stark Draper Prize and Bernard M. Gordon Prize were honored at a gala on February 19 at historic Union Station in Washington, D.C. This year's recipients accepted their awards before an audience of more than 200 guests with NAE President **Charles M. Vest** and NAE Council **Chair Craig R. Barrett** presiding. Presenters at this year's ceremony were James D. Shields of the Charles Stark Draper Laboratory Inc. and **Bernard M. Gordon**, founder of NeuroLogica Inc.

Charles Stark Draper Prize Winner

James D. Shields, Rudolf Kalman, Craig R. Barrett, and Charles M. Vest

Rudolf Kalman was awarded the 2008 Charles Stark Draper Prize for the development and dissemination of the optimal digital technique (known as the Kalman filter) used to control a vast array of consumer, health, commercial, and defense products. The Draper Prize, renowned as one of the most prestigious honors in engineering, is a $500,000 award given annually to an individual(s) who has contributed to an achievement or body of work that has enhanced the well-being and freedom of humanity.

The Kalman filter uses a mathematical technique to remove "noise" from series of data. From incomplete information, it can optimally estimate and control the state of a changing, complex system over time. The Kalman filter, which revolutionized the field of control theory, has been applied to systems and devices in nearly all engineering fields and continues to find new uses today. Applications include target tracking by radar, global positioning systems, hydrological modeling, atmospheric observations, time-series analyses in econometrics, and automated drug delivery.

Rudolf Kalman, Professor Emeritus of the Swiss Federal Institute of Technology in Zurich, conceptualized his filter in the late 1950s while working at the Research Institute for Advanced Studies in Baltimore (then part of the Glenn L. Martin Company, which became Lockheed-Martin Corporation). It was published in a breakthrough paper, “A New Approach to Linear Filtering and Prediction Problems” (*Transactions of the ASME-Journal of Basic Engineering*, 82D:35–45, 1960). Kalman soon published two more influential papers, one on the state-space theory of linear systems and another on concepts of controllability and observability.

When Kalman presented these new approaches at seminars, audience members were thrilled. With Kalman’s breakthroughs, a broad range of technologies were made much more accurate and could be used in previously unimagined ways. The Kalman filter was first used in aerospace and military applications, such as guidance, navigation, and control systems, and was subsequently applied to systems and devices in nearly all engineering fields.

Kalman’s studies of fundamental ideas in control and systems theories throughout his career have earned him many awards and honors, including the first Kyoto Prize in Advanced Technology (1985) from the Inamori Foundation, the IEEE Medal of Honor (1974), and the American Mathematical Society’s Steele Prize (1987). He is a member of the National Academy of Engineering, the National Academy of Sciences, and the American Academy of Arts and Sciences.

The Draper Prize was established in 1988 and endowed by the Charles Stark Draper Laboratory Inc., Cambridge, Massachusetts, to honor the memory of “Doc” Draper, the “father of inertial navigation,” and to increase public understanding of the contributions of engineering and technology to our quality of life.

Draper Prize Acceptance Remarks


Rudolf Kalman

Thank you very much, Dr. Vest. Thank you, Draper Lab. Thank you, National Academy of Engineering. I am deeply honored and very grateful for this high distinction.

The work that led us here began some 50 years ago. For inspiration and support I owe a debt to many. Unfortunately most of them are not here, cannot be here, and I have very little time to thank them individually. It works out costing about two dollars per millisecond.

But I would like to mention two people, at least. First, Professor Solomon Lefschetz, who could be regarded as a mentor, not because of what he did but because of what he did not do, namely interfere in any unpleasant way. And I certainly want to include my much younger colleague, Professor Larry Ho, whose predictions are sometimes even more accurate than those made using a Kalman filter.

I owe special thanks to the American dream. In my rare and unusual case, the American dream changed a DP into a DP. The first DP is a “displaced person,” and the second is a “Draper Prize” recipient. I am, possibly, the only one of some 200,000 DPs admitted to the United States as permanent residents, by special legislation, in the years 1948 to 1951, who has received such a high honor. I said “the only one,” but I am not sure of that. There could be others.

Finally, I thank my parents, who are not here, for giving me such excellent genes, so that I can enjoy this honor at a relatively advanced, but by no means completed, age.

After such heartfelt, but perhaps not newsworthy, remarks, I would like to express some strong personal opinions on the subject of research. My definition of research may not be suitable for a media sound bite, but I fully agree with Thomas Watson Sr. (founder of IBM), who noted that “research is not only looking for things but also finding things.” Whatever the definition, my intellectual motivation for a long time, especially after 1958 when I joined RIAS (Research Institute for Advanced Studies) in Baltimore, has been research. So why RIAS? What was RIAS?

In the wake of World War II, people who were eager to return to and continue their research—among them Lefschetz—soon came to the conclusion that basic research cannot be adequately supported by charity alone in the form of large fortunes committed to foundations or university endowments (like the Nobel Foundation, the Princeton Institute for Advanced Study, or the then not-yet-existing Inamori Foundation). Instead, the business model for RIAS, which was started in 1955 as a place to do research, basic research, was as an independent nonprofit institution supported by current income (from industry) but not constrained by the bottom line. RIAS didn't last, but it showed a way. Even after half a century, I am convinced it was an initiative that should be imitated.

The intellectual history of research, basic research, in the Western world begins with Copernicus, Galileo, and Kepler and continues with Newton. Newton was a fanatic for research, probably more so than anyone before or after him. His fanaticism was only limited by a brutal objectivity—he forced himself to abandon a line of research when it became clear that he had found nothing.

So here is a message for the younger generation. Research is still the endless frontier, but it is not a frontier that can be traversed without serious effort and a passionate personal commitment. As with Newton, this commitment stems from intellectual ambition and the excitement and pleasure of doing research, irrespective of personal or commercial or financial or military or political or any other rewards. If this appeals to you and think you can do it, I recommend it highly.

My time is up. Thank you all very much.

Bernard M. Gordon Prize Winners

Bernard M. Gordon, Lawrence E. Carlson, Jacquelyn F. Sullivan, Craig R. Barrett, and Charles M. Vest.

The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was awarded to Jacquelyn F. Sullivan and Lawrence E. Carlson for the Integrated Teaching and Learning (ITL) Program at the University of Colorado-Boulder, which infuses hands-on learning projects in grades K–16 to motivate and prepare future engineering leaders. The Gordon Prize is named in honor of **Bernard M. Gordon**, chairman of NeuroLogica Inc., and endowed by the Gordon Foundation. Awarded annually in recognition of significant advances in education, such as innovations in curriculum design, teaching methods, and technology-enabled learning, that lead to the development of engineering leaders, the prize carries a stipend of $500,000, half of which is divided equally among the recipients and half of which is donated to the recipients' institution.

The ITL Program is exceptional for its setting and for its curriculum. Anchored by the technology-rich ITL Laboratory, the program promotes the human connections of engineering through open, interactive, interdisciplinary design and experimental spaces. Engineering students from all university departments, beginning with their first year, can take design courses in the lab, where small interdisciplinary teams of students develop products to solve real problems.

