Table Of Contents:

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Understanding Urban Interactions:
Summary of a Research Workshop

Final Draft

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Executive Summary:
Understanding Urban Interactions

Urban areas—home to three-fourths of U.S. citizens—are undergoing major social, economic, and environmental transitions as their structures and functions change. The roles of basic urban infrastructure, such as telecommunications and transportation, are shifting. Human and natural environments are deteriorating in some places and improving in others. Demographic changes are challenging urban governance in many places but renewing others. The complexity and pace of these developments, positive and negative, has outrun researchers' ability to understand them.

New tools and methods of research promise to improve our understanding of these changes. A truly multidisciplinary approach, using improved statistical and modeling techniques and new systems for gathering and processing data, would let researchers address issues in greater complexity, and at a variety of scales. An integrated ecological, engineering, and social-science approach to urban studies could help reduce some of society's most difficult problems. Urban land could be used more rationally. Social capital could be integrated with physical infrastructure, making both more resilient and robust. Education could build on these results, integrating social and natural sciences with information technology for real-world learning experiences.

The National Science Foundation, planning to focus more resources on urban processes, convened a research workshop at NSF headquarters July 29–30, 1997. The group—28 researchers experienced with large-scale, multidisciplinary approaches to urban phenomena—identified seven research agendas in three broad multidisciplinary areas.

Tools for Modeling Urban Systems

Urban research requires a new, multidisciplinary methodology that exploits the integrative power of information and communication technology. For decades, the interactions of urban subsystems have been obscured by a discipline-bound approach.

- *NSF should encourage the scientific community to take a cross-disciplinary systems approach in future urban studies*. Fundamental data requirements will need to be identified in multidisciplinary forums. Data protocols that can be used by different disciplines at various spatial and temporal scales should be developed. Networks of researchers examining urban issues from different perspectives should be established, and technical and organizational structures provided to support these new links.

Information and the City

Urban areas are being changed in pervasive and subtle ways by the explosion of information and telecommunications technology, and by the forces of a global economy and society. The concepts and tools for documenting, monitoring, predicting, and planning for these changes need to be developed.

- *What are the characteristics and challenges of cities in a time of rapidly advancing information and communications technologies?* The urban area of the information age must be defined, and approaches to understanding, monitoring, and managing it developed.
- *How is urban infrastructure changing in the information age?* The multiple interactions of evolving infrastructure, especially communications and transportation, with urban economic, social, and environmental conditions are vital to the urban future, but poorly understood. They need to be studied, and guidance provided to those responsible for developing that infrastructure.
- *How can advanced information and communications technology be used to build an urban citizenry that is better educated and informed about science, the world, and its immediate local environs?* Community information technologies can offer greater variety and quality of educational opportunities for citizens. It could help If used wisely it could help in the pursuit of democratic goals and social equity. At the same time, it would degrade local control and the democratic mixing that takes place in local schools; it might also exacerbate distributional problems, by dividing the population into those with adequate access to information technology and those without.

Adapting to Change: Toward Sustainable Urban Systems

Can urban areas be developed sustainably? For a variety of reasons, public and private decisions in urban areas often lead to solutions that are socially, physically, or environmentally less than optimal in the long run and on the larger scale.

- *How can the viability and sustainability of urban areas be defined, at scales ranging from the metropolitan to the community or neighborhood?* What are the relationships of viability and sustainability at those three scales? What are appropriate indicators of viability and sustainability? How do human activities interact with the physical, social and natural environments over the long term?
- *What is required to produce strong and adaptable social capital and physical infrastructure in cities, able to withstand change, hazards, and disruption?* Building and maintaining physical infrastructure is a major challenge to local government and a major cost to citizens. Integrating public and private infrastructure programs with trends in social, environmental, and economic indicators would make possible more robust urban systems, better tailored to needs and more adaptable to change.
- *What factors—technological, infrastructural, institutional, educational, social, behavioral, and informational—determine the political participation of urban citizens?* One aspect of sustainability for an urban area is commitment of citizens to its future. It has been suggested that information technology can help encourage and enable civic participation by citizens, but there are many uncertainties about access to the technology and the skills and motivation to use it.
- *What are the characteristics of life and institutions in extreme social environments?* The extreme social conditions of some urban communities (with inadequate educational, social, and political institutions and poor social capital) are accompanied by degraded ecological conditions and infrastructures. The determinants of social stability are poorly understood at the neighborhood level.

