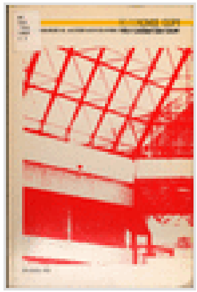

Technological Alternatives for Urban Infrastructure: Five Papers Associated With a Workshop Held at Lake Morey Inn, Fairlee, Vermont on August 12-16, 1984 (1985)

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Technological Alternatives for Urban Infrastructure

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PREFACE

The papers in this volume grew out of a workshop held in August 1984 to consider technological alternatives for urban infrastructure. The chapters in which the papers appear follow a logical progression, but they were not written as a continuous document. Rather, they are individual papers clustered around a common theme. Chapter 1 is based on the preliminary material that was distributed to participants prior to the workshop. Chapters 2, 4, and 5 were written after the workshop and emerged from some of the more provocative discussions that took place. Chapter 3, "The Needs of One American City," is based on the keynote talk delivered at the workshop by Mayor George Latimer of Saint Paul, Minnesota. A list of workshop participants is appended.

This volume can be read in different ways. It can be read straight through, with the understanding that there is some redundancy for purposes of clarification; or it can be read in separate parts. Chapters 1 and 2 may be read by those desiring only an overview of the challenge of urban infrastructure today. Chapter 3 will be of particular interest to those interested in the viewpoint of local government. Chapter 4 will be of interest to those concerned with the economics of urban infrastructure. Chapter 5 will be of interest to those concerned with urban policy and the application of engineering to urban needs.

The workshop was a collaborative effort of the National Research Council's Building Research Board, the Urban Land Institute, and the National Science Foundation. Forty-four planners, engineers, scientists, developers, and public officials met at the Lake Morey Inn in Fairlee, Vermont to discuss technological options for meeting the needs of urban communities for communication, transportation, waste disposal, energy, water supply, and flood control.[1]

The workshop was a response to the extensive concern that has been voiced in recent years about our nation's "crumbling" infrastructure. Most of this concern has focused on the cost of upgrading and maintaining existing infrastructure systems--a cost variously estimated at anywhere from $400 billion to $3 trillion over the next two decades. A great deal of attention has been paid to the question of how to finance the repair and upgrading of these systems, which represent the technology of half a century or more ago. Little has been done to rethink, reassess, and reevaluate the ways in which we design and use our infrastructure systems, and relatively little attention has been devoted to the premise that technological alternatives exist that may make it possible to meet some of our basic urban needs in more effective or much less expensive ways.

Underlying the workshop objectives was the assumption that today's infrastructure "crisis" offers an opportunity to take a fresh look at the needs of urban communities and the possible technological options for meeting these needs. The potential applications of alternative technologies include everything from new materials for paving highways and lining sewer pipes to automated traffic control systems and new waste disposal technologies. However, the workshop was not structured to examine the technical details of any particular

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[1]See Appendix A, which describes each of these systems in some detail.

infrastructure systems in depth. Rather, it was designed as a forum for imaginative and creative problem-solvers to engage policy makers in discussion, along with infrastructure designers and operators. The workshop was a gathering in which innovators were confronted by pragmatists and public officials who know from experience the practical difficulties of successfully introducing something new.

Workshop objectives were:

1. To identify the kinds of infrastructure technologies that will be required to support future public and private functions under alternative scenarios of urban development.

2. To consider both the capacity for retrofitting new systems into existing cities and the compatibility of old and new technologies when incremental improvements on the old seem appropriate.

3. To identify available or emerging technologies (including materials, equipment, methods, and management) that have the potential for substantial impact on the performance of existing or new infrastructure systems and on their capital, operating, and maintenance costs.

4. To identify any potential technological "breakthroughs" currently under development that could substantially change the design or management of infrastructure systems.

5. To examine the present rate of technological innovation and the process of innovation dispersion for infrastructure technologies.

6. To formulate options for improving the research, development, and innovation dispersion processes for infrastructure technology.

1 INTRODUCTION[1]

BACKGROUND

For several years there has been a growing consensus that a problem exists concerning the adequacy and maintenance of the nation's infrastructure, and especially its urban public facilities.[2] This crisis view suggests that the network of roads, pipes, tunnels, bridges, and cables that

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[1]Written by Louis A. Rossetti, John P. Eberhard, Abram B. Bernstein, and Douglas L. Porter.

[2]See, for example, the Urban Land Institute's statement "Financing Local Infrastructure in a Time of Fiscal Constraint," *Urban Land*, August 1983, pp. 16-21.

underpins our cities is in danger of falling apart unless we spend massive amounts of money on repair. There is, however, no consensus as to the extent of the problem; estimates of the backlog in facilities range from less than a trillion dollars to over three trillion. Determining the magnitude of the problem and assessing the proper course for public policy--beyond the obvious actions needed to repair deteriorated facilities and to replace those in clear danger of collapse--are complicated by the absence of reliable information and by confusion over the proper standards to apply.

In light of the growing demand that something be done about this, and the likelihood that the "infrastructure problem" will remain with us as urban areas make further adjustments to a changing economy, changing culture, and changing technology, there is a clear need to identify the most important and researchable issues, and to address them in order to provide guidance to those responsible for setting the nation's infrastructure policy and to those who plan and operate the infrastructure of the nation's cities.

In early 1983, the National Research Council held a symposium on the adequacy and maintenance of urban public facilities.[3] Participants included a cross-section of the academic, political, administrative, and professional leadership of the country in urban public works and civil engineering systems. The objective of that symposium was to lay the basis for a research agenda on salient policy issues.

The research agenda that emerged from the discussions at the symposium--and subsequent discussions stimulated by the symposium--encompassed four areas:

1. The development of standards and criteria for the design and performance of infrastructure systems, against which national and local "needs" for investment can be measured;

2. The identification of technological alternatives for

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[3] *Perspectives on Urban Infrastructure.* Royce Hanson, ed. National Academy Press, 1984.

urban infrastructure, with emphasis on the potential for using new or existing technologies not only to improve the performance (and reduce the costs) of existing systems and facilities, but also to develop new systems, materials, and devices capable of supporting public and private functions in the cities of tomorrow;

3. The financing of urban public facilities; and

4. The improvement of institutions for planning, managing, and decisionmaking with regard to urban public facilities.

ASSESSING THE IMPACT OF NEW TECHNOLOGY ON URBAN INFRASTRUCTURE

Infrastructure technology includes not only the physical facilities and equipment that underlie our cities but also the management and information systems needed to operate them. Any assessment of the potential impact of new technology on urban infrastructure should cover the spectrum from technological breakthroughs that might significantly change the nature of cities to incremental innovations that might exert pressure on systems performance or on the costs of their development and operation. It should also take into account the technology that will be available in the near future--such as fiber optic networks and telecommunication centers--as well as the existing physical infrastructure. It should consider opportunities for retrofitting new systems into existing urban areas as well as opportunities for equipping newly developing areas with the newest and most flexible technological capabilities.

Such an assessment should be concerned not only with the physical systems themselves but also with the institutions and processes that induce technological change by fostering research, development, and the dispersion of innovations. In particular, some attention should be devoted to strengthening these institutional mechanisms, creating new approaches to financing research on infrastructure technology, and developing new means for disseminating information about technologies and their applications.

It may be helpful to avoid the tendency to think only in terms of improving the urban infrastructure systems that are in place today and to focus instead on the needs that are met by those systems and to ask whether technology offers alternative ways of meeting those same needs.

As a specific illustration, consider water. Our present water infrastructure begins with large reservoirs from which water is piped to central purification plants, from which it is in turn piped to individual buildings. (A similar quantity of "used" water is then piped to central sewage treatment facilities.) This piped-in water is the sole water source in most buildings, and it serves in a variety of capacities--for drinking, bathing, washing clothes and dishes, preparing food, heating interior space, disposing of wastes, and extinguishing fires. Each of these has associated with it a variety of component subsystems--sinks, showers, washing machines, hot water heaters, hot water radiators, and toilets. The quantity of water used daily to meet all these needs far exceeds that which could be provided by any means other than the large municipal water systems we have come to know. But not all of these needs do indeed require water. In fact, some of these needs are met by means which were devised only because water was readily available. If these needs were to be met in other ways (for example, by warm air heating, chemical treatment of lawns, or chemical toilets) or by using water of a lower degree of purity than is required for drinking water, it might be possible to meet the basic need for clean drinking water from other sources, such as wells, bottled water, rain water storage and treatment, or other alternatives not yet devised.

If we think about alternative technologies for meeting these individual needs, instead of thinking about a "crisis" in which our water infrastructure is breaking down and urgently needs to be "patched," we may be better able to think of alternative ways of meeting our requirements for water. Similar thinking can be brought to bear on other urban infrastructure systems such as those for energy, waste disposal, communication, and transportation.

PUBLIC AND PRIVATE COMPONENTS OF URBAN INFRASTRUCTURE

Each of our major infrastructure systems consists of a public and a private component, although the line between them is not always distinct. (For example, our water infrastructure is based upon public facilities such as reservoirs, pipelines, and filtration stations, and also private facilities such as sinks, showers, and dishwashers.) These components, for five major infrastructure systems, are illustrated in Table 1-1.[4] In terms of total investment, the public component is usually the smaller of the two. However, it is the public component that sets the terms and constraints within which the larger private component functions.

The public component is typically operated either by governmental entities or by public utilities. In either case the public component displays a great deal of inertia--inertia associated both with the large physical mass of the system and with the political process for decision- making and change.

The private component adapts more rapidly, and is innovative, market-responsive, and tends toward optimization--within the constraints set by the public component.

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[4]Table 1-1 treats separately the five major urban infrastructure systems: water, energy, waste disposal, communication, and transportation. While some essential needs are met entirely by one system--e.g., the need for drinking water--other needs depend upon several or even all five of the systems. For example, the need to fight fire is met by a system involving a network of fire stations from which fire trucks, when summoned by a telephone call, travel over a network of roads to the scene of the fire. The trucks require fuel, and a network of fire hydrants provide water where needed. Sewers and haulage trucks remove the used water and debris from the fire. This system involves components that cover the entire range from basic public infrastructure (roads, water pipelines) to local public infrastructure (fire engines and fire stations) to private elements (telephones).

TABLE 1-1 Examples of public and private components of infrastructure systems.

Infrastructure System	Public Components	Private Components
Water	Dams, reservoirs, pipelines, purification stations	Sinks, showers, water fountains, sprinklers, washing machines
Energy	Oil and gas wells, pipelines, tankers; electric power generating stations, transmission lines, transformers	Furnaces, heaters, air conditioners, fans
Waste Disposal	Sewers, sewage treatment plants, garbage trucks, dumps, landfills, incinerators	Toilets, garbage disposals, trash compactors, trash cans
Communication	Post offices, mail trucks, telephone lines and cables, broadcasting stations and transmitters, satellites	Mailboxes, telephones, radios, television sets
Transportation	Highways, bridges, tunnels, railroad tracks, airports, seaports	Automobiles, buses, trucks trains, airplanes, boats

One goal for managers of the public component is, therefore, to foster optimization, adaptation, and innovation within the private component to as great an extent as is possible, consistent with public concerns for health, safety, standardization, and economies of scale.

The private component is usually produced in an innovative climate, characterized by personal choices that can be influenced by advertising. The public component, on the other hand, is usually characterized by hazy customer identification and institutionalized decisionmaking governed by a complicated set of rules. Although traditionally much of the public component has been built, owned, operated, and maintained either by governmental entities or by private companies operating under direct public controls (public utilities), recent constraints on public budgets have led either to the deferral of needed construction and maintenance or to a shift of the responsibility for infrastructure to private developers. The latter approach, aside from its fiscal implications, can involve less public control over crucial infrastructure decisions. It can also provide a potential climate conducive to more innovation, both in infrastructure technology and infrastructure investment. The separation between the public and private components, and all its political, economic, and technological implications, should be subjected to a fresh look in light of today's needs, capabilities, and constraints.

Our infrastructure systems have been with us for many decades. However, there have been many changes in our society--population shifts between cities and suburbs and between regions of the country, changes in the makeup of the labor force, etc. There have been changes in technology--new materials have been invented, along with new modes of communication and transportation. There have been changes in our perceptions of essential needs--as our standard of living has improved, things that were once seen as luxuries have become necessities. And there have been changes in the economic base that supports our activities and in the way that base is managed.