Jacquelyn F. Sullivan is founding co-director and current director of the K–12 component of the ITL Program, which focuses on integrating hands-on engineering. The goal of the program is to make the world of engineering and technology come alive for K–12 teachers and students through professional development workshops, children's classes, summer design/build camps, and a summer residential program for under-served high school students. Currently, about 1,700 students in grades 3–12 are enrolled in weekly hands-on engineering classes, teaching youngsters that engineering makes a real difference in the world. The classes are taught by graduate fellows from UC-Boulder.

Dr. Sullivan also co-developed the "First-Year Engineering Projects" course, which introduces the design/build process to entry-level engineering students, and an undergraduate "Innovation and Invention" course, which introduces students to entrepreneurship through the invention of a new product. She also directs the long-term TEAMS (**T**omorrow's **E**ngineers. cre**A**te. i**M**agine. **S**ucceed) partnership between the CU College of Engineering and a local school district. In addition, she heads a multi-institutional initiative that created TeachEngineering—an online, searchable, standards-based, digital library collection of K–12 engineering curricula.

Dr. Sullivan was a member of the NAE Advisory Committee for a recent initiative on improving the public understanding of engineering and the NAE Committee on K–12 Engineering Education. Prior to joining the higher education community in 1990, she had 14 years of engineering experience in the energy and software industries. For nine years, she was director of an interdisciplinary research center at CU-Boulder working on water resources and environmental engineering simulation and optimization.

Since 1993, Sullivan has been involved in the establishment of K–12 magnet and charter schools in Colorado dedicated to preparing all youngsters for college. She is also a founding board member of the Denver School of Science and Technology—a highly successful public high school that concentrates on engineering and technology. She received her Ph.D. in environmental health physics and toxicology from Purdue University.

Lawrence E. Carlson has seen a lot of changes in his 36 years of teaching engineering—many of which he initiated as a member of the faculty at CU-Boulder. He began his teaching career at the University of Illinois in Chicago in 1971, after earning master's and D.Eng. degrees in mechanical engineering from the University of California, Berkeley. His doctoral thesis was on designing an upper-arm prosthesis with coordinated motion patterns, and he continued to work on rehabilitation engineering in Chicago, where he collaborated with the Prosthetics Research Laboratory at Northwestern University.

Carlson was attracted to CU-Boulder in 1974 by an offer to join the Department of Engineering Design and Economic Evaluation, which brought together his fundamental interests in design and the development of new products. When the department was disbanded four years later, he moved to the Department of Mechanical Engineering, where he continued to pursue his dual interests. He was one of the first to introduce the "First-Year Engineering Projects" course, which provides students with hands-on design experience early in their undergraduate engineering education, and he worked with other faculty members to develop the award-winning ITL Laboratory, which has become a national model for collaborative, hands-on engineering education. He and Sullivan were co-directors of ITL Laboratory from its founding in 1997 to June 2007. "My favorite definition of engineering is building things that benefit society," Carlson says. "I try to instill this notion in all my students, and engineering design is an excellent opportunity to do just that."

Carlson received the CU Charles Hutchinson Memorial Teaching Award in 2001, was named an IDEO Fellow in 2001, and won the John and Mercedes Peebles Innovation in Education Award in 2004. At the dedication of the ITL Laboratory in 1997, the students who govern the Engineering Excellence Fund endowed the annual Sullivan-Carlson Innovation in Education Award, which is awarded to a faculty member, selected by students, who embraces hands-on learning.

Gordon Prize Acceptance Remarks

Lawrence E. Carlson and Jacquelyn F. Sullivan

"Imagine a World . . ."

Engineering is about creating things that have never existed. It's about imagination and innovation and making a difference in our world. Imagine a world where engineers lead the creation of both the technologies *and* policies that shape our planet, where engineers are recognized by youngsters as heroes and heroines, and where American students are envied for their prowess in math, science, and reading.

Imagine a world where engineering students reflect society at large, where children of color, girls, and first-generation and low-income youths are attracted in droves to our profession, where *all* engineering graduates are globally aware, culturally sensitive citizens of the world.

Imagine a world where engineering students learn the tools of our trade by tackling *real* problems for *real* people, where engineering is perceived by youngsters to be as appealing as an iPod, and where every student gains a perspective of the broader meaning of engineering through formalized service-learning projects.

Imagine a world where the tremendous advances in the *science of learning* ignite innovation in engineering education, where engineering faculty are encouraged and rewarded for innovating as much in their classrooms as in their research labs, and where engineering curricula, experiences, and teaching truly motivate student learning.

Imagine a world where departments of engineering education can even be found west of the Mississippi River, and where industry and academia are intimate partners working for the greater good of both, moving beyond profits and disciplinary silos to support educational reforms at *all* levels, both leading and stimulating U.S. competitiveness.

The journey before us is long, and the need to accelerate educational innovation has never been greater. Tonight we express our gratitude and humility at being recognized by the academy as educational innovators. In a world where peer review reigns supreme, the Gordon Prize is the *ultimate* peer review.

We are grateful that our ITL Program team has received this recognition—and it *has* taken a team—from a forward-looking dean and tremendous, risk-taking engineering faculty to visionary engineering students who tax themselves more than $850,000 annually to support engineering education initiatives. We thank David Packard, who personally beseeched the Colorado legislature to support our educational reform, and our many corporate and foundation supporters who continue to help us scale new heights. And we thank our special partner, Hewlett Packard—which enabled our dream for pervasive hands-on learning to become reality. For years, HP has spawned real educational change, including meaningful collaboration with three recent Gordon Prize recipients.

Our team has also been broad-based. We thank NSF for many votes of confidence for our early K–12 engineering initiatives, and our K–12 school partners, who took the risk that developing *engineering habits of mind* would benefit *all* children.

And, our team has "hung in there" with us. The members of our incredible ITL team back home—who put student learning first every day—are amazing, results-driven folks who make our jobs a delight. **Jim Dally**, who led our Gordon Prize nomination, has been our role model—and hero—for 15 years. Our families, here tonight, have endlessly supported us and our dreams. And, of course we're fortunate and proud to be part of a great engineering college at a fine university.

Tonight we extend a special thank you to the National Academy of Engineering—and especially to **Bernie Gordon**—for making all of this possible. We are truly humbled and honored.

We ourselves are part of the learning community. We haven't figured out yet how to provide the *best* engineering education, but we're working on it. We're committed to a culture of excellence, caring, and accountability. Although we know many things that work (and some that don't), our challenge going forward is to have the vision and courage to *continue* to innovate . . . to make the possible probable.

Report of the Foreign Secretary

George Bugliarello

I want to bring you all up to date on our international activities since the Annual Meeting last September.

Foreign Associates

In February, nine foreign associates were elected: **Isamu Akasaki** (Japan), **Ann P. Dowling** (United Kingdom), **Thomas W. Healy** (Australia), **Akihisa Inoue** (Japan), **Alexander I. Leontiev** (Russia), **Arthur John Robin Gorell Milner** (United Kingdom), **Ekkehard Ramm** (Germany), **Rutger Anthony Van Santen** (Netherlands), and **Tadashi Watanabe** (Japan).

Our foreign associates provide invaluable links between NAE and engineering leaders in other countries. Foreign associates not only participate in NAE and NRC activities; they also organize meetings of foreign associates in key locations abroad where they have an opportunity to exchange ideas with NAE leaders. In addition, they keep us up to date about recent technological developments in their countries and about opportunities for collaborative projects and activities.