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UNDERSTANDING URBAN INTERACTIONS

I. NEW TOOLS AND NEW IMPETUS FOR URBAN RESEARCH

Urban areas—home to three-fourths of U.S. citizens—are undergoing unprecedented social, economic, and environmental transitions that challenge our very notions of what "urban" means. The roles of basic urban infrastructure are changing. Telecommunications and transportation, for example, are increasingly substitutable, but also competitive and synergistic, and their interactions profoundly change traditional relations of distance and accessibility (of jobs, services, and other people). Both the human and natural environments in many urban areas continue to deteriorate, for reasons that we do not understand, or that are so complex that they defy solution. Typical urban development patterns in the United States lead to rapid conversion of rural land, disrupting ecological systems. Derelict parts of the earlier urban fabric raise their own environmental and social problems. Population movements and other demographic change challenge the governance of some urban settlements, while renewing others. Urban citizens' political participation—a primary indicator of social capital—has declined. These trends, at a time of momentous change in world markets,

present us with policy problems we are not prepared to face.

Those problems can be the basis of a renewal of urban research, taking advantage of powerful new tools of analysis and synthesis and a more integrated, multidisciplinary approach. Urban problems have been the subject of many studies, but fruitful attempts to describe them have been hindered by the political, economic, and social complexity of the (often multijurisdictional) metropolitan areas in our democratic society. Today researchers have the technology and concepts they need to address that complexity. Improved techniques of modeling and meta-analysis, more widespread and useable geographical information systems (GIS), and data from novel sources such as remote-sensing satellites can, if used appropriately, give urban research the ability to understand in substantial detail the interactions of human beings with their physical and social environments, at a variety of scales in both time and space.

Such an approach, in addition to its scientific interest, could have important applications. For example, an integrated ecological, engineering, and social-science approach to the study of "brownfields" (urban sites, often contaminated and abandoned by industry, that do not meet structural or environmental standards for development) could make reusing these sites feasible and improve the decision processes that lead to these costly problems. A richer and more detailed understanding of the phenomenon of urban sprawl could yield development strategies that address the social, economic, fiscal, political, and environmental impacts of such growth. Problems of regional governance and urban politics (such as interjurisdictional competition for jobs and revenue) could be treated in a more integrated way. Social capital and physical infrastructure could be built and maintained together.

Urban research of these kinds could also form the basis of educational programs at all levels that integrate the social and natural sciences with attractive technology such as GIS, giving students hands-on experience with challenging local problems. Environmental education programs, for example, might be linked to research on the problems of brownfields or urban watersheds. Undergraduate and graduate engineering schools could adopt curricula that would give the future designers and builders of physical infrastructure an appreciation of the socioeconomic and environmental impacts of that infrastructure, as well as a thorough understanding of public decisions. Such curricula would offer novel and important learning experiences that address pressing national problems.

The National Science Foundation (NSF) has recently begun planning to focus more resources on the study of urban processes. Planning has begun for a crosscutting program of basic research, educational reform, and graduate training that (a) focuses on the interaction of ecological, social, behavioral, and engineered processes in the urban environment; (b) requires substantive cooperation among researchers from different disciplines; (c) takes advantage of recent advances in computing and communications technology; and (d) integrates developments in research and education from kindergarten through postdoctoral training, as appropriate. Part of that effort has been plans for establishing two new urban research sites in the Foundation’s Long-Term Ecological Research (LTER) program. These multidisciplinary activities will complement the Foundation’s traditional core of disciplinary research and education.

To identify promising multidisciplinary urban research topics, NSF convened a research workshop at NSF headquarters July 29–30, 1997. The group—28 researchers experienced with large-scale, multidisciplinary approaches to urban phenomena—identified seven research agendas in three broad multidisciplinary areas.