As a consequence, many of the old "solutions"--the means for meeting the needs of our urban society--no longer work. This has come about not only because the systems are breaking down mechanically as a result of insufficient attention to maintenance, but also because the "problems" that they solved have changed. The broad goals may be the same--e.g., a comfortable and safe work environment--but what we are willing to settle for has changed as a result of changed perceptions of what is possible, what is desirable, what is necessary, and what is affordable.

INDUCING TECHNOLOGICAL CHANGE IN URBAN INFRASTRUCTURE SYSTEMS

Infrastructure systems deteriorate. They must be maintained, which usually involves a substantial continuing expense, and at some point they must be retired with minimal disruption. They must respond to such demographic changes as regional population shifts and aging of the population, and also to new technological developments. Extensive rural road systems may no longer be needed as the population becomes increasingly urban, but at the same time those rural roads and bridges that do remain in use may have to bear the weight of heavier farm and construction equipment. Schools, roads, and sewers may no longer be needed in the declining cities of the Frost Belt, while new schools, highways, and waste disposal facilities are being built in the growing cities of the Sun Belt.

At any given time there are, across the nation, a large number of "in-place" systems and a smaller number of systems in the process of being put in place (in new towns, for example). In-place systems represent a large economic, political, and social commitment to a specific technology and a maintenance program to support it, and they are often only "patched" until the point where they are sufficiently deteriorated that they must be replaced. New systems represent opportunities for innovative solutions to new, newly perceived, or old problems.

In thinking about change in urban infrastructure systems, it may be useful to look for strategies that introduce changes into public systems at certain "natural" times in their life cycles. For example, water distribution systems can be changed most easily, and with the least disruption to the community, when the streets under which they run are being torn up and replaced. This might be the time to go to small diameter pipe systems for specialized purposes, capable of providing not only potable water for drinking, but also less pure water for waste processing.

While invention and innovation can sometimes be induced in response to a perceived need backed by sufficient injection of funds, it is widely thought that invention usually occurs not in response to a need but as a result of basic human inventiveness, and that "needs" then arise--often slowly--to make use of the new possibilities that the inventions offer. The telephone, the automobile, and the airplane (and perhaps, now, the personal computer) were not originally perceived as necessary. They were initially viewed as luxury items until people started developing ways to carry out a variety of activities differently by making use of these new technologies. It is therefore important to recognize that needs may change, and to look at current and newly arising technologies with an eye to the roles they might play in current or new public facility sytems.

If we wish to find ways in which public infrastructure systems can foster--or at least not hamper--innovation, adaptation, and optimization, we must answer questions such as the following:

1. What infrastructure systems do we have? What do they do? Do they do it satisfactorily, as indicated by some upper and lower limits to an acceptable range of quality, cost, etc.?

2. Are changes in the community--increased population, or reduced availability of water, electric power, and other resources--likely to render a currently satisfactory system inadequate?

3. What will happen if the system becomes inadequate?

4. What are the technological possibilities for making an inadequate system adequate? What obstacles stand in the way, such as costs, institutional mechanisms, etc.?

5. How can we get from here to there?

Questions such as these at the Lake Morey workshop were the starting point for the discussions from which the individual papers collected in this booklet emerged.

2 PERCEPTIONS ABOUT URBAN INFRASTRUCTURE IN THE UNITED STATES TODAY[1]

THE CONTEXT

While it is true that much of the urban infrastructure in the United States is old, and that large portions of it have been poorly maintained, we do not know very well how to assess the present physical condition of most of our infrastructure. In fact, the rules for determining what is

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[1]Written by John P. Eberhard and Abram B. Bernstein. Portions of the material in the preface and in this chapter appeared under the title "A Conceptual Framework for Thinking About Urban Infrastructure" in *Built Environment*, volume 10, number 4, 1984, Alexandrine Press, Oxford, England, pp. 253-261.

meant by a workable condition are as old and technologically obsolete as the systems themselves, and there is considerable disparity in the estimates of what it might cost to upgrade and repair our existing systems.

The problem, if indeed it is accurate to characterize the situation as a problem, seems to be related not so much to finding ways to pay for repairing, and building more of, today's systems, but rather to a lack of analysis bearing on the purposes these systems serve, a lack of imagination in looking for alternatives, and a history of reluctance by the nation to invest in research and development relating to urban public works. This is not to suggest that a city with water shortages looming on the horizon does not need to take some immediate action, or that a community with an overloaded sewage system will not need to find some short-term relief, or that there aren't *any* new ideas around, but rather that it is possible to see the problems of infrastructure in quite different terms than those in which they are commonly presented.

The primary, and pervasive, problem is that our best scientific and engineering minds have not seen garbage, or drinking water, or urban transportation as worthy of their attention. In the near future Congress is likely to pass legislation that will provide substantial funds for research and development related to infrastructure. We need to think seriously about the scope and range of this research before it all gets allocated to the conventional notions of financing and supporting the present technologies.

THE ORIGINS OF TODAY'S URBAN INFRASTRUCTURE

Most of the infrastructure technology that we use today is based on a set of primary developments that date from the last two decades of the 19th century. During that short period we invented, reduced to practice, and--by dint of enormous investments--installed in our cities eight significant technologies:

- central power plants to generate electricity, wires to distribute this new form of energy, and hundreds of devices to use it--most importantly the *electric light*;

- central reservoirs and processing stations to store and treat water, thousands of miles of pipes to distribute the water through our cities, and *indoor plumbing* systems for washing, bathing, and disposing of our human wastes (which did more to remove the curse of epidemics from our modern cities than all of the medical research from earlier centuries);

- *central heating* systems in buildings, which removed the need for the dangerous and logistically difficult stoves and fireplaces of earlier centuries, and led the way to modern heating, ventilating and air-conditioning systems;

- *structural frames* for buildings, separate from the external walls, made possible by the development of steel (which in turn was made possible by the invention of the steel-making process by Bessemer). Buildings could now be erected to heights undreamed-of since the time of the Pharaohs, because the parallel invention of the *elevator* made it possible for the occupants of these tall buildings to move from floor to floor without climbing stairs;

- the *internal combustion engine*, and its incorporation in a variety of vehicles that enabled movement of persons and goods along the roads of cities at a speed, and eventually within a comfort range, never before available;

- the *telephone*, which made the 20th-century office possible, made the emergency network of community support more responsive, and enabled all of us to expand our network of contacts beyond the time and space of our "village"; and

- the *subway*, the train running under the streets of the city that still serves as the paradigm for all urban mass transportation. At the turn of the century a nickel not only bought a good cigar or a glass of beer, but bought access for the urban dweller to hundreds of square miles of jobs, entertainment, and friends.

In the years since World War II we have made only minor improvements in the performance of most of these inventions. Today's perception that there is an urban infrastructure "crisis" presents us with an opportunity to increase the level of investment in "civilian" research and development that will advance the quality and character of our cities. We also have, at the same time, a challenge to turn what is commonly perceived to be a *problem* with our urban infrastructure into an *opportunity* for creative engineering and scientific minds.

WAYS OF THINKING ABOUT URBAN INFRASTRUCTURE

Urban infrastructure systems are conventionally thought to comprise the physical structures embedded in our cities: streets, bridges, tunnels, water and sewage systems, public transportation systems, oil and gas pipelines, electric power and telephone cables, and other essential public and semi-public facilities on which the day-to-day functioning of our cities depends. These systems typically consist of surface and underground networks of roads, pipes, and wires, together with large central facilities such as those in which water is purified, wastes are treated, and electricity is generated. The resulting physical networks provide a setting for such social and economic functions as health care, education, welfare services, fire fighting, law enforcement, commerce, banking, and finance. These functions clearly require a network of service systems that distribute and process pure water, storm water, liquid and solid wastes, and energy, that make movement possible for people and goods, and that permit communication, information dissemination, and remote and automated controls.

Viewed in this way, infrastructure is a matter of traditional engineering. Facilities must be built and operated, pipes must be laid and maintained, traffic must be controlled. Yet there is another, more comprehensive way to view infrastructure. Every infrastructure system has, in addition to its physical and institutional elements, important economic and social aspects. The physical elements are the roads, pipes, wires, and processing facilities described above and the institutional elements are the administrative and managerial mechanisms for planning, building, operating, and maintaining the system. The economic aspect centers on the means for financing the system and the collection of regulations and economic incentives that are devised to induce individuals and organizations to use the system in specific ways. The social aspect has to do with the impact the system has on its users, and with the public's perception of the way in which the benefits and costs of the system are distributed among the population. In addition, every infrastructure system has a conceptual aspect that affects the way in which the system is viewed by both managers and users. For example, a wastewater system can be thought of as a collection of pipes and valves that need to be periodically inspected, cleaned, and repaired, or as one element of a control system designed to protect health and the environment, or as a revenue-generating system.

An important concept in thinking about urban infrastructure is that every physical infrastructure system contains three generic components: an *origin*, where some desired material or service is created or generated; a *destination*, where the material or service is transformed into usable products or converted into waste products for disposal; and a *distribution network* for transporting things from where they are generated to where they will be processed. These three components are more clearly evident in some systems than in others.

Wastes, for example, are generated in individual buildings, are transported by truck and sewer pipe to centralized processing facilities, where they are either removed from the system by burial or dilution or are chemically treated and converted into a useful item such as fuel or fertilizer. Drinking water is generated in reservoir-fed filtration plants, transported to individual buildings, and there utilized for a wide variety of purposes including drinking, washing, and flushing wastes. Electric power is created at central generating stations, transmitted through power lines to individual buildings, and there used for activating light fixtures, running motors, and providing energy for electronic devices. Information is generated in some commercial or private activity, transmitted via mail, telephone lines, or airwaves, and used in commercial or private activities at the receiving end. Here only the transmission network is normally considered part of the infrastructure, but clearly the utility of information transmission lies in the fact that information is generated in one place and used in another. Similarly, transportation involves a point of departure for people or goods (private garage, train station, airport, seaport, warehouse or factory), a point of arrival (office building garage; distant train station, airport, or seaport; distributor or retailer), and a means of getting from one to the other; here again, only the paths along which movement occurs are normally thought of as part of the infrastructure. In the case of storm drainage, the origin is rainfall or river flooding, the destination is a large natural body of water or a drainage basin, and the part normally thought of as infrastructure is a system of drains and storm sewers that transports the water between the two.

The above illustrations contain imperfections. For some transportation systems the "origins" and "destinations" are considered part of the infrastructure network (e.g., subway stations, airports) whereas for others they are normally considered components of the private sector (garages, parking lots). Similarly, in subway systems the guideways and vehicles are both considered part of the infrastructure, whereas for road traffic the highways are considered part of the infrastructure while the vehicles are not.

A useful question that emerges from this conceptual context is "Can the origins, the destinations, or the distribution networks serving two or more infrastructure systems be combined?" In district heating systems using cogeneration, for example, the source of electric power is also used as a source of heat. As another example, not only do roads and highways serve to transport people and goods; they also serve as part of the waste disposal system when they are used to transport solid wastes carried in garbage trucks.

Another important concept in thinking about infrastructure is the notion of modular flexibility. This concerns the degree to which the origin, destination, and distribution network are sufficiently independent that any one of them can be removed and its replacement simply "plugged into" the system. An electric power distribution network will be particularly versatile if it is capable of accepting electric power from a number of different sources--coal, oil, hydroelectricity, solar power, nuclear power. Then as power plants become obsolete, or as economic or political factors favor one power source over another, power plants can be removed from or plugged into the grid but the same distribution network can be used. One can, in fact, conceive of the community as a giant board underlaid with wires and pipes, with individual buildings and central facilities plugged in and replaced at will. This way of thinking is consistent with the notion that infrastructure consists of essential physical systems that are put in place, often on and under the ground, before the construction of various buildings that are commonly thought of as making up a community (although in older established cities the infrastructure systems were put in place after the city was built, rather than before). It is probably more realistic to view the grid of roads, pipes, and cables as an additional modular element plugged into the bottom surface of the board, just as the buildings and central facilities are plugged into the top surface. As the physical components of computers can be replaced as new advances are made in electronics, so portions of the physical infrastructure can be made removable and replaceable from time to time as new, improved engineering techniques are developed.