In the future, when we elect new associates, I believe we should try to address the underrepresentation of countries of increasing technological and geopolitical importance. In addition, we must find a way of keeping abreast of the achievements of outstanding engineering leaders abroad who may not be well known to our members. Home Secretary Dale Compton and I are working to enlist the help of our colleagues in this effort.

Two foreign associates passed away recently, **Wolfgang Schmidt**, a major figure in the aerospace industry in Germany, and **Konstantin Frolov**, director of the Institute of Machine Design of the Russian Academy of Sciences. A few months earlier, **Nikolai Platé**, a chemist and vice president of the Russian Academy of Sciences, passed away. Although he was not a foreign associate, he was a friend of NAE and of many NAE members and a leader of the joint Russia-U.S. Counterterrorism Committee. All three will be greatly missed.

Bilateral Activities

On November 4–8, 2007, the 7th Japan-America Frontiers of Engineering Symposium was held in Palo Alto, California, hosted by the Hewlett-Packard Corporation. The themes of the workshop sessions were human-computer interactions; battery technologies; rocketry/aerospace; next-generation data centers; and materials for medicine.

On February 27–March 1 of this year, the second Indo-American Frontiers of Engineering Symposium was held at the Beckman Center in Irvine, California. Presentations focused on four topics: infrastructure engineering, clean energy for baseload power, bioengineering and health care, and chemicals and automotive manufacturing.

On April 25–27, 2008, the German-American Frontiers of Engineering Symposium was held at the Beckman Center. The topics for the meeting were nanotechnology for medical therapies; micromanufacturing/microprocess engineering; energy harvesting; and advanced imaging technologies.

We continue to receive requests from academies and scientific organizations abroad to participate in collaborative meetings and projects. Currently, we are exploring expanding the Frontiers of Engineering Program to include regional symposia (e.g., with the European Union). In addition, NAE member **Bert Westwood** represented NAE on a visit to Belarus in December 2007 in response to an invitation from the Belarus Academy of Sciences.

Because of limited resources, our program to maintain liaisons with academies in other countries is still limited to academies in India, Mexico, and Russia.

In November 2007, NAE Council member **Siegfried Hecker** co-chaired a bilateral workshop in China on protecting cities from terrorist attacks with conventional explosives. The workshop was carried out under the umbrella of the joint memorandum of understanding between NAE and the Chinese Academy of Engineering, which was renewed in December 2005.

NAE also participated in the International Council of Academies of Engineering and Technological Sciences (CAETS) Convocation in Tokyo on October 21–26, 2007. NAE President **Charles Vest**, Executive Officer **Lance Davis**, and I were the NAE delegates. The theme of the convocation was "Engineering for Sustainable Development." NAE member **Michael Ramage** made a presentation on alternate energy sources, and NAE member **Glen Daigger** spoke on the environment and sustainable development in North America. At the end of the convocation, CAETS issued a statement on global priorities for sustainable development. The next CAETS meeting will be held in Amsterdam in July 2008, hosted by the Netherlands Academy of Technology and Innovation (AcTI-nl).

Last fall, NAE was asked to represent the National Academies in planning a joint conference with the Leopoldina and Acatech (the engineering academy) in Germany. The conference will take place in Germany, probably at Halle, in October 2009. Specific topics and logistics are still under discussion. The National Academies will provide appropriate speakers on the selected topics.

George Bugliarello

Second Indo-American Frontiers of Engineering Symposium

On February 28–March 1, NAE hosted the second Indo-American Frontiers of Engineering (IAFOE) Symposium at the National Academies' Beckman Center in Irvine, California. This biennial symposium series was inaugurated in 2006 in Agra, India. The 2008 symposium was sponsored by the Indo-U.S. Science and Technology Forum (IUSSTF) and was jointly organized by NAE and the Indian Institute of Technology, Madras. NAE member **Athanassios Panagiotopoulos**, Susan Dod Brown Professor of Chemical Engineering at Princeton University, and Ravinder David Koilpillai, professor of electrical engineering at the Indian Institute of Technology, Madras, co-chaired the meeting.

Attended by approximately 60 engineers, ages 30 to 45, from U.S. and Indian universities, companies, and government laboratories, this three-day meeting focused on leading-edge developments in four fields of engineering: infrastructure engineering, clean energy for base-load power, bioengineering and health care, and chemicals and automotive engineering. The topics were selected for their relevance to both countries.

In the session on infrastructure engineering, speakers noted the high correlation between the quality of infrastructure and economic productivity in countries throughout the world. Civil infrastructure systems must be robust enough to withstand natural and man-made disasters, which can cause significant social and economic disruptions. The session on clean energy for base-load power focused on developments in clean-coal technology and nuclear energy generation, neither of which has the negative climate-change effects of burning coal. The third session, on bioengineering and health care, was focused on two areas: (1) the merger of computational science with biology and (2) advances in medical devices. The last session was on state-of-the-art and future directions in automotive and chemicals manufacturing.

The dinner address by NAE member **Henry Samueli**, co-founder, chairman, and CTO of Broadcom Corporation, touched on a variety of subjects, such as the convergence of communications devices, the importance of investment in R&D and constant innovation for maintaining competitiveness, and the experience of founding a company. Dr. Samueli noted that the most successful companies effectively leverage globalization, and he described how his company does this. He suggested that speech recognition, seamless security and authentication, content protection, and integrated biosensors for health management are promising areas for future R&D.

In addition to the technical sessions, the group toured two facilities on the University of California-Irvine campus. At the National Fuel Cell Research Center (NFCRC), director Scott Samuelsen provided an overview of the research at the center, after which attendees rotated through a series of labs and demonstrations of the 5 kW plug power PEM fuel cell and the operating characteristics of solid-oxide fuel cells at high altitude. Attendees also saw fuel-cell vehicles manufactured by GM and Toyota. At the second facility, the California Institute for Telecommunications and Information Technology, or Calit2, the group was given demonstrations of the world's largest visualization display wall and state-of-the-art scanning electron microscopes.

The IAFOE Symposium was sponsored by IUSSTF, an autonomous, nonprofit society founded (and funded) by the governments of India and the United States to promote bilateral collaborations in science, technology, engineering, and biomedical research. Additional funding was provided by the U.S. Office of Naval Research Global and the Arnold O. and Mabel Beckman Foundation.

The next IAFOE Symposium will be held in February or March 2010 in India. For information about the symposium series or to nominate an outstanding engineer to participate in a future symposium, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail at *jhunziker@nae.edu*.

NAE Regional Meeting on Sustainable Energy in Transportation

An NAE regional conference, "Sustainable Energy for Mobility in the 21st Century," hosted by the University of Wisconsin, Madison, on April 10, 2008, was attended by more than 150 people from seven states and the District of Columbia. The conference was co-sponsored by the Energy Institute, the Midwest Regional University Transportation Center, and the Wisconsin Public Utility Institute (WPUI).