II. MULTIDISCIPLINARY RESEARCH AREAS

A. Tools for Modeling Urban Systems

Contemporary urban research requires a new, multidisciplinary methodology that takes full advantage of the integrative power of information and communication technology. While urban subsystems (such as housing, communications, transportation, land use, and energy supply) have been studied for several decades, relationships among subsystems are often obscured by the discipline-bound approach of past research. Social scientists, engineers, and ecologists do not speak the same languages, and do not approach urban data in the same ways. Their data, models, and findings cannot be simply merged, yet they need to be made compatible with one another. It is necessary to look critically at the information available from such disciplinary research, and to identify systematically the intersections and boundaries of the knowledge thus generated, where fruitful clusters of multidisciplinary research problems can be found. Such a systematic approach can offer novel, integrated and multidimensional descriptions of the city. It can be applied to many research questions that span disciplinary areas, such as the adaptive or flexible use and reuse of urban space; the allocation of scarce resources; the impacts of information technology on the physical and the social fabric of the city; the privatization and deregulation of urban services; disaster response planning; and the maintenance of ecological diversity amidst urban restructuring and growth.

Although the systems approach to urban research dates from the 1960s, contemporary information technology offers rapidly growing capacity for modeling complex systems in a more integrative and cross-disciplinary way. Database standards, interoperating information systems, distributed computation, the Internet, spatial decision support systems, the profusion of remotely sensed data, and especially the broad diffusion of GIS systems, are developments that cut across disciplinary boundaries and foster collaborations that were hardly possible before. Hand in hand with these developments go new methods, such as meta-analysis, for dealing with very complex problems on which a great deal of inconclusive research is already available, and the formation of new university programs

in information management and related fields.

The scientific benefits of a fresh systems approach capitalizing on these recent developments would be substantial . A systematic reexamination of past research through the lens of modern information technology, and with a multidisciplinary approach, would amplify the benefits of previous research at relatively small additional cost, and set directions for more effective future data collection and modeling. At the same time, it would offer broad new insights into urban systems over a wider range of geographical and temporal scales, from the neighborhood to the metropolis and beyond, and into its daily, seasonal, and long-term rhythms.

1. Research agenda. NSF should mount a broad research program to develop the tools and methods of a systems approach to urban studies:

- *NSF should encourage the scientific community to take a cross-disciplinary systems approach in future urban studies*. Fundamental data requirements will need to be identified in multidisciplinary forums. Data protocols that can be used by different disciplines at various spatial and temporal scales should be developed. Networks of researchers examining urban issues from different perspectives should be established, and appropriate technical and organizational structures provided to support these new cross-disciplinary links. The goals are to:

  -Encourage researchers in different disciplines to identify functional relationships, interactions, and linkages among the social, physical, and ecological urban subsystems they study.

  -Encourage the development of new urban models that integrate social, physical, and ecological components and their interactions at different geographic and temporal scales.

  - Identify data shortages, methodological shortcomings, and disciplinary barriers hindering the scientific understanding of the structure and function of urban systems.

  - Develop the technical and organizational infrastructure needed to support efforts that are widely distributed, in both the geographical and the intellectual senses.

  - Develop data protocols that will facilitate the sharing and use of data by different disciplines and constituencies, and at different spatial and temporal scales.

  - Develop information dissemination programs that facilitate the transfer of findings from scientific studies to government officials, educators, business leaders, and the public.

2. Research plan. Research in this area must be built on a systematic foundation of multidisciplinary communication. NSF, with other interested organizations, should begin by convening a group of experts in all of the disciplines at issue in urban studies (social, behavioral, and economic sciences, ecology, urban planning, various fields of engineering, and geography and regional science), along with experts in systems modeling and operations research. This group would establish a preliminary list of crosscutting research issues, whose intersections offer both (a) opportunities to advance the science and technology of modeling complex systems and (b) fruitful research problems in one or more disciplinary areas.

NSF and its partner organizations should form an Urban Interactions working group, building on the NSF Urban Communities working group. The Urban Interactions group would hold a second, larger, interdisciplinary meeting, to discuss and refine the list of urban research issues and formulate guidelines for research. The group would identify available sources of urban data that are suitable for systems-level analysis, and data requirements that are not met by existing databases (with attention to consistency of data formats and database structures).