There is a tendency for those who advocate the application of new technology to infrastructure to concentrate on the physical and institutional elements, even though economic, social, and political considerations may present major barriers to the introduction of new engineering technologies. At the same time, it is essential to keep in mind the social view that urban infrastructure affects people who are not generally significant participants in the decision-making process--the poor, the uneducated, and those with little geographic mobility, who often have tightly knit inner-city communities and for whom the images of the future suggested by new technologies may be frightening.

CHANGES IN THE REQUIREMENTS FOR URBAN INFRASTRUCTURE

The requirements for urban infrastructure are continually changing, as a result of:

- changes in demand and in the patterns of peaks and valleys of demand, triggered by changes in population patterns, changes in the age distribution of the society, changes in work and lifestyle patterns, and the growth or shrinkage of communities;

- changes in the availability and cost of raw materials, energy, transportation, and labor; and

- changes in social expectations and in political views about public participation, equity, and the question of who pays and who benefits.

The lack of flexibility associated with the limited capacities of most of our 19th-century systems imposes severe constraints on the ability of today's infrastructure to respond to such changes. Because these older technologies were geared to community growth and not to adaptive changes they become easily outmoded.

It is important that we find ways to modify present systems to accommodate changing requirements, and even more important to develop new notions that provide built-in flexibility. Our older waste disposal systems must now accommodate toxic chemicals and heavy metals--new kinds of wastes that have resulted from new materials and new technologies and that pose new hazards to health and to the environment. Our transportation systems must accommodate a changing mix of cars and trucks, the introduction of longer and heavier trucks, and changed traffic patterns. Our network of centralized public facilities must accommodate changing patterns of land values that give an economic advantage to compact rather than sprawling facilities. New technologies may lead to further changes of this sort. For example, new telematics technology may allow (or even induce) "work at home" practices that could lead to the disappearance of concentrated urban centers as we know them. At the very least, modern communications and computers will free offices and the work done in them from one of the needs to cluster together in large buildings. The capacity to decentralize may radically affect the urban structure and its infrastructure needs. It is important to recognize the possibility of such changes and to plan for future infrastructure elements that will be responsive to these changes. It is also important to recognize a distinction between old, established cities and new, growing cities. In older cities, the primary concern is likely to be the upgrading of the infrastructure with minimum disruption to traffic and commerce. In new cities, the primary concern is more likely to be the provision of sufficient flexibility to accommodate future changes.

In general, what the current situation calls for is not simply repair and replacement of the existing physical infrastructure, but technological modernization of the entire infrastructure system, including the institutional components. Infrastructure development should incorporate a continual reassessment of what is needed, based on inquiry into the changing requirements of the community and into changing societal expectations--e.g., a pollution-free environment, ready access to recreation, homes of low cost and high quality, etc. Infrastructure decision-making should also respond to the trend toward greater equity achieved though participatory democracy. There should be greater participation in establishing needs and priorities by those who will be individually affected. The development of research programs to advance the performance of existing systems or to generate entirely new concepts should include a wide spectrum of those likely to be affected by the new systems.

Communications will be the principal technology driving this new infrastructure, contributing to the improvement, integration, and management of all the other elements. Information technology, computerized mapping and modeling, telematics (the combination of computers and communication systems), automation and automated decision-making and control systems, telefactoring (remotely controlled mechanical manipulation), position determination technology, and measurement technology (including remote sensing, lasers, x-rays, and acoustic measurements) will have great potential value in the operation, inspection, diagnosis, maintenance, and repair of all infrastructure systems. Integrated computer systems that permit various parts of the infrastructure to share a common information base will significantly affect coordinated infrastructure performance. Ultimately, the nation's agenda of research for new and improved infrastructure should be based on these principles.

While new engineering technology can lead to many improvements in infrastructure, there are other far-reaching improvements that are likely to stem from institutional innovations. Economic and regulatory incentives may lead to changing practices in such areas as water conservation and waste material separation, which in turn may lead to a greater degree of decentralization of facilities and to a new mix of public and private participation in the overall infrastructure system. Some of these changes in approach will require the development of new institutional mechanisms, especially at the local government level, for infrastructure management.

Although regulation and pricing are important inducements to effecting changes in infrastructure, they may not be sufficient to make today's infrastructure systems work well because the conditions and prices that led to the design of those systems may no longer apply. Many infrastructure systems have been historically inefficiently priced, or not priced at all. New technology will allow measurement of the quantities used and the time of use for such services as energy, waste, and water, thus creating both a record for user charges and price determination and a data base for technology development. The use of public funds, especially from the federal government, is an important stimulant to the research required for new technologies that will benefit all of society. Private investment in development costs will be possible once the public benefit is sufficiently clear through experiments and public demonstrations.

Congress has considered a number of bills to deal with the so-called "crisis" in urban infrastructure. Some form of legislative action is likely, and this may include the provision of funds for a national infrastructure research and development program. It is to be hoped that such a program would not be limited to the development of incremental improvements in present physical systems, but would also explore technological alternatives for the planning, design, and management--as well as the engineering--that are undertaken to provide the water, the roads, and the networks of pipes and wires required to meet a community's needs for health, education, commerce, industry, and recreation.

The growing inadequacy of existing urban infrastructure systems calls for a shift from exclusive emphasis on the physical aspects of infrastructure to emphasis on the comprehensive infrastructure system, including its institutional setting and its economic and social aspects. It also calls for a move away from emphasis on repairing or replacing physical structures to emphasis on research and development programs that will generate fresh thinking on how we may accomplish our community goals through wise investments in new and renewed physical systems. If we can do this, we may move from a period of technological stasis--during which even minor improvements are difficult--to a new era of creative invention and innovation for our cities.

3 THE NEEDS OF ONE AMERICAN CITY[1]

INTRODUCTION

We've all heard today's popular rhetoric. There is a national scare about our collapsing infrastructure and the need to find incomprehensible sums of money to fix it immediately. It is an important issue, and I am glad that it is receiving national attention. But we can't just throw money at it and expect it to go away as we have done with some national issues in times past. As all of us in government are painfully aware, we can no longer afford trying the financial quick-fix. National concern has been

[1]Keynote address presented at the Lake Morey Workshop by George Latimer, Mayor of St. Paul, Minnesota.

created, and it is time for technical folks to clarify and quantify accurately the dimensions and scope of the problem, and to help develop solutions.

THE CITY OF ST. PAUL

St. Paul is on a riverbank, as are most major cities. Our population is about 270,000. As an established city, we're a little over a hundred years old. All of our land slopes from the surrounding bluffs to the Mississippi River which winds for eighteen miles through the City. Our infrastructure systems vary in age and condition. Overall, St. Paul's infrastructure is not as old as that of many other cities, and has been found to be in fairly good condition in two recent studies.

The Citizen's League (a highly-respected metropolitan-area citizens' group) has found that the Twin Cities' (St. Paul and Minneapolis) infrastructure probably performs better now than it did two decades ago. New construction and major reconstruction are not what is needed; maintenance should get highest priority. Also, we need to build more maintenance-scheduling into our budgeting processes. We need to understand better the existing condition of our facilities. We need to reassess our standards of maintenance. And we need to improve our ability to communicate this information to the general public in terms they can understand.

BEFORE WE CAN ACT WISELY, WE MUST KNOW WHAT WE ALREADY HAVE

We need to know the history of the existing system: how old it is, what special circumstances affect it (temperature range, geology, population size, type of industry, etc.), and what it's made of (streets of asphalt, concrete, or oil; sewers of sandstone, brick, or concrete).

Today in our Sewer Division we are already using both black-and-white and color television to give us photographic descriptions of the condition of our sewer pipes, down to the smallest sizes.

In order to know better what we already have in our system and its condition, our Public Works Department has a massive effort under way to inventory all of our public facilities (a state-of-the-art project according to the Citizen's League Report). We have developed and expanded our computer capability to accomplish this. Through the use of interns we have been able to get much of the tallying work done in a short time, with little additional labor cost.

Then, in order to keep the system in good condition, once the inventory is basically complete, we will begin to record maintenance data, including the work done through outside contracts.

These data are being filed in such a way that they interface with an already completed "geobase" of street names, street segments, intersections, blocks, tracts, and many other special geocodes compiled from other city and county offices. The geographically-related data are entered based upon "X-Y" (north-south and east-west) coordinates using "state plane" coordinate values. Each coordinate pair is known as a "node." As long as all data are entered using the same coordinate system, it will be possible to interface any files in the future as desired. We are working with our local power, telephone, district heating and cable TV utilities to use the same system.

In addition, a system based on coordinates can be plotted on a map, and we are now developing the software for our mapping program. Once developed, we will be able to map any of our systems, their conditions, overlays of two or more systems, our maintenance record, work schedules, and more, and we will be able to provide the utilities, contractors, and the public with immediate and up-to-date information on conditions, locations, boundaries, and lists of detail. The basics of this system should be operational by the end of 1984 and the overall system should be in place within a few years.

Beyond this project is a dream for the future--that someday we will have the capacity to be able to afford financially three-dimensional computer records of our systems. Think what help it could be to one of our engineers, if s/he could flash on the computer screen an exact and three-dimensional segment of an underground sewer or water main.

Today's new technology offers us more diversity and options than we had in the past. Tomorrow's technology will offer us even more.

BEFORE WE CAN KNOW WHAT DIRECTION TO TAKE, WE MUST KNOW WHAT IS HAPPENING AROUND US AND WHAT OUR OPTIONS ARE

Now that the data on the history of our systems and a clear picture of their present conditions are becoming available, we can begin to make more informed decisions. A process for making reasoned decisions is needed. Over the years, "reasoned" has meant many things--the engineer's judgement, the mayor's opinion, the city council's resolution, the special-interest group's conviction. We've improved over using just any one of these opinions by establishing processes which allow for them all (granted, the process gets slower at the front end, but is not necessarily longer by the time the task gets done).

In St. Paul we have developed four basic tools which help us plan, budget, and spend. For many years Public Works has had a Five-Year Plan by which priorities are determined for each year's work and for budget requests. In addition to its plan, we have a Unified Capital Improvement Planning and Budgeting (UCIPB) Committee, representing each of our seventeen planning districts. This citizen group biennially reviews all projects proposed from departments, citizen bodies and others, and makes a recommended budget which is submitted to me for approval and submission to the City Council. Our capital improvement bond funds, CDBG funds, and all other bond and grant funds for capital improvements are included in this budget.

Also, we have a Program for Capital Improvements (PCI), as required by Minnesota law, which defines our five-year program for all capital improvements, and we have developed a Capital Improvement Policy (CAP) which establishes our goals, priorities and the parameters within which all projects will be evaluated.

Our overall neighborhood citizen participation process, comprising seventeen district councils and community organizers chosen and paid for by the councils themselves, keeps us honest and open and keeps most of the special interest lobbying at the local level.

All these tools give us the opportunity to operate in a more professional manner--something government must do if it is going to serve adequately its business community and its citizens-at-large at the lowest possible cost.

The management data which will be available from our computerized inventory will help us make these decisions even more responsibly and will allow us to communicate summary information to the citizen groups involved so that their decisions also can be more professional.

The running of government has become much more complex--a reflection of our society at large. It is necessary that we interact with our business community as peers. We have learned from years of experience that what is good for the local business community is good for the community at large. With that awareness, St. Paul has established its Office of Business Development and its emphasis on the "homegrown economy"--our approach toward becoming an innovative and self-reliant city.

It is here that we can realize the close relationship between economic development, business, jobs, and a healthy and adequate infrastructure. The city's arteries of roads and sewers must serve local industry at a price it can afford, or it goes elsewhere. The street and transit systems must invite the consumer or goods don't sell.

When and how much to build are not only government questions. The answers should take into consideration the local job market and future business projects. Ideally, the "when" will include some consideration of the fluctuations in the local job market and the overload or shortage of construction work for local contractors. The "how much" will take into consideration the likelihood of future business construction and trade.

Built cities find themselves in a new situation. In cities like St. Paul, construction and population increases have leveled off. The need for new facilities has diminished and the need now is for well-thought-out maintenance, replacement, and redesign.