Professor David Foster, director of the Engine Research Center at the University of Wisconsin, gave the keynote address, "Energy for Transportation in the 21st Century." He provided an overview of energy use and the portion of our fossil fuels necessary to produce the liquid hydrocarbon we use for mobility. He then addressed the possibility that peak oil production would occur in the near future, if it has not already occurred, and raised the question of future oil supplies. Tar sands, oil shale, and coal-to-liquid processes, he said, have the potential to more than offset the shortfalls if/when we pass the peak of current supplies. The key issue, he said, will be carbon emissions and the energy footprint associated with converting these new sources of oil to liquid energy carriers.

He noted that using alternatives to liquid hydrocarbons for fuel would require that we re-examine our paradigm of mobility, because it takes decades for new power plants and energy-carrier technologies to achieve significant market penetration. Thus he concluded that engines powered by liquid hydrocarbons will be the mainstay of our mobility systems for decades to come. Although biofuels can replace some of the demand for traditional liquid hydrocarbons, he cautioned that we must carefully evaluate the carbon emissions and land and water requirements required to produce them. Subsequent speakers expanded on these themes.

Jason Bittner, deputy director of the Midwest Regional University Transportation Center (*http://www.mrutc.org/*), spoke on freight transportation, a critical component of the national economy. Even conservative estimates, he said, predict that total freight tonnage nationally will double by 2035. Air- and truck-based freight will double, and rail-, water-, and pipeline-based freight will increase substantially. A major challenge for U.S. competitiveness, Bittner said, is that our transportation infrastructure is not growing fast enough to keep pace. This will result in capacity crises for all modes of freight delivery.

We must also keep in mind, he said, that freight facilities and vehicles are immense consumers of energy and land resources. Although the freight community is attempting to advance sustainable concepts, and the business case for energy conservation and improved land-use decisions is beginning to penetrate decision-making processes, he warned that, to prevent freight growth—a burgeoning "tsunami" of freight—from choking the economy, we must take action now.

Tracey Holloway, professor of civil engineering and environmental studies, discussed emissions from transportation and efforts to identify options for low-carbon transportation systems. Current available strategies to reduce CO_2 emissions from transportation include: reducing the number of miles driven; increasing the fuel efficiency of vehicles (including more widespread adoption of hybrid and diesel vehicles); and promoting the electrification of the transportation systems (electric or hybrid-electric vehicles that use electricity provided by non-carbon-emitting technologies). Most likely, Dr. Holloway said, we will need a combination of these strategies to achieve significant reductions in CO_2 emissions from transportation, both nationally and globally.

Andreas Lippert, director of Global Energy Systems at General Motors R&D Center, discussed energy-conversion technologies being developed to improve the efficient use of liquid hydrocarbons as well as alternative energy carriers. Lippert projected that even though global energy demand for transportation will exceed the "glide path" for supply, a combination of improvements in efficiency and fuel diversification will compensate. He noted that gas and diesel engines will be the primary systems for the foreseeable future, but improvements in conventional power trains and alternative fuels, including electricity, biofuels, and ultimately hydrogen, will reduce petroleum consumption and greenhouse gas emissions.

The lead scientists from the new DOE Bioenergy Research Center then presented an overview of the organization of the research center and described its contributions in biology, physical sciences, and engineering to new or ongoing scientific programs. The ultimate goal of the research center is to advance the understanding of the biological mechanisms that underlie biofuel production so those mechanisms can be redesigned and improved to develop novel, efficient bioenergy strategies that can be replicated on a mass scale. Specifically, the research teams have been charged with the grand challenge of conducting fundamental research on the underlying principles necessary for generating technology that will improve the efficiency of the conversion of cellulosic-plant biomass to ethanol and other liquid hydrocarbons.

The conference was organized by NAE member, **Michael Corradini**, and WPUI director, Cara Lee Braithwait, as well as UW Energy Institute Director Paul Meier. Presentations and videotape of the presentations are available online at *http://wpui.wisc.edu/programs/Institute%20Lunches/NAE/NAE_home.html.*

NAE Regional Meeting at Princeton Focuses on Global Warming

The scale of global warming and ideas for addressing the problems it raises were the main themes of the Symposium on Energy, Climate, and the Environment held in conjunction with the NAE Regional Meeting and hosted by Princeton University on March 4, 2008.

Robert Socolow, professor of mechanical and aerospace engineering at Princeton, opened the half-day symposium with a wide ranging discussion of the buildup of carbon dioxide in the atmosphere. He noted that there are currently 800 billion tons of carbon in the atmosphere and that an often-cited goal is keeping that amount below 1,200 billion tons. Given the current pace of fossil fuel consumption and carbon buildup, he said, any delay in reducing emissions will greatly reduce our options. The longer we wait, he said, the fewer choices we will have. "We can accept a higher target, or we can come down at a faster pace . . . the question that has had almost no attention . . . is what pace is possible and at what cost?"

Citing a seminal 2004 paper he co-wrote with Stephen Pacala, Professor Socolow divided the necessary reductions in emissions into "wedges," each representing 1 billion tons of avoided emissions after 50 years. He noted that there are many ways to achieve reductions but focused on improving efficiency and replacing coal power. "If we do any of these things that are substitutes for our current consumption, we [must] do them well," he said. "I think we are far too relaxed about the notion that we can wave a wand, and we'll have these great solutions."

Denise Mauzerall, associate professor of public and international affairs at Princeton, then discussed interconnections between air pollution, climate change, and human health and the opportunities for improving all three. She noted that some actions that would address air pollution and health can exacerbate warming, while others could be mutually beneficial. The pollutant sulfur dioxide, for example, tends to counteract warming; thus efforts to reduce it could worsen the climate problem. "Integration of air quality and climate stabilization goals in environmental policy would be highly beneficial," she said. "Right now they are decoupled." Clear ways to decrease air pollution without exacerbating global warming, she said, would be to reduce emissions of methane and black carbon.

The main theme of the presentation by David Crane, chief executive officer of NRG Energy Corporation, was that energy producers can be part of the solution, despite their current dependence on coal-fired power plants. As an owner of many coal-burning power plants, NRG is willing to accept legislation that causes "a little bit of pain if we don't address global warming, but I will fight as hard as I can against anything that would kill our company," he said. Nonetheless, he said, if energy companies move quickly to find cleaner ways of producing power, he believes they would also find new business opportunities. "If we can clean up our act, then the other industries will have to come to us, particularly the transportation industry," he said. He cited the mandatory use of plug-in cars as an example, which "would be the single best thing to happen to the power industry since the invention of the electric air conditioner." Wind and solar energy, Crane said, are short-term solutions. Long-term solutions will involve "clean-coal" technology and nuclear power.

Daniel Rubenstein, professor of ecology and evolutionary biology at Princeton, presented a regional ecological perspective on environmental problems in one area of Africa. That landscape could vanish, he said, unless we balance the tensions between the wildlife and people who live there. He then described how scientists and engineers could work together to help policy makers find sustainable solutions. The answer, he said, is not to adopt the American model of forcing wildlife into reserves but to find ways of supporting wildlife *and* improving people's livelihoods. He then described how he and other scientists had used technology to understand animal movements, predation, and the water cycle and helped change simple behaviors among local herders that have improved their situation and preserved animal populations.

