INFRASTRUCTURE: Research Across Disciplines

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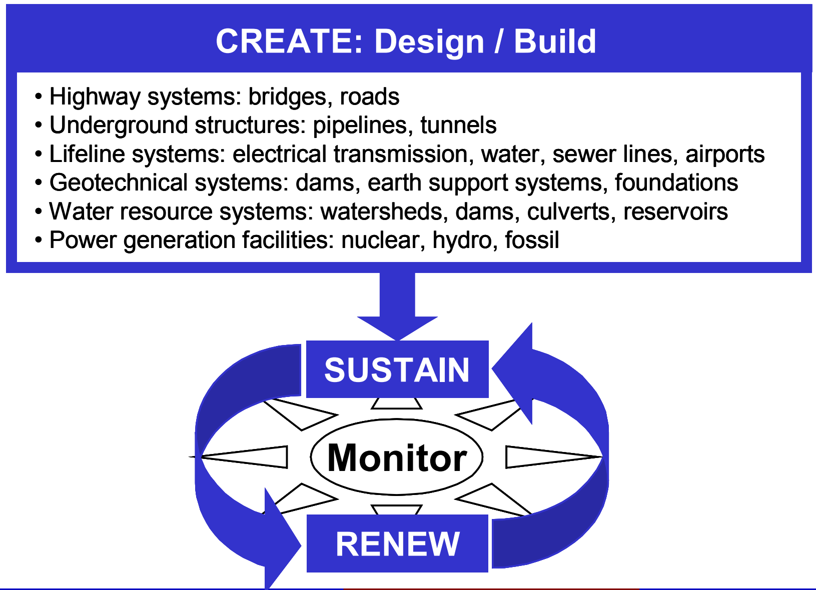
Civil infrastructure includes large-scale systems (highway systems, underground structures, lifeline systems, geotechnical systems, power generation facilities) and provides resources (water, electricity, sewer), means for transportation (highway systems, tunnels, waterways, airports, railways), and the basic facilities to support communities (hospitals, emergency services, structures). Until the past two decades, most efforts related to civil infrastructure have been relatively traditional. Systems are created through a rigorous design / build process that may have design constraints requiring innovative solutions. Once constructed, systems are in use until deterioration or damage requires partial or total renewal, which also consists of the traditional redesign / build process. Research focused on facility design, system optimization, advanced analytical techniques to support earthquake and wind loads, and experimental testing to discover system behavior.

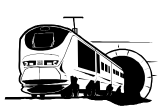
Attention today has been redirected towards sustaining the nation's multi trillion dollar investment in infrastructure. Highway systems alone are a one trillion dollar investment. Initial efforts focused on asset management that incorporates civil and environmental engineering disciplines with data mining tools, decision science, systems engineering, optimization, statistics and economics to answer the complicated question of what, how, and when to maintain or rehabilitate infrastructure components to minimize cost. Tightening budgets as well as life safety concerns and natural (earthquake, flood, wind, environment) and manmade hazards have continued to direct attention towards sustainability. Questions about how to maintain, monitor, and predict potential problems become imperative.

Three phases (Fig. 1) in the life of civil infrastructure are: Creation, Sustainability, and Renewal. Infrastructure is **created** using a design / build process that is still performed by primarily civil and environmental engineers and often involves the traditional design and analysis tools. The system is **sustained** until a monitoring process indicates a need for **renewal**, leading again to **sustainability**. The creation and renewal phases employ primarily civil and environmental engineers. Current innovations with creation and renewal include integrated advanced technologies (sensor systems, base isolators, active / passive control, composite materials), life cycle cost analysis (LCCA), and system network analysis.

Sustainability is a relatively new philosophy and must be integrated with a maintenance and monitoring system that includes an indicator for renewal. At the most basic level this monitoring can be "low tech" visual inspections. The most exciting work involves the integration of modern sensing technologies and sensor network systems coupled with automated diagnostic systems. At this time, a comprehensive monitoring system does not exist. The infrastructure systems and the responses are so complex, that diagnostic systems that can identify, locate, and quantify a problem remain technological and mathematical challenges. Successful sustainability requires state of the art expertise from many other disciplines that can bring adaptive computer networks, innovative sensors (nanotechnology, chemical, electrical, and mechanical sensors), and wireless technology (networks) to develop new ways to monitor civil systems. For example, remote sensing (a developed discipline in defense applications) can and has been applied to monitor water systems, critical facilities, and highway systems after or during hazardous events. Sustainability solutions also extend to experts in social science, decision analysis, management and public policy who can break down the social and organizational barriers that often limit the adaptation of monitoring systems.

The most important research done today and in the future will be accomplished through creative interdisciplinary collaborations. There is tremendous opportunity to develop innovative sensors from other fields. For example, little work has been done using chemical sensors in our highway systems and there are opportunities to learn from other successful applications in biology and water resources. Research is needed to extract meaningful parameters from new sensors. For example, electromagnetic sensors do not detect mechanical properties (which are important for decision making) directly, and additional information (perhaps from other sensors) can lead to more reliable results. Successful strategies must be exploited across civil infrastructure systems: highway infrastructure to underground systems or water resource systems. As sensor technology becomes smaller and smaller, the number of sensors on and embedded in infrastructure will increase in number leading to the need for wireless sensor networks with smart sensors that can communicate and make decisions. The opportunities are endless, however, one thing is certain. Significant advances in civil infrastructure require substantial contributions from a wide range of disciplines.



PHASE	CREATION	SUSTAINABILITY	RENEWAL
WHAT ?	• Traditional CEE systems • Incorporation of advanced technologies into traditional systems	• System monitoring & diagnostics • Sensors and sensor network systems • Maintenance	• Retrofit • Rehabilitation • Replacement
HOW ?	• Design • Analysis • Life cycle cost • Network analysis • Applied mathematics	• Novel sensor design: electrical, mechanical, & chemical sensors • Nanotechnology • Inverse problems • System identification • Financial planning • Decision analysis • Management • Public policy	• Design • Analysis • Life cycle cost • Network analysis • Incorporation of advanced technologies
WHO ?	• Civil & environmental engineers • Additional experts contracted on a limited basis	• Traditional CEE engineers • Electrical engineers • Mechanical engineers • Chemical engineers • Computer engineers • Computer scientists • Physicists • Economists • Social Scientists	• Civil & environmental engineers • Additional experts contracted on a limited basis
	TRADITIONAL	MODERN	BY NECESSITY

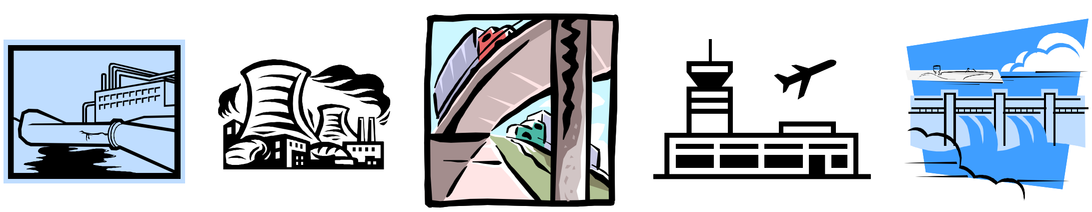


Figure 1: Civil infrastructure life phases.