Cutbacks in funds have caused extreme hardships and forced critical rethinking about how much government is enough and about how services should most equitably be paid for. I don't think we have adequately begun addressing the options of cutback services. We have lost population over the last few decades. Our family size has become smaller and our uses of time have changed. Jobs have changed, both in location and tasks. Maybe we need more recreational space and fewer roadways, more hiking and biking paths. For instance, a broken grid system for automobile traffic could be created by narrowing or eliminating some street segments and using them for housing or recreation. The freeways have changed our use of local arterials. We have been able to save money by taking out a number of signals on University Avenue (the major arterial between Minneapolis and St. Paul). It carries less traffic in total, and more of its traffic is local, since the construction and use of the I-94 freeway connection.

As the relationship between business and government changes, we may find that we are in businesses that could be better done in the private sector. Trash collection is one example. We found in St. Paul that the small entrepreneur could collect trash more efficiently, at less cost, and with more individual service than we could. We quit (not without some local turmoil about cutting city jobs), and the fifty or so licensed, private haulers are doing a good job. We are also giving moral support and very limited financial support to local recycling and composting enterprises--again trying to develop local businesses rather than to expand or protect government activity.

BEFORE WE CAN REACH TOWARD THE FUTURE, WE NEED TO KNOW WHAT THE FUTURE CAN BRING

The combination of extreme financial constraints and new technology can bring creativity. Today, on many of our paved streets, we are roto-milling the surface and laying a thin, even overlay, rather than tearing up and replacing pavement. This much less costly solution is possible because of new technology in roto-milling and in the production of fine-tuned, electronically operated, small paving equipment.

The public attitude is changing and is bringing changes in what we do. There is more public demand for conservation, for small scale, for repair rather than replacement, and a greater appreciation for the old. As an example, when we converted our entire street lighting system to high-pressure sodium, our neighborhoods were determined to keep the old "green lanterns" rather than replace them with the modern, "bent-straw" fixtures.

Recently, on a street reconstruction project in a Heritage Preservation District, the crews (with best of intentions) tore out the "old" granite curbing and installed integral sidewalk and curb. Red-faced and apologetic, we are replacing the granite. In our downtown, a grand, new, privately-funded opera theater (the Ordway) is being constructed. We are replacing the adjoining streets, not with concrete or asphalt, but by carefully replacing the old, existing brick streets with new brick.

On street reconstruction projects we are running into trouble with antiquated street-width standards. The public has changed its mind. It no longer demands wide streets for fast-moving, large cars. Residents want narrower streets with slower-moving traffic, and they drive smaller cars. Our future street construction must keep pace with the changes in habits and equipment. We're seeing a renewed interest in light-rail transit and other transit options. There is lots of room for new technology here.

River quality standards need to be reassessed. One of the major construction projects on St. Paul's horizon is separation of the entire sewer system. Interest in cleaning up the river is reaching a peak and separation is seen as important. But how clean is a clean river? At what cost? And over how long a time? As we learn more about the condition of our waterways and long-term effects of the pollutants, and as we acquire a better understanding of our groundwater supplies, their use, and changing attitudes among the public about water conservation, we will find need for other adaptations in our sewer systems.

Availability of more information about our systems and the availability of finer-tuned equipment with which to do the job will allow each city to meet its unique needs better as well as the unique wants of its neighborhoods.

We in the north have different maintenance and construction problems than cities in the south. Removing snow, melting the ice, dealing with the effects of salt, and high energy needs create problems for St. Paul that are different from those in the south. With our better access to information and technology, we will be reassessing how we do these jobs.

Probably our biggest citizen complaint in the spring is the potholes. They appear and reappear faster than the dandelions. We still repair them, literally, by hand, using antiquated, 30- to 40-year-old techniques. Granted, this is a seasonal, mundane, daily chore, but in the area of public facilities, we cannot lose track of mundane needs. We have improved our response time. We have a telephone hot-line to help find pot-holes, and our trucks and supplies are somewhat better. But this is an area where we could use a breakthrough in technology--a small area, but a very important one to a northern city like St. Paul. Maybe, through our "homegrown economy," we can incubate a new business that will truck through our neighborhoods, filling potholes by individual request.

Plowing snow is another seasonal and regional problem in need of new answers. We now have an excellent fleet of equipment in St. Paul. We have the newest in reversible plows and other more flexible tools. But nowhere in today's newest snow-plowing technology is there an answer for the banks of snow left blocking intersections and private driveways after the plow has passed. This is not an exciting problem; its solution will not provide worldwide fame to the inventor. But a solution is badly needed. In St. Paul, our annual average snowfall is 45 inches and, for the last few years, we've been averaging more than 90 inches of snow.

In addition to snow, we have ice. The age-old solutions are sand and/or salt. We have tried various mixes, and to minimize the environmental impact we use a mix of about 85% sand to 15% salt, even though it is much less effective than salt alone. We have tried calcium alternatives, cinders, fly-ash, and others. None are satisfactory. No existing solution is satisfactory. It seems like a simple problem. It is not. Somewhere out there in the minds of our creative population, there must be a better way. Meanwhile, our cars and bridges rust and fall apart, or nearly fall apart. Just two weeks ago our 95-year-old historic link across the Mississippi River, the High Bridge, was prematurely closed because it had rusted beyond safety standards. The replacement structure will not be completed for three years.

We need new solutions to fit the maintenance and conservation mode that we find ourselves in today and that will probably persist throughout the remainder of this century.

Since 1983, we have connected 94 downtown buildings to a new, hot-water district heating system. This single, coal-fired, state-of-the-art plant uses an old, outmoded, steam-heated system as its base. HUD has given it its "National Excellence Award" for both 1983 and 1984. Its ownership is shared among the City, the Building Owners and Managers Association, the State of Minnesota, the Northern States Power Company, local trade and labor associations, and concerned citizens.

It's a super energy-efficient system. One large central-heating plant works better than 94 small ones of varying ages and efficiencies, and our system can, one day, be easily converted to some future technology to reduce our dependence on scarce fossil fuels. Expansion is planned into a public housing project and a single-family residential community, both adjacent to downtown.

Public Works has coordinated the district heating construction with street and sewer construction and maintenance. The ability to share information immediately will help us coordinate better all the jobs we do. Cable TV is about to lay its cables in the St. Paul streets. Again we will coordinate our work with theirs. In the future, with a shared and computerized information system, all utility work can be coordinated on a day-to-day basis, as well as improving coordination among our own city operations.

Diversity also becomes more available in the ways in which we hire the people who do the work. With the opportunity to maintain more payroll and contract information, we can do more work with part-time people, youth training programs, and specialized contract forces. The entire economy indicates to me that we can no longer expect local government to operate with a stable budget and workforce. Nor should it. Like private enterprise must, government should be able to react to economic fluctuations in socially constructive ways. We should be able to provide more work when the market is slow and hold back when the private market is filled. Government should be held accountable for the costs and benefits of what it does, just as businesses are, through a competitive economy. Government workforces should be able to fluctuate to the degree necessary to match the tasks which the public determines should be done. And modern business practices should be an integral part of government's planning, operations, and evaluations.

Our growing partnership with the public, the availability of new technology, and quicker access to more complete information allows more strategic, long-term planning and a better environment for unique and creative project planning.

For instance, on a recent street reconstruction project, we broke away from tradition by not doing all of the street at one time, even though the design and engineering were complete. We found that the citizens and businesses were interested in trying to create a friendlier environment which would result in a better atmosphere along the business stretch of Ford Parkway. We agreed to hold off and, over the winter, work together with the residents and business owners to see what creative design we could come up with, possibly including aesthetically pleasing medians and plantings. We've done this before on other streets (Snelling Avenue and Lexington Parkway) and it has worked out to everyone's advantage.

We in government are learning and we are changing. New technology, better information, and new attitudes are bringing the public and private sectors together for a clearer, a more diverse, and an adaptable vision of the future.

FIGURING OUT AN EVEN BETTER WAY

As we elected officials and government administrators deal with the crises of each day and try to keep service levels at an acceptable level of public satisfaction, someone in the background has to be figuring out an even better way of doing things.

St. Paul sits on top of a deeply-buried, giant dish, the Jordan Aquifer. Like meringue on pie, it is covered with a thick layer of pure, white sandstone, which is again covered with a box-top of strong, rigid limestone. We drink the water, use the sandstone for manufacturing, and cuss the limestone when we construct below ground.

There must be a better way. Maybe some bright mind can figure out how we can use some of the aquifers to store hot water from our district heating system and to find new and expanded uses for the system. It has been suggested that we look into heating our streets and sidewalks with the system as well as our buildings, so that we wouldn't have to worry at all about those snow-rows at the intersections and driveways!

Another suggestion has been to open up space in the sandstone (which is very easy to excavate) and use it for underground travel corridors, for warehouse space and even for tennis courts or river-barge storage. The natural roof of limestone allows the opening-up of large areas with minimal vertical support required, and, in some locations, it can be entered right from the Mississippi River level.

The new Engineering Building at the University of Minnesota has been constructed in just that way--an exciting innovation which has received the "Outstanding Civil Engineering Achievement Award" of 1983 from the American Society of Civil Engineers. It has only a marker above ground. The entrance and three stories are constructed in the glacial till below grade; shafts, two stories deep, are cut through the hard limestone layer; and then it opens up again into two, massive, doughnut-shaped floor areas of mined space--offices and laboratories, nestled in that soft sandstone. One quick, six-story elevator ride will get you there, and light shafts bring down the sunshine.

Northern cities must find new ways of using existing resources if we are to maintain reasonable self-reliance and keep from freezing. Southern cities will have shortages of water, and we in the North are surrounded with water resources. Is this a commodity we should be storing, while we develop ways of selling it to the South, in exchange for their oil? There are energy sources we haven't tapped--haven't even dreamed of yet. We need great minds at work on the solutions for tomorrow.

Mainly, I have pointed out to you the fairly immediate and attainable tasks for the future. I do not want to stop short and offer only these goals. I want you to think in greater terms as well. Help me with grand solutions to our energy problems and the conservation of our water. Help find new solutions to congestion and distribution. We need your help to create reasonable alternatives to the crises we know we will be facing in years to come.

4 INFRASTRUCTURE AND ECONOMICS: LESSONS FROM THE ENERGY CRISIS[1]

INTRODUCTION

The nation's trillion dollars' worth of urban infrastructure normally experiences a relatively slow evolutionary process of replacement and modernization. Occasionally, however, abrupt changes in the cost of certain technologies can make large segments of that infrastructure instantly obsolete. That is what happened during the 1970s in the case of energy.

Many elements of urban infrastructure systems serve as conduits for channeling energy to specific functions. The

[1]Written by Clark W. Bullard

relationship between energy resources and energy infrastructure (buildings, industrial equipment, transportation systems, etc.) during the 1970s was not a flexible one. Since the infrastructure could not be easily modified, lines formed at gas stations, thermostats had to be turned down, and factory production schedules were curtailed. Today, adequate energy is available, but at a cost several times that of 1970, discounting inflation. In response to these high prices, the inflexible energy infrastructure is being replaced sooner than normal. Energy-inefficient buildings are being demolished and new ones built. Inefficient factories must be rebuilt, giving many firms an unexpected opportunity to consider relocation as well.

EFFICIENCY AND FLEXIBILITY

As their energy infrastructure is replaced, many cities are making efforts to ensure that their new infrastructures are more efficient and flexible than the buildings, equipment, and transportation systems being replaced. A more efficient energy infrastructure reduces the cost of municipal services such as transportation, water supply, and disposal of solid and liquid wastes. The additional capital invested in efficient systems, in turn, has a multiplier effect on the local economy, and reduces the outflow of dollars to energy suppliers outside the region.

A flexible urban infrastructure is essential if cities are to continue to evolve. Our cities are relatively young by world standards, and, like most cities, were originally set up to serve a single major purpose: capital cities to govern, commercial cities near harbors and rivers for trade and transportation, manufacturing cities near resources on which they depend, and college towns for education and culture. As technologies changed, many of these cities evolved into more complex multipurpose urban centers. Other cities, some old mining and mill towns for example, were simply "thrown away" because their infrastructure was not sufficiently flexible to keep up with technological change. Moreover, as new technologies--such as automobiles and freeways--have made it feasible to live away from the noise and pollution of the city, many community leaders--merchants, professionals, and industrialists--moved out of town, leaving their valuable homes to deteriorate into slums. Complicating the situation is the fact that in many metropolitan areas in the United States the control of the physical infrastructure is fragmented and distributed over many municipalities. In contrast, the major cities of Europe have survived centuries of technological change, evolving into multipurpose centers of trade, manufacture, culture, communications and government. This evolution has been accompanied by an increasing reliance on a flexible urban infrastructure.