Stephen Pacala, the Fredrick Petrie Professor of Ecology and Evolutionary Biology and director of the Princeton Environmental Institute, returned to the question of climate and whether technology can solve the problem. After stressing the enormous uncertainties in addressing climate change, he recited a litany of possible risks of warming, including: the destabilization of ocean circulation patterns; the loss of arctic sea ice, which would exacerbate warming; the loss of continental ice sheets, which would dramatically raise sea level; an increase in the number of tropical hurricanes; drought; shortages of water and food; and heat-related deaths. "The overall conclusion of the scientific community," he said, "is that extra CO_2 in the atmosphere is simply dangerous."

With half the world's carbon emissions coming from the 500 million wealthiest people, even modest solutions must begin with "radical decarbonization of the rich countries." However, as current emission levels continue to rise, he concluded, a dramatic reduction in U.S. emissions in the next 50 years will require "an influx" of new technologies that only engineers can provide.

The symposium was moderated by NAE members **Pablo Debenedetti**, Class of 1950 Professor of Chemical Engineering, and **George Scherer**, William L. Knapp '47 Professor of Civil Engineering, both at Princeton. The event was introduced by NAE member **H. Vincent Poor**, dean of the Princeton School of Engineering and Applied Science, and **Charles Vest**, president of NAE and President Emeritus of the Massachusetts Institute of Technology.

Video of the full symposium is available at *http://uc.princeton.edu/main/index.php?option=com_content&task=view&id=2878*.

Randy Atkins Wins Award for Journalism

Randy Atkins

Randy Atkins, NAE Senior Program Officer for Media Relations, was presented with the Northern Virginia Society of American Military Engineers (SAME) Award for Journalism at the Fort Belvoir Officers Club on May 1. Atkins was honored for his radio series "Engineering Innovation." The award was presented by Rear Admiral Ron Silva.

Chair of the SAME Awards Committee Richard Ragold praised Atkins for his work. "We hear constantly about great accomplishments in other walks of life…but rarely are engineers, design professionals, or contractors given credit for all the things necessary for living progress. So many young people assume the cars, roads, buildings, bridges have always been there and somehow just happened. Your work in broadcasting is invaluable in explaining to the public how all the things in our physical universe affecting our daily lives come about."

The purpose of the award is to honor a journalist in the print and/or broadcast media who has through his or her works recognized the achievements of architects, engineers, and contractors in the built environment. Nominations were invited from SAME members, the media, government, business, professional organizations, and academia.

"Engineering Innovation" airs weekly on the all-news format WTOP-FM, the most-listened to radio station in the Washington, D.C., area. Atkins' pieces also air on Federal News Radio. Please visit *www.nae.edu/radio* for more about the series or to sign up for the podcast.

Winners of the *EngineerGirl!* 2008 Essay Contest "Engineering Energy for the Future"

EngineerGirl! (*www.engineergirl.org*) recently announced the winners of its 2008 essay contest, "Engineering Energy for the Future." Students in grades 3 through 12 were asked to tackle the tough question of how engineers might work together to meet the changing needs of people without damaging the environment. They were asked to specify what engineers should focus on and how energy will affect the future of engineering.

This year, NAE received more than 200 entries, a 100 percent increase over last year, from youngsters around the world. Prizes were awarded in three categories, grades 3 through 5, 6 through 8, and 9 through 12, ranging from $500 for first place to certificates of honorable mention. The essays were judged on the basis of organization, depth of detail, and use of language.

The first prize in the third through fifth grade category was awarded to Jennifer Shulman of Boca Raton, Florida, for her essay "Role of Engineers in Our Energy Future." A fourth grader at Banyan Creek Elementary School, Jennifer wrote that "engineers are faced with the responsibility of finding ways of producing clean energy and developing new, more environmentally friendly ways of using energy." Through innovation, advocacy, and education, she said, engineers should be at the "forefront of protecting our planet for future generations." Jennifer's mother, Ileana Shulman, told us that Jennifer "loves math and robotics and wants to be an engineer when she grows up."

In the sixth through eighth grade category, first place was awarded to Nupur Garg of Cupertino, California, for her essay entitled "Engineer's Next Focus—Renewable Energy." Nupur, an eighth grade student at Kennedy Middle School, discussed wind- and water-powered turbines and solar panels. "Engineers should focus on making easy and efficient inventions, using renewable energy sources, to power the buildings and appliances that play significant roles in our lives. With this, our past will no longer be our future. Instead, our future will be a bright and healthy one."

In the ninth through twelfth grade category, the first-place winner was

Angela Rae Woods of Carrollton, Kentucky. In her essay, "Look Up and See the Light," she argues that engineers should focus their efforts on harnessing solar energy and improving ways to use it.

Additional winners included Alexandra Kung, Chappaqua, New York; Tori Meredith Deibler, Christiansburg, Virginia; Jacqueline Feffer, Boalsburg, Pennsylvania; Ashley Thomas, Auburn, Washington; Sarah Booth, Chelmsford, Massachusetts; Danielle Feffer, Boalsburg, Pennsylvania; Jennifer Chen Li, Apex, North Carolina; and Devon Frazier, Tualatin, Oregon. All of the winning essays can be found on *www.engineergirl.org*.

EngineerGirl!, NAE's innovative website for middle-school girls, provides timely, accessible information about the engineering profession. Through the website, outreach programs, and partnerships, NAE hopes to inspire girls to study engineering and pursue careers in the field. For further information on *EngineerGirl!*, see *www.engineergirl.org* or e-mail *cdidion@nae.edu*.

A companion website, *www.EngineerYourLife.org*, is geared for academically prepared high-school girls. This website is a collaborative project with the WGBH Educational Foundation, as well as 50 engineering and educational organizations.

NAE Annual Meeting, October 5–6, 2008

The 2008 NAE Annual Meeting will be held October 5–6 at the National Academies Building and the Keck Center of the National Academies in Washington, D.C. Members of the NAE Class of 2008 will meet on Saturday, October 4, for an orientation and that evening will be guests at a black-tie dinner in their honor hosted by the NAE Council.

The induction ceremony for the class of 2008 will be held at noon on Sunday, October 5. An awards program will follow, featuring talks by the winners of the 2008 Founders Award, Arthur M. Bueche Award, and Bernard M. Gordon Prize to be followed by the Armstrong Endowment for Young Engineers-Gilbreth Lectures. Events will conclude with a guest speaker (to be announced).

The topic of the technical symposium, on Monday, October 6, will be Grand Challenges for Engineering (see *www.engineeringchallenges.org* for more information). Activities will continue with section meetings in the afternoon and a dinner, dancing, and entertainment by "The Capitol Steps" in the ballroom of the JW Marriott Hotel. Registration information will be sent to all members in early August.

Calendar of Meetings and Events

June 19	NAE/NAEF Audit Committee Meeting
July 15	NRC Governing Board Executive Committee Meeting
July 30–31	NAE Council Meeting Woods Hole, Massachusetts
August 1–2	NRC Governing Board Meeting Woods Hole, Massachusetts
August 25–26	Workshop on Encouraging Responsible Research (tentative)
Sept. 4	NRC Governing Board Executive Committee Meeting
Sept. 18–20	U.S. Frontiers of Engineering Symposium Albuquerque, New Mexico

All meetings are held in the Academies Building, Washington, D.C., unless otherwise noted.