The key to designing flexible infrastructure is separability of functions. Many European buildings have provided shelter for hundreds of years, but activities have changed every few decades as technologies have changed. The energy infrastructure is one that lends itself to flexible design, but opportunities to take advantage of this were not widely exploited in the United States during the era of cheap energy. Combined heat and power generation is a classic example of such flexibility. Nearly any kind of energy resource can be used to boil water in urban-scale power plants such as those in European cities. The steam is used to produce electricity which can be transmitted and distributed with ease, and used in a variety of equipment, appliances, and transportation systems. The waste heat from power generation, in the form of hot water or steam, can also be distributed rather easily to buildings and industry. Such a system is inherently more flexible than the assortment of single-purpose elements that make up the energy infrastructure now used to heat buildings in American cities: pipelines for distributing gaseous fuels; and barges, tank cars, and tank trucks for delivering liquid fuels. Cities heated by hot water can change heating fuel without changing the transmission, distribution, or end-use equipment; the only modifications needed are back at the power plant where the heat and power are generated. Today, the district heating capacity in the United States is estimated at 40,000 MWth[2]--a modest-sized industry in absolute terms, but only a fraction of the total heating market.

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[2]International Energy Agency, *District Heating and Combined Heat and Power Technologies*, OECD/IEA, Paris, 1983.

Many other opportunities exist for making the energy infrastructure in urban areas more flexible. "Utilidors" --shared utility corridors--are already being designed into the newest buildings: the same horizontal and vertical ducts and shafts carry elevators, electricity, telecommunications cables, heating and cooling ducts, water, sewage, etc. As technologies change, so can the contents of the utilidors. The same opportunities exist outside buildings; common rights-of-way can be shared by highways, railways, pipelines, water, sewer, power and other infrastructure elements.

INFRASTRUCTURE ECONOMICS

Because infrastructure is so tightly coupled with a city's economic competitiveness many public agencies, in order to capture the public benefits of economic growth, have traditionally underpriced infrastructure services. For example, water is not even metered in many cities. Many of these subsidies have been financed by deferring maintenance, leading to crisis situations in many metropolitan areas. In virtually all cities, prices will have to be increased substantially to pay for replacement and modernization of infrastructure elements that are now becoming obsolete. In all but a few cases, technological progress has not reduced the cost of new facilities below the prices charged for services from old facilities. In this respect, most infrastructure technologies face the same dilemma that the energy infrastructure faced during the 1970s: *new facilities cost several times more than the ones they are to replace.*

The energy crisis was a manifestation of the increased cost of providing cities with energy at a time when the cost of energy resources was increasing dramatically due to geological and geopolitical factors. Similarly, the increasing pollution of clean air and water has created the need for massive investments in new types of infrastructure technologies (waste treatment and pollution control technologies) to support the high population densities in urban areas. Finally, since many water, storm water, and sewer systems have been literally buried by billions of dollars' worth of streets, buildings, and other types of infrastructure, the replacement cost--of which excavation and access are major components--will far exceed the original cost. As in the case of energy, the nation must face the reality that the real price of most infrastructure services may double or triple.

Responding to a doubling of the real price of energy for millions of consumers (which amounted on a national level to a price increase of $150 billion per year) presented a formidable political task and took more than a decade to accomplish. What had to be fundamentally changed was the method of pricing energy. Traditional regulations set prices equal to the "embedded costs" of old and new supplies. This masked the real cost of the newest oil and gas supplies (e.g., from Alaska and offshore) by averaging it with older, more inexpensive resources. Electricity, too, was priced at its embedded cost, masking the fact that the real costs of nuclear power plants and coal have nearly tripled since 1970 due to the cost of meeting environmental and safety standards. As long as prices were regulated at artificially low levels, consumers had little incentive to conserve, and shortages occurred. The nation's experience in extricating itself from the problems created by this now-obsolete form of regulation should be relevant to water, sewer, and other infrastructure technologies where the same regulatory practices are common.

The simplest and most obvious way to resolve the problem--deregulating the price so that "old" oil sells at the same high price as new--was rejected as politically infeasible until 1979. It was accepted by Congress only when accompanied by a "windfall profits tax" on oil companies, partially earmarked for grants to help low-income persons pay their energy bills and weatherize their homes. Following the 1980 election, however, this tax was abolished and the welfare programs severely curtailed, leaving many citizens feeling betrayed. For this reason, price decontrol policies may not be viewed as credible options for other infrastructure technologies in the future.

Another approach, perhaps more generally applicable and acceptable, was taken with electricity. Instead of selling all electricity at the same "average" price as in the past, many utilities employ "increasing block rate structures," or "lifeline rates," where the first units of electric power used by a customer are priced at a lower rate, reflecting the cost of the older, less costly supplies. The last units of electricity, however, are priced at a cost reflecting expensive new supplies. This higher "tail block rate" creates tremendous incentives for conservation and for development of small-scale decentralized technologies for generating electricity. The utility still collects the same revenues as if it had sold all of its power at a single average cost, but the incentives for conservation and new technology development are as high as in the case of price decontrol.

The same types of environmental, resource depletion, and safety trends that caused the real costs of new energy in the 1970s to increase are also likely to cause the marginal costs of water supply, waste treatment transportation, and flood control technologies to exceed the average embedded costs. To the extent that old policies regulate prices at levels below the long-run marginal cost (the levels that prices would achieve in a deregulated equilibrium condition), the incentives for innovation will be symmetric. For example, it may be possible to develop and implement decentralized, diverse technologies for reducing the use of water, the generation of wastes, and the need for passenger-miles, at costs far lower than the costs of adding new infrastructure to increase supplies. But these technologies will not be developed unless tail block rates are set at levels high enough to stimulate such innovation. The money thus saved (by reducing the need to expand infrastructure capacity) might then be available for renovating and modernizing the existing infrastructure.

Price deregulation is not likely to be feasible in many cases due to social welfare considerations and such factors as the existence of natural monopolies. Similarly, high tail block rates may not be technically feasible in many cases due to a lack of sophisticated metering technology. Therefore, it may be necessary and cost-effective to offer financial incentives or to develop performance standards in order to create an environment for technological innovation and the adoption of diverse decentralized technologies. Many electric utilities such as TVA as well as several in California have done this, stimulating tremendous progress in conservation and solar energy while reducing the need for expensive new power plant construction programs.

Some communities, such as Fort Collins, Colorado, have recognized this problem with other infrastructure technologies and altered the institutional/pricing environment to deal with it. For example, in Fort Collins a new development must pay the entire cost of the new water and sewer infrastructure designed to support it. The impact of this particular policy is somewhat different from energy price deregulation because incremental revenues are collected only from new users. If prices had been decontrolled instantly, however, all users would have been confronted with the higher marginal price (and the associated incentives for conservation), and "windfall profits" would have accrued to the owners of the old water and sewer infrastructure.

In some cases it might be politically feasible for the city to capture those "windfall" revenues and rebate them to old customers alone or to old and new alike, depending on what was perceived as equitable. An alternative would be not to collect the excess revenues in the first place and to offer increasing block rates (lifeline rates) to all customers--an approach that is perhaps more equitable in the eyes of new users, but administratively less efficient due to the diversity of customer classes and the current limitations of metering technology.

THE IMPACT OF PRICING POLICIES ON TECHNOLOGICAL INNOVATION

Incentives for the development and deployment of decentralized electric power (e.g., cogeneration, wind) can be quite effective because the transmission/distribution network is flexible enough to accommodate dispersed generation with relatively minor incremental modifications. It is not clear, however, how this analogy extends to other infrastructure technologies. For example, if the development of decentralized technology (e.g., photovoltaics with storage batteries, microflush toilets with small septic systems, individual water wells) allows users to "drop off the system," the centralized system could become unstable as fewer users were left to continue paying off the costs of building the original infrastructure. This problem would not arise, however, if infrastructure costs were paid early on. For example, a new all-electric home might require more than $10,000 worth of electricity-generating capacity to serve it. Currently, such power plant capacity additions are financed jointly by all utility customers. If, on the other hand, the costs had to be paid early on by the developer of a 100-home subdivision, the developer might find it cheaper to super-insulate the homes, install more efficient appliances, and perhaps use part of the $1,000,000 saved to hire a third party to build and operate a small coal-fired fluidized-bed cogeneration plant with a large underground hot-water storage tank. Such a plant could supply a neighborhood district heating system and sell peak electric power to the utility while recharging the thermal storage. Without such institutional innovations in the utility pricing system, however, this more economical "21st-century technology" may never be developed and implemented; utilities may simply go ahead and expand and replace their existing infrastructures of 20th-century centralized generating plants.

The point here is not that technology development should be biased toward decentralized technologies, but that there is a need for policies that will create symmetrical price incentives for potential innovators and developers of both types of technologies. In the telecommunications area, the original stimulus for technology innovation occurred in the defense industry. At that time, the private sector had little or no access to the non-defense telecommunications market. But once deregulation eliminated entry barriers, especially in the inherently non-monopolistic and diverse "end-use equipment" segment of the market, innovation and implementation of new technologies accelerated greatly. Telecommunications was an unusual case, where the marginal costs of new infrastructure were declining rather than rising, but the major policy issues are similar: they concern the equity and social welfare implications of the transition to an economically efficient pricing system. Without policies to ease the transition to 21st-century infrastructure technologies, the nation will continue to waste money and effort on obsolete technologies.

5 IMPLICATIONS FOR THE ENGINEERING COMMUNITY[1]

INTRODUCTION

From detailed discussions of a half-dozen major urban infrastructure systems--communication, transportation, waste disposal, energy, water supply, and flood control--several themes emerged clearly and frequently. They comprise a basis for planning more useful roles for engineering and applied science in helping private and public officials deal with present needs, emerging problems, and unfolding opportunities. In what follows, first, some themes characterizing all of these urban infrastructure situations are noted. Then,

[1]Written by Joseph F. Coates

trends influencing the difficulties and the opportunities for amelioration are presented, followed by a discussion of tensions in dealing with the situation. Finally, implications for the engineering community are presented.

IS THERE A CRISIS IN URBAN INFRASTRUCTURE?

The past several years have seen a rising tide of technical, semi-popular, and most recently, lay-oriented publications, articles, and news coverage of potholed roads; decaying and collapsing bridges; broken, leaky, defective water mains and sewage lines; clogged canals; crumbling levees; crowded ports; faltering electric supplies; crumbling and decaying public buildings; floods; washouts; dam collapse; endless road repairs; and so on and so on. Responsible and respected organizations and people have characterized this situation as a crisis; some have even attached price tags, some as low as 400 billion dollars, others as high as three trillion dollars, over the next two decades to put the nation's public facilities back in shape.

Others, including participants in the Lake Morey workshop, reject any strident cries of crisis and rather see the situation as serious, nationwide, varied in texture, and diverse in its implications for solution and resolution. A multi-pronged strategy is called for to stanch decay, to stimulate rehabilitation and improve maintenance of existing facilities, to enhance the capabilities for retrofit and repair, and to develop new infrastructure devices and systems as an alternative to perpetuating the technologies of the last century.

In no area examined was there any agreement on imminent collapse or widesweeping public disaster. Rather, the sense was that if the situation is not attended to, there will be a continuing increase in system failures, a further decline in performance, a rise in overall cost to society, and a general deterioration of the quality of urban life.

A half-dozen themes surfaced repeatedly throughout the workshop. One such theme rested on a view of each physical infrastructure system as made up of three generic elements: an origin, where the desired material or service is produced; a destination, where the material or service is used, transformed, or converted; and a distribution network for getting from origin to destination.[2] This model, while conceptually powerful, has its obvious flaws, since it is a model which casts all the problems of the urban infrastructure into engineering or hydrodynamic terms. The merit of this concept is that virtually all the infrastructure systems do involve flow in one form or another, whether it is the flow of fresh or drainage water, of traffic, of information, or of energy. These flows occur in networks that overlap any convenient political or administrative boundaries. As a consequence, any serious thinking about the infrastructure must give close and continuing attention to the institutional, administrative, managerial, and political elements and mechanisms for planning, building, operating, maintaining, financing, and regulating each system, for the effective involvement of all the relevant actors, and for the effective linkages of systems one with the other.

This emphasis on interactions and links characterizes the second theme to emerge from the workshop: complexity. Further adding to the complexity is a rough, but in itself falsifying, sorting of communities into old and new. The old are the declining big cities of the Northeast and North Central regions; the new and growing ones are in the South and Southwest. In the extremes, each of these are presented with separate and special problems. Maintenance, rehabilitation, and repair mark the older community. The introduction of innovation, flexibility, and accommodation for future developments mark the new and expanding communities. Still another dimension of complexity has to do with the divisions, overlaps, and conflicts in authority and responsibility that call for a broad sweep of participation by many affected parties, defining the choices, choosing among them, and moving toward an agreed on plan of action.

While each problem crops up locally, making it a highly distributed situation, the repetition of problems from area to area raises the issue to national concern. On the other hand, the overlapping of boundaries, the complexity of networks, and the historical involvement of the national government, as in the highway program and sewage plants, also raises many of the issues to national level. All of this suggests that clear-cut solutions in restricted geographic

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[2]See Chapter 2.

areas by small numbers of actors taking definitive action are likely to be impossible; at best, a remembrance of things past. Today's (and tomorrow's) solutions will require a degree of participation by various segments of our society far in excess of that to which we were accustomed in the past.

These themes can be joined under a single rubric: connectedness. At the most local level in the healthy community, there is a social connectedness which makes collective action, innovation, planning, novelty, and improved productivity work. The absence of connectedness stymies effective change. At a different level, connectedness among systems calls for integration and system governance. A vertical connectedness links local and central governments, which ideally would permit highly distributed systems of local action to work effectively in a national framework. Finally, there is a connectedness in imagery and information, which permits any or all of us to share knowledge, visions, analyses, and solutions at any distance in time or space.

TRENDS SHAPING URBAN INFRASTRUCTURE

Public facilities generally have planned lifetimes of 25 to 60 years. Good engineering design, careful maintenance, and good luck often find systems (e.g., water and sewage systems) still operating effectively after a hundred years, while misfortune, poor design, abuse, or unexpected burdens can accelerate deterioration (as often happens in highways and bridges). Much of the urban infrastructure of the United States was built during the period between the Great Depression and the early post-World War II years. The inevitable damage of time is beginning to show. Accompanying this natural maturation and declining performance are a number of other trends affecting our ability to repair, maintain, and replace our aging facilities and systems or to build new ones.

The population is shifting. Rapid growth in the South and Southwest (the so-called Sun Belt) is complemented by stability and even decline in the large central cities of the Northeast and Midwest (the Snow or Frost Belt). Further, even within the older regions, local migration is shifting people and jobs away from the central cities and suburbs.

Paralleling and stimulating population shifts are associated with the migration of companies and associated jobs and the shift in the urban tax base. At the very time that the old cities are wearing out physically, their tax base for maintenance and renewal is declining. The conjugate problem for the new communities is how to design a system for expansion and flexibility with a tax base which is too small to sustain future needs.

National policy is changing. Continuing pressure to manage expanding budgets and debt burdens has been characterized for several decades by a shift in responsibility from the national government to state and local government. This has been fueled by a more general social move toward localism. The public is demanding more and more direct or immediate control over those aspects of life most closely tied to the community: schools, housing, public facilities, and so on. The consequence of declining budgets is a near-revolutionary change in federal and local governments' fiscal policies compared to the previous period of expansion. In the old days, one year's errors could be compensated for in the next year's budget. The field is reversed, and public administrators often find themselves unprepared to deal with stable revenues, much less cutbacks.

There is a widespread shift in public attitudes to favor conservation, preservation, and repair. There is a shift in public attitudes away from an acceptance of pollution to a demand for clean air, clean water, safety, reduced risks, and more urban amenities. There is spreading skepticism of the needs for public funding, as reflected in Proposition 13 (the California referendum that dramatically reduced the local tax rate) and its numerous variations. Nevertheless, there is a continuing, stable trend of enthusiasm for innovation--of the physical sort exemplified by the development of light rail systems, and of the public administrative sort exemplified by the privatization of such services as trash collection, recycling, and prison maintenance. There is a broad public and private enthusiasm for increased productivity. The steady rise in the cost of energy is now a mature trend.

With these factors as background, the urban infrastructure situation can be characterized by a series of tensions between and among key actors. One role for engineers in this situation, even those who are actors in the events, is to help relieve some of these tensions by enriching and clarifying choices and their implications.

TENSIONS AS A FRAMEWORK FOR RESOLUTION OF URBAN INFRASTRUCTURE ISSUES

Tensions and conflicts characterize American political and public administrative processes simply because, in a representative system, each group is not only able but is active in defining and fighting for its interest. The tensions and conflicts enumerated below are exemplary, but they do define the environment in which decisions must be made and they implicitly highlight the role of engineering, technology, and applied science in assisting in the resolution of those conflicts.

- The shift in responsibility from federal government to state and local government creates tensions because the new financial responsibilities were not anticipated or planned for. The burden of new demands for competence and skill at the state and local level to manage the new responsibilities is itself disruptive. As an example, the federal highway program and the federal sewage assistance programs each in their own way throw the burden on state and local government for maintenance and repair. The federal government assisted construction through heavy subsidization. Had state and local governments been involved earlier in planning, they might have chosen alternative designs to deal more effectively with their long-term responsibilities.

- Cutbacks in funds at all levels of government generate tension because of the threat to expectations for maintenance or even expansion of customer services. No level of government in the United States is comfortable with a stable, much less a declining, budget.

- The pressure of increasingly urgent short-term needs for pothole repair, bridge maintenance, mending the overtaxed sewage systems, and the installation of cable network all drive to an incremental approach to facilities planning. Yet, as every public official and planner knows, facilities will be around for a long time. Pressures of the short-term conflict with the need to plan and design a flexible, durable facility for a changing future.

- Present systems whose characteristics, performance, and administration are well understood are in chronic tension with the obvious desire and often visible need for innovative or radical change. Innovation is intrinsically risky and potentially costly, yet the price of continuing with any present system is almost sure to leave the city saddled with a deteriorating system, mismatched to future needs.

- Social innovations such as the move to privatization or the creating of market mechanisms for the delivery of public services conflict with the comfort and stability of established mechanisms. There is a legitimate general concern that innovation will create inequities and incur political risks. This tension is particularly clear in the case of market-based planning, which in many areas is likely to be far more efficient and cost-effective than planning based on administrative criteria.

- The need for long-term investments in the infrastructure is in chronic tension with a nearly universal lack of faith in long-range planning, or more specifically, in the long-range planners and the processes they bring to bear in public administration.

- A "problem" orientation toward the infrastructure is in chronic tension with an "opportunity" orientation. It is relatively straightforward to diagnose the shortfalls and failures of the system, to define corrections and repairs, and to cost them out and argue their merits. It is much more difficult and requires a different attitude to create a vision of what could be, to define the benefits of that vision when made real, and to assess its cost realistically and recruit its support.

- Region-specific tensions abound in the infrastructure systems. As noted earlier, the old Northeast and North Central communities are caught in a tension between maintenance and repair on the one hand, and redesign and innovation on the other in a context of declining budgets, now overbuilt or decaying systems, and reduced or changing demands. New communities, on the other hand, are caught in a tension between meeting present needs out of current resources while needing to design the infrastructure to both encourage and meet the sought-for community base.

- There are major tensions generated by diagnosis with regard to the infrastructure. To marshal large resources to change public facilities calls upon an explanation of why it must be done. Every explanation has in it a pejorative element. For those who argue a lack of innovation in the system, the problem is identifying and dealing with dullards who have resisted innovation in the recent past. The argument that the performance of the present system is basically effective invites incrementalism and makes it difficult to bring about the overhaul of complex systems. One has to deal with the argument, "Why bother; let's stick with incremental improvements." If one sees the troubles in the failure of local government or in the abrogation of federal responsibilities, one gets caught up in an argument that may be morally satisfying in placing blame but is largely irrelevant to the choice of solutions.

There is no single cause of the urban infrastructure situation. Complex, interacting system elements of many kinds have created the present system and situation. Surely, remedies call for a complex of actions to create a new system. That is a difficult message for both the public and the public administrator. It does create a role for the engineer and the technologist in clarifying what new systems could be and the routes for getting to them.

Taking engineering, applied science, and technology as the units of discussion, their roles in stanching the deterioration and accelerating the rehabilitation and maintenance of existing infrastructure, and in shaping the development of infrastructural innovation, are quite clear. It is the details that are confounding. In broad outline, engineering will be the mediating mechanism for presenting, designing, evaluating, constructing, operating, and maintaining infrastructure systems. Engineering will also be, because of its conceptual orientation to systems and its basic commitment to the concept of tradeoffs, a primary means for assisting political and public administrative and other active community elements with their options and choices. In approaching these broad goals, more specific implications for infrastructure engineering are to:

- Strive for more broadly based goals, which go beyond specific technologies, beyond a narrow constituency, beyond a circumscribed administrative entity or jurisdiction, and beyond problem-solving.

- Push to integrate the total resource situation into the understanding of technological choices and in the organization or reorganization of the infrastructure for productivity improvements.

- Provide the basis for the testing and evaluation of proposed and already field-tried innovations.

- Point to a realistic sorting of those aspects of the infrastructure which are better served by a market orientation and those that are better served by the public administrative supply side approach.

- Stimulate systems innovation and systems integration by defining the specific routes and mechanisms for achieving this and the associated short-term and long-term costs and benefits.

- Strive to widen everyone's choices.

- Promote the inclusion of all affected parties early and often in the situation.

- By indirectly pushing for innovation in a more integrated infrastructure systems technology, engineering will also serve to:

  - energize the improvement of services.
  - broaden the resource base.
  - broaden the range of resources brought to bear in the infrastructure systems.

- Engineers as a community, reflecting back into the educational sector, must revitalize the excitement, the opportunities, and the enormous sense of accomplishment in engineering when effectively dealing with the infrastructure.

- Invent the infrastructure of the future. Only engineers can do that.

- Finally, engineers must re-educate themselves to recognize that their expertise, however solidly grounded, is limited. They must consciously be alert to and integrate with the expertise of the public administrator, the politician, the user, the businessman, the citizen at large. The day of the engineer as the ultimate authority is past. The day of the engineer as the interlocutor in our technological decisionmaking is in ascendancy.

There are also important questions associated with the political and social context which surrounds the application of new technologies to our infrastructure. These include:

- The development of priorities for infrastructure maintenance, repair, or construction, including preferences for strategies, remedies, or technological choices.

- The roles of social, institutional, and organizational considerations as key points of leverage and crucial factors in effective intervention, which will require setting priorities among those institutional, organizational, or managerial measures, and the provision of explicit attention to the mechanisms for linking technological and institutional factors.

- Estimates of costs or preferences for schedules for dealing with the infrastructure need to be considered.

- The broad range of actors involved in implementing technological alternatives such as governors, state legislators, community councils, mayors, the U.S. Congress, federal executive agencies, engineers, engineering organizations, or institutions of higher learning will require specific recommendations for action.

RESEARCH BROADLY AFFECTING URBAN INFRASTRUCTURE

There are four areas of engineering research that would benefit all aspects of urban infrastructure.

First, research should be undertaken to explore the possible benefits of combining one or more infrastructure functions--either within the confines of a particular infrastructure system or across the boundaries of two or more systems. For example, at present the distribution and treatment processes for liquid wastes are separate. Untreated wastes are transported through sewers to a central location where they are chemically and biologically treated. It might be possible to introduce chemicals and biological microorganisms into sewer lines so that the treatment process, or as much of it as possible, takes place during transport. As another example, pure water and wastewater pipes might be arranged coaxially or in bundles, and both could serve as conduits for power lines and telephone or fiber optic cables. These communication cables might also contribute to the water and sewer management process by transmitting information about fluid quality, flow rate, pressure variations, pipe condition, leaks, and contaminants, derived from sensors in the pipe lining. (A similar sensing system could be used in oil and gas pipelines.)

As a final example, water being transported from one location to another might serve as a transporting agent for other materials. This is done now when water is used to transport human wastes and to transport coal and ore in slurries. Water (and other fluids) could in principle be used to transport other materials as well, through a system of "commodity pipelines" that use whatever fluid is flowing in a pipe as a transport medium for other commodities--bulk commodities such as coal and ore, liquid commodities that can be separated from the carrier fluid at the terminus, packaged commodities, and perhaps even solid wastes. Ideally, the fluid that serves as a transporting agent might itself be used at the point where transport terminates, or could form a closed cycle, transporting other commodities back to the starting point. Experiments and demonstrations could test these ideas.