In Memoriam

MALCOLM J. ABZUG, 87, TRW Inc., retired, died on May 24, 2007. Dr. Abzug was elected to NAE in 1996 "for contributions to aircraft and missile dynamics, control, and guidance."

LAURENCE J. ADAMS, 86, former president, Martin Marietta Corporation, died on February 13, 2008. Mr. Adams was elected to NAE in 1988 "for exceptional engineering leadership in space vehicle systems."

YOSHIO ANDO, 85, doctor of engineering and Professor Emeritus, University of Tokyo, died on July 4, 2007. Dr. Ando was elected a foreign associate of NAE in 1978 "for contributions to reactor safety in Japan's nuclear power programs."

WILLIAM M. BROWN, 76, Chief Scientist Emeritus, Air Force Research Laboratory, died on February 23, 2008. Dr. Brown was elected to NAE in 1992 "for leadership and contributions to the theory and practice of synthetic aperture radar."

ARTHUR C. CLARKE, 90, author/broadcaster, died on March 19, 2008. Sir Arthur was elected a foreign associate of NAE in 1986 "for conception of geosynchronous communications satellites, and for other contributions to the use and understanding of space."

FERDINAND FREUDENSTEIN, 79, Higgins Professor Emeritus of Mechanical Engineering, Columbia University, died on March 30, 2006. Dr. Freudenstein was elected to NAE in 1979 "for leadership and research in kinematics and design of mechanisms."

JOHN HILL, 86, retired chairman, U.K. Atomic Energy Authority, died on January 14, 2008. Sir John was elected a foreign associate of NAE in 1976 "for leadership in all phases of the British nuclear energy program and the promotion of international cooperation in nuclear energy undertakings."

JOSEPH M. JURAN, 103, Chairman Emeritus, Juran Institute Inc., died on February 28, 2008. Dr. Juran was elected to NAE in 1988 "for pioneering contributions in developing the practice of statistical quality control, and in developing engineering design principles based on statistical concepts."

HARRY O. MONSON, 88, retired senior mechanical engineer, Argonne National Laboratory, died on May 1, 2007. Dr. Monson was elected to NAE in 1983 "for outstanding contributions to the design and development of fast breeder reactors and the safety of nuclear power plants."

ANTONI K. OPPENHEIM, 92, professor in the graduate school, University of California, Berkeley, died on January 12, 2008. Dr. Oppenheim was elected to NAE in 1978 "for contributions to the elucidation of the gas dynamics of explosions and to the analysis of surface radiant-heat exchange."

RALPH B. PECK, 95, Professor of Foundation Engineering Emeritus, University of Illinois, Urbana-Champaign, civil engineer, Geotechnics, died on February 18, 2008. Dr. Peck was elected to NAE in 1965 "for his distinguished contributions as a soil mechanics and foundation engineer."

JOSEPH G. RICHARDSON, 84, retired president, J. Richardson Consultants Inc., died on November 18, 2007. Mr. Richardson was elected to NAE in 1988 "for pioneering studies of oil recovery by water flooding and water imbibition, and for development of broadly applicable reservoir engineering technology."

FRANKLIN F. SNYDER, 97, retired hydrologic engineer, died on March 13, 2008. Mr. Snyder was elected to NAE in 1985 "for basic contributions to the hydrology and technology of predicting and controlling water level and flow in streams and reservoirs."

JAN VAN SCHILFGAARDE, 79, retired director, Pacific West Area ARS, PWA, U.S. Department of Agriculture, died on March 25, 2008. Dr. van Schilfgaarde was elected to NAE in 1989 "for distinguished contributions to agricultural drainage concepts, theory, and design."

MICHIYUKI UENOHARA, 82, Professor Emeritus, Tama University, and retired chairman, NEC Research Institute Inc., died on December 12, 2007. Dr. Uenohara was elected a foreign associate of NAE in 1985 "for pioneering work in the development of low-noise parametric amplifiers for application in satellite communications and semiconductor microwave devices."

JIN WU, 73, Distinguished Professor of Engineering, Cheng Kung University, died on January 14, 2008. Dr. Wu was elected to NAE in 1995 "for advancing knowledge of the air-sea interface through experiments with applications to remote sensing and the environment."

JOHN ZABORSZKY, 93, professor, department of electrical and systems engineering, Washington University, St. Louis, Missouri, died on February 1, 2008. Dr. Zaborszky was elected to NAE in 1984 "for contributions to adaptation of advanced control theory and system science for improved reliability and economy of interconnected power systems."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Nanophotonics: Accessibility and Applicability. The Committee on Technology Insight–Gauge, Evaluate and Review, which was established by the National Research Council at the request of the Defense Intelligence Agency, selected a number of emerging technologies to investigate for potential threats to and opportunities for national security. This first study is on emerging applications of nanophotonics, the interactions of matter and light at the scale of the wavelength of the light. When matter is manipulated at that scale, its optical properties can be tailored for a variety of commercial and defense applications. This report provides a review of the basic nanoscale phenomena in nanophotonics, an assessment of enabling technologies for the development of new applications, a discussion of potential military applications, and an assessment of foreign-investment capabilities.

NAE member **Anthony J. DeMaria**, chief scientist, Coherent-DEOS LLC, was vice chair of the study committee, and **Eli Yablonovitch**, professor of electrical engineering and computer sciences, University of California, Berkeley, was a committee member. Paper, $50.75.

Metropolitan Travel Forecasting: Current Practice and Future Direction—Special Report 288. This assessment of the state-of-the-practice in forecasting travel demand identifies shortcomings in forecasting models, obstacles to better practices, and actions to ensure that appropriate technical approaches are being used. The committee finds that the "four-step" models currently used are not adequate for meeting policy and regulatory requirements and recommends the creation of a cooperative research program (a "metropolitan planning organization") and a substantial increase in federal funding for the development, evaluation, and implementation of models that can meet current and anticipated requirements. The report is written for use by officials and policy makers who rely on travel forecasts.

NAE member **Thomas B. Deen**, retired executive director, Transportation Research Board, National Research Council, was a member of the study committee. Paper, $31.00.

Space Science and the International Traffic in Arms Regulations: Summary of a Workshop. International Traffic in Arms Regulations (ITAR), the U.S. Department of Defense protocol that controls defense trade, includes the U.S. Munitions List (USML), which specifies categories of defense articles and services covered by the regulations; in 1999, space satellites were added to the USML. In 2002, ITAR was amended so that U.S. universities no longer have to obtain ITAR licenses when conducting fundamental research involving foreign countries and/or persons. Despite this provision, there is still a great deal of uncertainty among university researchers about whether the regulations apply to their research, which has led to a conservative interpretation of the regulations and the imposition of burdens that might not be necessary. To explore this concern, the National Aeronautics and Space Administration asked the National Research Council to organize a workshop of all stakeholders to clarify the implications of ITAR for space science. This volume provides a summary of the workshop discussions on recent developments and implementations of ITAR; overarching issues; problems arising from ITAR's implementations; and opportunities for near-term actions and improvements.

NAE member **John R. Casani**, special assistant to the director, Jet Propulsion Laboratory, was a member of the study committee. Paper, $15.00.

Workshop Series on Issues in Space Science and Technology: Summary of Space and Earth Science Issues from the Workshop on U.S. Civil Space Policy. The

National Aeronautics and Space Administration (NASA) requested that the Space Studies Board (SSB) of the National Research Council hold a series of workshops to examine issues related to space science and technology. The first workshop was held in November 2007, in conjunction with a joint workshop by SSB and the Aeronautics and Space Engineering Board, to provide an overall assessment of U.S. civil space policy. This volume, which focuses on the sessions of particular interest to the NASA Science Mission Directorate (SMD), provides a summary of the perspectives of various participants on issues relevant to SMD. A separate volume will cover issues related to U.S. civil space policy.

NAE members on the Space Studies Board are **A. Thomas Young**, Lockheed Martin Corporation, retired; **Soroosh Sorooshian**, UCI Distinguished Professor and director, Center for Hydrometeorology and Remote Sensing, Department of Civil and Environmental Engineering, University of California, Irvine; **Richard H. Truly**, retired director, National Renewable Energy Laboratory; and **Warren M. Washington**, senior scientist and section head, Climate Change Research Section, Climate and Global Dynamics Division, National Center for Atmospheric Research. Free PDF.

Assessment of the NASA Astrobiology Institute. Astrobiology is a scientific discipline devoted to the study of the origin, evolution, distribution, and future of life in the universe. Based on new information from solar system exploration and astronomical research in the mid-1990s, as well as advances in the biological sciences, the National Aeronautics and Space Administration (NASA) established an astrobiology program (NASA Astrobiology Institute [NAI]) in 1997. To help NASA evaluate NAI, the National Research Council was asked to review progress by the institute in developing the field of astrobiology. This report includes an assessment of NAI's success in meeting its goals of encouraging interdisciplinary research, training future astrobiology researchers, providing scientific and technical leadership, using information technology to explore new research approaches, and supporting outreach to K–12 education programs.

NAE member **Yvonne C. Brill**, aerospace consultant, was a member of the study committee. Paper, $21.00.

Grading NASA's Solar System Exploration Program: A Midterm Review. The NASA Authorization Act of 2005 directed the agency to ask the National Research Council (NRC) to assess the performance of each division in the National Aeronautics and Space Administration (NASA) Science Directorate at five-year intervals. As one of those assessments, NASA requested that the NRC review progress by the Planetary Exploration Division toward implementing recommendations from previous NRC studies. This assessment includes an evaluation of how well the division is doing, current trends, and key areas of science investigation, such as flight missions, Mars exploration, research and analysis, and enabling technologies. Recommendations are provided for areas that need improvement.

NAE member **Spencer R. Titley**, professor of geosciences, University of Arizona, was a member of the study committee. Paper, $21.00.

Soldier Protective Clothing and Equipment: Feasibility of Chemical Testing Using a Fully Articulated Robotic Mannequin. The U.S. Department of Defense (DOD) and its counterparts in other countries are considering trying to develop human-like mannequins as subjects for advanced testing of personal protective equipment designed to protect against chemical warfare agents. At the request of DOD Product Director, Test Equipment, Strategy and Support, the National Research Council formed a committee to evaluate the feasibility of developing a protection-ensemble test mannequin (PETMAN), an advanced humanoid robot that would meet DOD requirements. The report concludes that a robot that meets all of the requirements is currently not possible and recommends that DOD prioritize system requirements, use qualified contractors for some technical aspects of testing, and incorporate complementary testing approaches to a PETMAN system.

NAE member **Hadi Abu-Akeel**, consultant, robotics and automation, Bloomfield Hills, Michigan, was a member of the study committee. Paper, $41.00.

NASA's Elementary and Secondary Education Program: Review and Critique. Even though the National Aeronautics and Space Administration (NASA) is uniquely positioned to attract students to pursue courses and careers in science, technology, and engineering, this new study by the National Research Council finds that the elementary and secondary education programs of NASA's Office of Education could be much more effective than they are. The authoring committee of the report recommends that NASA work with outside experts in education to improve its programs and that some of them be restructured to capitalize on the agency's expertise and on new technologies.

NAE member **Edward F. Crawley**, executive director, CMI, and professor, Aeronautics and Astronautics, Massachusetts Institute of Technology, was a member of the study committee. Paper, $38.25.

Wake Turbulence: An Obstacle to Increased Air Traffic Capacity. Unless major changes are made, the current air transportation system will not be able to accommodate the expected increase in demand by 2025. One proposal for addressing this problem is to use the Global Positioning System to enable aircraft to fly with less space between them. The effectiveness of this change, however, might be limited by wake turbulence, which can be a safety hazard if smaller aircraft follow relatively larger aircraft too closely. To determine if this potential hazard might be reduced, Congress in 2005 directed the National Aeronautics and Space Administration to request that the National Research Council conduct a study to assess the federal wake turbulence research and development program. This report provides a description of the problem, an assessment of the organizational challenges to addressing the problem of wake turbulence, an analysis of the technical challenges presented by wake turbulence, and a proposed program plan. The report also includes recommendations for addressing the problem.

NAE members **Paul Bevilaqua**, manager, Advanced Development Programs, Lockheed Martin Aeronautics Company, and **Fazle Hussain**, Cullen Distinguished Professor, Department of Mechanical Engineering, University of Houston, were members of the study committee. Paper, $21.00.

Managing Materials for a Twenty-First Century Military. Since 1939, the U.S. government has maintained a National Defense Stockpile (NDS) of strategic materials critical to our national defense. However, the economic and national security environments have changed significantly since the NDS was created. Current threats are more varied, production and processing of key materials are globally dispersed, global competition for raw materials is increasing, the U.S. military is more dependent on civilian industry, and industry depends far more on just-in-time inventory control. In light of these changes, the U.S. Department of Defense asked the National Research Council to assess the current value of the NDS. Following an overview of the history of NDS, this report provides an evaluation of supplies of raw materials and minerals, changing needs for defense planning and materials, an overview of tools for managing materials supply chains, and a review of current NDS operational practices.

NAE members on the study committee were **Katharine G. Frase**, vice president, Technology and Business Strategy, IBM Software Group; **Ralph L. Keeney**, Professor Emeritus of Systems Engineering, Daniel J. Epstein Department of Industrial and Systems Engineering, University of Southern California; **Kwadwo Osseo-Asare**, professor of metallurgy and geo-environmental engineering, Department of Materials Science and Engineering, Pennsylvania State University; and **James C. Williams**, Honda Professor of Materials, Department of Materials Science and Engineering, Ohio State University. Paper, $46.00.

Review of DOE's Nuclear Energy Research and Development Program. In the past few years, an upsurge of interest in nuclear power in the United States has led to a rapid increase in the research budget of the U.S. Department of Energy Office of Nuclear Energy (ONE). In light of this rapid increase, the Office of Management and Budget included a request in its FY2006 budget request for a study by the National Academies to review and recommend priorities for ONE research programs. The programs evaluated were: Nuclear Power 2010, Generation IV, the Nuclear Hydrogen Initiative, the Global Nuclear Energy Partnership/Advanced Fuel Cycle Initiative, and the Idaho National Laboratory facilities. This report provides descriptions, analyses, findings, and recommendations for each program, as well as an assessment of ONE program priorities and oversight.