Second, research should explore the possibility that certain functions that are now combined could usefully be separated. For example, technologies have been developed for pipe construction, relining, and repair that differentiate between the pipe's outer housing (a long-lasting housing providing structural stability) and the pipe lining (which can be a short-lived, high-technology lining that is frequently replaced). Leaving the housing intact, as well as repairing only the lining, have led to development of *in situ* techniques for lining repair that do not require extensive excavation and the attendant disruption to traffic and commerce. Other ideas for separating functions and hardware systems should be tried.

Third, pipes, roads, and cables do age, and must ultimately be replaced. At the same time, technology keeps on changing. If whenever a section of pipe, road, or cable needs to be replaced, it is replaced with a section that, while compatible with the existing system, reflects the latest technology, the system can be continually upgraded. Tests and demonstrations should be carried out in which, when surface work or excavation is done for any reason, that entire infrastructure section is upgraded and accurate records are kept of costs and performance to provide data for further development.

Fourth, to an ever-increasing extent, infrastructure systems should incorporate automated controls and should be made self-diagnosing. A series of R&D projects can be organized around these principles. Modern automation and communication technology might be developed to provide continuous information about the condition and operation of all parts of the system and to signal actual and incipient failures and other conditions that need attention. Fluid flows might be designed that would be automatically controlled using a combination of variable pressure and local and on-line storage reservoirs to cope with peaks and lulls in demand. For wastewater, sensors could identify flow segments containing toxic chemicals and other hard-to-treat materials, and automated controls could divert these fluid volumes for special treatment. Computerized wastewater systems that apply treatment appropriate to the measured water quality rather than applying uniform treatment to all wastewater regardless of its quality might be developed and evaluated in actual installations.

IMPLICATIONS FOR THE ENGINEERING COMMUNITY

Based on workshop discussions, some general implications for the engineering community emerged.

- There is no crisis in infrastructure in the sense of any imminent nationwide collapse of any or all of the systems, or in the sense of any precipitous decline in the quality of performance and service. However, the trends argue strongly for continual erosion of performance unless changes are made.

- There is no universally valid statement of the infrastructure problem. It is clear, however, that it is in the public interest to frame the problem in such a way as to draw all of the key actors toward a cohesive, integrated long-term objective and to systematic, shorter-term actions to build toward the long-term. Conversely, it is a public disservice to frame the issue in a way which seeks scapegoats or strives to lay blame.

- Business-as-usual is impossible, in the sense of expanding budgets, generous federal largesse, and the anticipation that next year's venture will correct this year's shortfalls.

- The situation is crying out for innovation in its technological and engineering dimensions and even more loudly in the domain of social, organizational, and administrative innovation.

- The primary need of politicians and public administrators is for a widening of their choices and a solidly based understanding of the short- and long-term costs and implications of those choices.

- While there are striking differences between new and old cities, only in the extreme cases can one base planning on stereotypes. Each community must approach its problems in terms of the local situation.

- For most infrastructure problems, while there are no radically new or revolutionary changes in sight, the technological options do afford many opportunities for substantial improvement in productivity, effectiveness, reliability, and service.

- One area of technological development stands out in striking contrast to all the others in affording the greatest, most broadsweeping, attainable improvement in present and new infrastructure systems: telematics is the complex of telecommunications, computers, microprocessing, and related technologies. There is no infrastructure area which will not be substantially enhanced in its performance, cost, maintenance, flexibility, and durability by the judicious introduction of telematics technology.

- The greatest single obstacle to overhauling infrastructure is the fragmentation of public administrative responsibility and the associated jurisdictional conflicts which yield divisive rather than cooperative action.

IN SUMMARY

Our technological capabilities are so boundless that there is little we cannot do to improve or create a socially sound infrastructure for the decades ahead. Little will be done until we act upon the realization that the social, institutional, political, and organizational infrastructure is central to repair or construction of durable, financially and socially sound public physical facilities. This means that we will need to apply our research and development capabilities to the innovative questions associated with alternative infrastructure technologies.

Appendix A:
SIX URBAN INFRASTRUCTURE SYSTEMS[1]

Communication

Telematics, that is, the combined technologies of telecommunications and computers, is today's star technology. It has the most promise of bringing about basic alterations and substance enhancements in the quality of all urban infrastructure. Information technology is the dominant technology in urban infrastructure. It is also an infrastructure system in itself. Its interconnectedness with other systems shows its dependencies on energy, transportation, waste management, and its potential

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disruption from flooding and other disasters. In spite of this, telematics stands out as a common element with the largest potential for innovation within its own infrastructure system, and more significantly, for beneficial innovation in every other infrastructure system.

Telematics technology is the nervous system of the public enterprise, the source of signals and messages. It is the mechanism for central processing, and the means of control. In the absence of adequate information and its communication, we cannot monitor, locate trouble spots, diagnose, understand causes of effective or ineffective functioning, or understand how operators and users are responding to the system. In the absence of an information system that functions well, knowledge about choices within and among systems and their elements are inadequate and performance must be well below the optimum. Unfortunately, information related to management and planning, where it does exist, is largely of questionable quality and limited credibility. Telematics systems are generally so far behind the complex demands of the system that they have difficulty sensing and correcting errors, making our other infrastructure systems generally unforgiving of mistakes and making us all susceptible to catastrophic failure. In the absence of adequate information, systems tend to be brittle, not resilient.

Table A-1 illustrates some telematics capabilities available today and some opportunities for the near future. The exhibit is a pale image of what telematics technology will offer the public and private sector over the next few decades. Further enhancing the appeal of intensive telematics employment is a rapidly expanding availability and use in business, industry, and among individual citizens.

Telematics is fully legitimized as a technology, bringing with it high expectations of improved performance. It is a technology whose virtues are increasingly widely understood and whose expectations for employment are continually and plausibly expanding. An effective telematics-based communications system would bring the following generic benefits to urban government:

- an inquiring system capable of including feedback, error tolerance, teaching, and learning in an infrastructure system;
- interactive guidance;
- multidimensional analysis;
- information sharing, citizen participation, and new forms of government-citizen interaction;
- monitoring and self-diagnosis of systems;

- infrastructure management, both of single systems and of integrated systems; and
- communication-transportation trade-offs.

The potential benefits of telematics technology have so permeated the five other areas of discussion that it becomes clear that a public strategy for the introduction of telematics into urban infrastructure is a pressing and urgent need.

New developments in communication technology such as global positioning systems, personal two-way communication systems, automated control systems, automated diagnostic systems, vehicle guidance systems, traffic control and vehicle information systems, telefactoring, and holography, together with robotics, could form the basis for R&D projects designed to develop improved methods for inspecting, maintaining, and repairing infrastructure systems. The greatest immediate impact of new communication technology is likely to be on the management and control of other infrastructure systems, but a secondary impact--the use of communication to replace some portion of the transportation system--needs much more research and experimentation.

Transportation

Urban transportation is by far the most expensive and diverse of urban physical infrastructure systems, and after communication, the most complex. It is also the system in greatest need of continual care and maintenance. Transportation infrastructure is particularly severely affected by the large-scale trends in society leading to redistribution of population and jobs; by long-term changes in energy costs; by public-private conflicts over system options (such as personal versus mass transportation); and by the conflict between short-term and long-term remedial measures.

More than any other infrastructure element aside from communication itself, the transportation network will benefit from the introduction of new technology associated with the integration of information transmission and processing and computerized control systems (telematics).

Table A-1. Communication Capabilities Available Today and Opportunities for the Near Future

TYPE OF COMMUNICATIONS	AVAILABLE TODAY	OPPORTUNITY FOR FUTURE
Voice	Personal travel Telephone SAF Radio Limited teleconferencing	Mobile telephones with frequency reuse Feedback systems
Text	Television Videotex Computers	Voice input and output Mobile data terminals
Personal identification	Fingerprints Photographs Voice identification Handwriting identification	Reliable, on-line voice and signature identification "Personal style" identification

Holographic images	Limited (tomography)	Mass audience events Traffic signs Superb teleconferencing
Locational information	Beacons Transponders Ground signposts	Satellite-based global positioning system with transponder capability
Touch, feel, etc.	Personal travel	Telefactoring (design for servicing) Increased dimensionality (e.g., smell)
Other senses	Limited (e.g., ultrasound)	More possible

The urban transportation infrastructure involves four distinct but overlapping physical functions: (1) to move people to and from work; (2) to move goods and services; (3) to move people in more random patterns for activities not connected with work; and (4) to link the urban area physically with the rest of the world.

Transportation systems and their managers are frequently confronted by evolving situations and highly conflicting demands. System capacity is almost always insufficient in growing communities. In established communities and neighborhoods, there is a limited capability to expand or relocate transportation corridors. Planning and construction times are very long; the capital investments are high and are raised further by many legally mandated requirements. High operating costs, along with chronically inadequate integration among the sub-elements of the system and associated diffuse management responsibilities, add to the complexity of the system, its interconnectedness, and the high risk involved in innovation. In transportation more than in any other system, scale beleaguers capability for change.

Technological innovations which would have significant marginal benefits are available in vast numbers for improving the transportation system. Improved materials for roads, roadbeds, and highways; recycling of aggregates; and improved methods of road construction and maintenance are all high payoff areas. Changes in vehicle construction and the use of corrosion- and erosion-resistant materials would reduce net cost over time. Large benefits could accrue from improvements in vehicle technology in terms of reliability, modularity, repair, maintenance, quality, specificity and diversity; from engineering practices permitting more use of modular construction (as in bridges) or improved construction scheduling (as in roadways or light rail systems); and from improved federal administrative practices. Technological improvements in design would lower cost, improve safety, improve ride quality, enhance energy efficiency, and improve the ergonomics of virtually every mode of transportation, from escalators and moving sidewalks to automobiles and subways.

Energy and fuel are more technologically speculative. Their interconnectedness and complexity tend to act as a brake on innovation. Social and managerial innovations are most significant in fuel and energy matters. The development and use of alternative fuels, improved power conditioning, application of inductive coupling in electric systems, and energy recapture and storage are all technically practical but stymied by the locked-in technology.

Managerial, administrative, and institutional innovations are also significant points of leverage. These include the adoption of an integrated urban transportation system, the integration of consumers and users into planning; the move to some market-based systems; innovations to make better use of existing infrastructure; and the collection, generation, and distribution of management-related information.

Cutting across all of these categories are the great benefits seen in the introduction of new electronic technology. This promises a substantial improvement in control and scheduling, in vehicle inspection, in performance monitoring, in dynamic automation of systems, in the rationalization of the capacity of an integrated system, and in vehicle operating information for drivers and passengers. Perhaps most significant is the expansion of the base of governmental and private information to make better planning decisions.

Concerns about clean air and about the costs and availability of fuel, along with the development of new forms of motive power (e.g., magnetic levitation and linear induction motors) and new, lightweight, corrosion- and erosion-resistant materials, are likely to lead to major changes in transportation technology. It is not inconceivable that these will include a shift away from the dominant role of the internal combustion engine for personal transportation. Such a shift, by affecting the speed and range capabilities of private vehicles, could have a major impact on patterns of settlement and consequently on all aspects of infrastructure. New sources of motive power and new materials could also form the basis for R&D designed to produce innovations in public transit systems and guideways for public and private vehicles. High-speed moving sidewalks could also be further developed. All these innovations are likely to be characterized by an increase in fuel efficiency, and consequently provide a double return for public R&D investments--improved performance of the infrastructure and reductions in energy consumption.

Waste Disposal

The waste disposal infrastructure has two primary goals: the protection of public health and the effective use of resources. The primary strategy for meeting the first objective is the disposal of potentially hazardous wastes in a manner that prevents harm. The strategy for the second goal is to extract whatever value remains in a used or partially used resource before its final disposal as waste. Against that background, there have been no recent major technological innovations in waste disposal. The biggest area of concern and the primary opportunity lies in slowing down the volume and changing the nature of the generation of waste. Major improvements in these areas will come from governmental and managerial changes, e.g., pricing changes that induce users to reduce the amount of waste generated. Complementing the metering and pricing of waste are deposits on packaging materials such as bottles. One area of technological innovation that could indirectly improve the waste disposal system is the development of means for modifying the use and nature of packaging materials to make them more suitable as fuels or at least to make them biodegradable. Other technological and institutional innovations are listed in Table A-2.

The major institutional challenges facing waste disposal managers center on:

- the vast quantities of waste that are produced;
- the inadequacies of the system for transporting waste;
- the administrative and technological inadequacies in the handling of toxic and highly hazardous waste; and
- political difficulties in selecting locations for waste disposal sites.

In spite of the numerous regional and local waste disposal problems that are serious and even urgent, there is no waste disposal crisis at the national level. It is clear, however, that the power and leverage lie in the social and managerial innovations and that the strictly technological innovations are only likely to be used after the managerial innovation has taken place.

The demand for waste processing and disposal might be reduced either by reducing the amount of waste that is generated or by increasing the recycling and reuse of waste products. Research could be undertaken to determine the extent to which the quantity of solid waste could be reduced by restricting the use of packaging materials and bulk mail, by requiring packagers and advertisers to reclaim and recycle such materials (e.g., bottle return laws), or by making those materials edible, biodegradable, usable as fuel, or usable in some other fashion. It is worth noting that municipal solid waste has a moderately high energy content and could conceivably be used as a fuel, by itself or in combination with other fuels, for electric power generation and district heating. Waste material separation could be encouraged by means of financial incentives, such as charging customers of trash pickups by weight or bulk of different kinds of trash. Such incentives need to be tested in structured experiments.

Energy

Energy is a universal enabling element in the physical systems of urban society. In analogy to the body, if information and communications are the sensory and nervous system, and transportation is mobility, then the energy infrastructure is the muscle and metabolism. Energy illustrates the basic infrastructure themes of complexity, connectedness, flow, and networks more fully than any other system. It also illustrates the opportunities for both incremental technological improvements and for technological system alternatives that are strikingly more efficient, more effective, or less costly, and that can have far-reaching effects on the nature of the city itself.

Since the oil crisis and the rise of the environmental movement, energy technologies have occasioned recurrent promises for major and minor innovation. To some extent, innovation has been stymied by legitimate and general technical and economic considerations, uncertainties about the future cost of fuel, and confusion about the short-term and long-term benefits of system changes. Adding to the inflexibility and sluggishness of the system is a complex degree of both public and private involvement in the energy infrastructure, making the points of leverage more diffuse and each less powerful. There is no area of urban

Table A-2. Technological, Social, and Managerial Innovations That Could Contribute to Waste Disposal

Technological Innovations	Social and Managerial Innovations
Waste Generation:	
Packaging reforms; substitutes for toxic materials, better methods for materials separation at the source or at the treatment site; biodegradable materials.	Education about the full cost of waste; toxic labeling; materials separation in the home; and the benefits of recycling.
	New pricing methods; deposits on solid wastes such as containers, packaging materials, tires, appliances, etc.
	Promote collection and recycling; set standards for packaging materials to encourage use of easily treated or recyclable materials.
	Subsidize technological retrofit.
Waste Transport:	
Effective use of telematics for monitoring, control, and diagnostics; use of on-line holding tanks to accommodate peaks in waste flow (similar	Cooperative arrangements for multiple uses of sewers; promote private competition in waste collection and disposal; levy channel sanctions.

to use of on-line storage tanks in a water supply system); sensors to identify and locate toxic wastes for diversion to special treatment centers; techniques for in situ relining of pipes.

Waste Treatment:

New treatment methods on the large and small scale including concentration, accelerated dehydration, separating, biological "superbugs," and biological and physical substitutes for chemical decomposition.

Earlier start to the treatment process, e.g., aeration in the pipes while wastes are being transported, or superbugs in the toilet tank to begin decomposition as soon as the toilet is flushed.

Incentives for reducing the amount of waste delivered to the treatment site.

Increased government oversight of treatment of toxic wastes.

Waste Disposal:

Techniques for recovering useable resources.

Better waste dispersion technologies.

Intergovernmental and interjurisdictional cooperation

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infrastructure in which private market and non-market forces come together in such intimate and complex ways.

Energy, by being part of every urban infrastructure system, has the potential for influencing all those systems. Pricing of energy resources, environmental concerns, shifts in fuel availabilities, changing design of transportation systems, power requirements for those systems--all of these create major and minor opportunities for technological change.

In the matter of solid waste disposal, materials recycling to conserve energy (e.g., in the aluminum and paper industries) and the use of solid waste for combustion relieve both the physical disposal problem and the fuel bill.

Energy recovery from waste streams is not limited to solid or liquid waste. Energy streams themselves find greater and greater use in district heating. Thousands of miles of district heating networks now function in the United States.

Energy and communications interact in a strikingly new way. Communications can be traded off for energy. The most popular, widely touted form of this, telecommuting, is already a noticeable part of our business economy.

Overlying all of the details of the many technological choices concerning energy are a few principles regarding choice. The infrastructure of energy transmission and distribution systems can be inherently flexible. If additional flexibility is planned in buildings and building complexes, some of the structure can be separated physically from the activity in the building. Thereby, the building can service many generations of changing technologies in energy (heat, light control, etc.) and telematics (communications control) uses. Separation of structure from functional use promotes flexibility. The extensive use of well-planned horizontal and vertical "utilidors" (that is, utility corridors) and the use of extensive underflow distribution systems in high-rise buildings are further strategies for the enhancement of flexibility. The concept of flexibility would apply to the supply side of energy. It gives greater emphasis to systems integration and the capability to accommodate a variety of energy sources, not only the conventional ones of petroleum, coal, natural gas, and nuclear power, but the newly emerging, distributed ones of energy recycling, photovoltaics, wind energy, and so on.

Reliability and manageability of maintenance and control are other features essential to an effective long-term, viable energy infrastructure. Accommodating multiple stakeholders in this highly complex public and private network implies more effective participation and the need to stimulate entrepreneurship and leadership as the routes to effective innovation.

The technologies available today are expected to develop at a rate more than adequate to keep up with the needs of any infrastructure program. The selection of technological alternatives that have low revenue requirements and meet specified functions should produce a long-range, flexible framework against which specific projects can be evaluated.

Energy technology is likely to change significantly in the coming years, largely under the impetus of economic, environmental, and geopolitical concerns having to do with the availability of energy resources and the hazards of air pollution. Research will likely result in new fuels, use of liquid and solid wastes and their by-products as fuel, increased emphasis on recovery and utilization of waste heat from power generation and from waste treatment and industrial processes, new heat-carrying fluids and new insulating materials that will make it possible to extend the reach of district heating and cooling systems, new techniques for storing thermal and electric energy, and more efficient electric motors, appliances, vehicles and industrial equipment. Similar developments may well alter the considerations that in the past have favored centralized energy generation over decentralized systems. Therefore the research needs to be supported and undertaken by a wide range of organizations, so the process of technological innovation is not dominated by those having vested interests in the energy infrastructure technologies.

Water Supply

The areas of technology relevant to urban water supply include telecommunications, computers, instrumentation, and remote sensing; construction techniques; new materials; energy systems; fluid flow technologies; water treatment and waste disposal techniques; as well as those methodologies applicable to system management and control.

Technologies that may make it possible to augment water sources or reduce water losses include evaporative and other controls to reduce water losses; weather modification; and conservation measures such as low-flow showers, microflush toilets, prompt and effective repairs of leaks, and recycling of used water. Measurement technology, together with modern communication technology and automated control technology, can make all of these practices more effective.

Technologies that can improve water treatment include sensing devices and automated controls that incorporate detection and treatment of hazardous contaminants and that permit treatment to be carried out to a degree suited to the quality required of the water for a particular use; multiple water systems incorporating any combination of dual water supply systems (potable water and "gray" water), closed or self-contained (recycled) systems, or decentralized systems in which water is treated at the point of use rather than at a central facility;[2] and the provision of mobile treatment units that can be used where pipe breaks and infiltration temporarily affect local water quality.

Two kinds of technologies can improve distribution. First are those that provide flexibility to accommodate future growth. Second are those that minimize disruption to the system when repair or renovation is undertaken. Because of the expense and disruption of excavation to repair a failed pipe, replacement is preferable to repair; when replacement is undertaken, the new section should reflect both the latest technology and the latest future plan for the community. When excavation is undertaken for any reason, it should be coordinated with replacement of other buried infrastructure elements and with surface renovation as part of an integrated plan. Technologies should be developed that, by permitting *in situ* replacement of pipe linings, eliminate the need to excavate and replace the pipe housing. Better methods of flow monitoring and leak detection (e.g.,

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[2]However, it is important to note that the reliability of present technology is not adequate to permit such approaches with the assurance that there will be no detrimental impacts on health.

flow metering and video scanning) would make it possible to diagnose and correct incipient problems. Communication cables and sensors embedded in the pipe itself would be most effective and could be used to transmit other kinds of information as well as pipe-diagnostic information. System design that permits isolation of certain sections that are hard to get to and that could be temporarily replaced by mobile units would make it possible to repair or renovate with minimum disruption to users.

Institutional and administrative considerations include:

- the need to promote investment in, and use of, technology that provides a better capability for data collection, data processing, and information management;

- the need to adopt computerized management systems that integrate various elements of urban infrastructure and foster coordination among activities that share a common database;

- the fact that drainage basins and water regions do not respect political boundaries, necessitating a regional system management approach;

- the need for prompt and effective emergency response to system failures, especially those with public health implications; and

- the differences between the mature city--where the primary requirement is to minimize disruption while maintaining the system--and those urban areas undergoing rapid growth--where the primary requirement is to provide flexibility to meet future needs.

Urban Drainage and Flood Control

Urban drainage and urban flood and storm water management center around the problem of what to do with large amounts of water that appear where they aren't wanted. The strategies for dealing with storm water and flood management have been well-known for decades: modify the hazard by managing the water flow with dams and levees; moderate the impacts through flood insurance, floodproofing, relief, and rehabilitation; and reduce the risks by regulating use of the flood plain.

The potential contribution from technological improvements lies in two distinctly different and complementary domains: marginal improvements leading to small increases in performance, and major improvements leading to large increases in performance. Of course the latter--and very desirable--improvements are the ones which are most uncertain, most research-dependent, and farthest in the future. Research could be undertaken on ways to control the amount of water, or the rate at which it appears in the streets, by controlling the amounts of rain and snow and the rates of snowmelt and runoff through such techniques as climate modification, cloud generation and dispersion, cloud seeding, managed snowmelt (using solar mirrors to increase snowmelt or artificially-maintained cloud cover to decrease it), and the management of runoff, evaporation, and evapotranspiration (using chemicals on the water surface to change the rate of evaporation or using genetic engineering and biotechnology to develop living ground covers that will absorb water and slowly release it). More significantly, storm and flood water--now viewed as an unwanted commodity--could instead be viewed as a welcome additional source of water. Multipurpose detention basins and channels could be built, including street-center canals suitable for recreation, water storage, and flood drainage. New materials and flexible sizing of channels could be used to manage flows. Flood waters could be diverted and stored in cisterns, detention basins, or reservoirs to be used immediately or in dry periods, either directly for irrigation, heating, cooling, fire-fighting, or waste disposal or--after appropriate treatment--for industrial processing, cleaning, and personal consumption. All of these ideas should be experimentally tested under simulated conditions and then demonstrated *in situ*.

All of this is far in the future. However, many opportunities exist now for significant incremental improvements. Some of these are technological; others are institutional. Technological opportunities include improved dams, levees, spillways and channels; better methods of water storage in retention basins and reservoirs; improved forecasts of floods, rain, and snow melt; and better warning systems. Institutional opportunities include more effective and enforced land use restrictions; better emergency management; and perhaps most significant of all, better disaster recovery plans. Sound disaster recovery plans not only lead to effective relief and rehabilitation but take advantage of the disaster to restructure radically the physical aspects of the community for a more durable future.

The civil engineering community, and to a substantial degree, the public administration community, know what needs to be done. The problem is how to bring about the necessary changes. Innovation is needed not only in technology but also in information delivery, better planning, and more effective management associated with the long duration of the public policy process. The capabilities that government should be striving for over the next fifty years are best expressed in performance goals rather than prescriptive standards to be met by civil works or social inventions. The combination of available technologies and the results of yet-to-be-conducted research will lead to new uses of technology in a fully integrated flood hazard management system.

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