NAE members on the study committee were **Douglas M. Chapin**, principal officer, MPR Associated Inc.; **Michael L. Corradini**, professor and chair, Department of Engineering and Physics, University of Wisconsin, Madison; **James W. Dally**, Glenn L. Martin Institute Professor of Engineering Emeritus, University of Maryland; **Salomon Levy**, owner, Levy and Associates; **Warren F. Miller Jr.**, associate director, Nuclear Security Science and Policy Institute, Texas A&M University; and **John J. Taylor**, vice president of nuclear power (retired), Electric Power Research Institute. Paper, $28.00.

State Science and Technology Policy Advice: Issues, Opportunities, and Challenges: Summary of a National Convocation. Although the federal government is still the predominant supporter of research and development (R&D), and federal policies have an enormous affect on science and technology (S&T) in the United States, state and local policy makers are making more and more decisions that affect all of us on a daily basis, and states are assuming increasing responsibility for the development, formalization, and institutionalization of policies and programs that support R&D and enable S&T evidence and expertise to be incorporated into policy decisions. These issues were the subject of a first-of-its-kind national convocation organized by the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine in collaboration with the National Association of Academies of Science and the California Council on Science and Technology. Scientists, engineers, state policy makers, experts from state regulatory agencies, representatives of foundations, and experts in scientific communication from 20 states and the District of Columbia participated in the event. This report highlights the major themes that emerged from the presentations and from the discussions during plenary and breakout sessions.

NAE member **Karl S. Pister**, Dean and Roy W. Carlson Professor of Engineering Emeritus, Department of Civil and Environmental Engineering, University of California, Berkeley, was an organizer of the convocation. Paper, $21.00.

State Voter Registration Databases: Immediate Actions and Future Improvements, Interim Report. State and local election officials could improve their voter registration databases for the November elections by making several short-term changes. Officials could raise public awareness about the importance of writing legibly on voter registration cards and completing them fully; review names that have been flagged for removal from the database; and use online registration forms to improve list maintenance and reduce data entry errors.

NAE member **Rakesh Agrawal**, Microsoft Technical Fellow, Microsoft Search Labs, was a member of the study committee. Paper, $21.00.

Integrating Multiscale Observations of U.S. Waters. Effective water management requires tracking the inflow, outflow, quantity, and quality of groundwater and surface water, much like balancing a bank account. Currently, networks of ground-based instruments measure these parameters in individual locations, while airborne and satellite sensors measure them over larger areas. Recent technological innovations offer unprecedented possibilities for integrating space, air, and land observations to advance water science and guide management decisions. This report concludes that to realize the potential of integrated data, agencies, universities, and the private sector must work together to develop new kinds of sensors, test them in field studies, and teach users to apply the information to real problems.

NAE member **Daniel P. Loucks**, professor, School of Civil and Environmental Engineering, Cornell University, was a member of the study committee. Paper, $46.25.

Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report. The FreedomCAR and Fuel Partnership is a collaborative project by the U.S. Department of Energy (DOE), U.S. Council for Automotive Research (USCAR), and five major energy companies to manage research that will point the way to clean, sustainable transportation energy. The program envisions a transition from more efficient internal combustion engines (ICEs) to advanced ICE hybrid electric vehicles to a private-sector decision by 2015 to develop a hydrogen-fueled vehicle. At the request of DOE, the National Research Council agreed to provide biennial reviews of progress toward these goals. In this second volume, the review committee assesses progress in the management of research programs and the responses of program management to recommendations in the Phase I report published in 2005. This volume covers major crosscutting issues; vehicle subsystems; the production, delivery, and dispensing of hydrogen; and an overall assessment of the program.

NAE members on the study committee were **Craig Marks** (chair), vice president of technology and productivity (retired), Automotive Sector, AlliedSignal Inc.; **Peter Beardmore**, retired director, Chemical and Physical Sciences Laboratory, Ford Motor Company; **John B. Heywood**, Sun Jae Professor of Mechanical Engineering, and director, Sloan Automotive Laboratory, Massachusetts Institute of Technology; **Christopher L. Magee**, professor, Engineering Systems and Mechanical Engineering, and co-director, MIT-Portugal Program, Massachusetts Institute of Technology; **Michael P. Ramage**, retired executive vice president, ExxonMobil Research and Engineering Company; **Bernard I. Robertson**, retired senior vice president, Engineering Technologies and Regulatory Affairs, DaimlerChrysler Corporation; and **Kathleen C. Taylor**, retired head, Physics and Physical Chemistry Department, General Motors Corporation. Paper, $38.75.

Assessment of Technologies for Improving Light Duty Vehicle Fuel Economy: Letter Report. Since 2001, when the NRC released *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, high oil prices and legislation mandating an increase in CAFE standards have renewed interest in improving automobile fuel efficiency. Accordingly, the National Highway Traffic Safety Administration requested that the National Research Council provide an objective, independent update of the 2001 study, as well as an assessment of technologies that have emerged since that time. This report presents an interim assessment of the technologies selected for analysis and of the computational models that will be used to assess them. Estimates of the fuel-economy benefits in this report are in keeping with estimates in the existing literature and in presentations made to the study committee. A final report is scheduled for publication in late spring 2008.

NAE members on the study committee are **Trevor O. Jones** (chair), chairman and CEO, ElectroSonics Medical Inc.; **Thomas W. Asmus**, retired senior research executive, DaimlerChrysler Corporation; **Rodica A. Baranescu**, professor of mechanical and industrial engineering, University of Illinois at Chicago; **Patrick F. Flynn**, retired vice president research, Cummins Engine Company Inc.; **G. Kassakian**, professor of electrical engineering and director, Laboratory for Electromagnetic and Electronic Systems, Massachusetts Institute of Technology; and **Robert F. Sawyer**, Class of 1935 Professor of Energy, Emeritus, Department of Mechanical Engineering, University of California, Berkeley. Free PDF.

Innovation in Global Industries: U.S. Firms Competing in a New World (Collected Studies). According to common wisdom, the world is "flat," that is, innovative capacity is spreading uniformly, and as new centers of manufacturing emerge, research and development and new-product development will follow. This collection of papers challenges that wisdom. These individually authored studies provide an in-depth assessment of structural changes in the innovation process in 10 service and manufacturing industries: personal computers; semiconductors; flat-panel displays; software; lighting; biotechnology; pharmaceuticals; financial services; logistics; and venture capital. Although global sourcing of innovation has accelerated and new locations of research capacity and advanced technical skills are emerging, the patterns are highly variable. Many industries, and some firms in nearly all industries, have retained their leading-edge capacity in the United States. Nevertheless, the authors warn of the dangers of complacency and recommend that innovation be given more emphasis in performance measures and more sustained support in public policies. This volume will be of special interest to business people and government policy makers, as well as professors, students, and researchers in economics, management, international affairs, and political science.

NAE members **Nicholas M. Donofrio**, executive vice president, Innovation and Technology, IBM Corporation, and **Mary L. Good**, Donaghey University Professor and dean, Donaghey College of Engineering and Information Technology, University of Arkansas at Little Rock, and former under secretary for technology, U.S. Department of Commerce, were members of the study committee. Paper, $54.00.

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