NSF would then issue a program announcement in "Modeling Urban Interactions." Criteria for awards under this program would include (a) fundamental contributions to the science and technology of modeling complex systems and (b) multidisciplinary approaches to the research issues identified by the working groups.

In addition, NSF should establish a National Center for Urban Analysis and Synthesis, as a point of scientific exchange, data-sharing, and synthesis. A good organizational model is the recently established, NSF-funded National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California. NCEAS functions as a meeting place for ecologists and other natural scientists from around the world, studying diverse processes at various scales. It offers workshops, conferences, and residential seminars of varying duration, supported by up-to-date GIS-based computational facilities for help in synthesizing data and insights.

3. Data needs. Data requirements will need to be determined in multidisciplinary fashion, through structured interactions of experts on the discipline-based research. Much of the data required has been collected over the years in support of disciplinary studies in the social sciences, engineering, and ecology. Building the multidisciplinary databases for a systems approach will require attention to the intersections of disciplinary databases, where interesting research issues and novel links between disciplines are most likely to be found. Consistent data protocols must have a high priority, to permit the widest possible use of data.

Data collection in the future will need to be better integrated from one discipline to another. The outcome of these studies will include findings that have implications for data collection by local, state, and federal agencies.

4. Research funding sources. Sources of funding for research in modeling urban problems include a wide variety of NSF programs: the Social, Behavioral, and Economic Sciences (SBE) Directorate's Methods and Models for Integrated Assessment program; the Knowledge Modeling and Computational Intelligence program of the Directorate for Engineering (ENG); the Database and Expert Systems, Information Technology and Organization, and Special Projects in Networking and Communications programs of the Computer and Information Science and Engineering (CISE) Directorate; and the cross-directorate initiative Knowledge and Distributed Systems (which includes competitions in Learning and Intelligent Systems, Knowledge Networking, and New Challenges in Computation).

In addition to NSF, support for a systems approach to urban research can be found in other federal agencies, in foreign and international research agencies, nonprofit foundations, and industry. The U.S. Departments of Housing and Urban Development, of Defense, and Energy can support research aimed at near-term applications. Industry may join in support of such applied research, under various federal programs that involve cost-sharing by industry. Foundations are also likely sources of support.

5. Related educational initiatives. The research would have broad implications for undergraduate and graduate engineering education, to which engineering schools will need to pay heed in their curricula. The systems approach to describing urban areas will offer new perspective on urban physical infrastructure, which will require engineers that appreciate the extent to which infrastructure is embedded in social, behavioral, and ecological context. Funding for engineering education projects that reflect this context is available from various NSF programs and from private foundations.

6. Graduate training requirements. Graduate programs will be needed in computer and information sciences (information management, database design, and geographical information systems) as well as in a wide variety of disciplinary fields (economic and physical geography, sociology, political science, ecology, civil engineering, and urban planning).

B. Information and the City

Urban areas are being changed in pervasive and subtle ways by the explosion of information and telecommunications technology, and by the forces of a global economy and society. The concepts and tools for documenting, monitoring, predicting, and planning for these changes need to be developed. The economic and social well-being of cities increasingly depend on their ability to harness and transform information for the benefit of citizens. In particular, the information revolution offers the opportunity for dramatic improvements in the delivery of urban services such as jobs, education, planning, policing, and environmental protection. The future of urban areas as viable places for living and working in the information age has been called into question by some, who say that the traditional economies of concentration are ebbing as telecommunications grows cheap and ubiquitous. Indeed, there is evidence that many human activities are becoming more "person-based," rather than "place-based," as they follow increasingly mobile citizens. Yet urban areas continue to grow and remain attractive as sites of commerce, culture, and community, and many urban amenities are enhanced rather than threatened by telecommunications trends.

These changes are largely shaped and propagated by developments in urban infrastructure. The modern city has developed according to the needs of trade and has been influenced by three major infrastructures: transport, telecommunications, and energy. While all remain important, the driving force behind in the new period of urban growth that is underway is increasingly the information and communications infrastructure. The new infrastructure will be different from today's, and will serve the needs of a different kind of city. For public policy makers and business, managing the transitions resulting from the interplay of supply and demand for infrastructure services will be challenging. In economic development, environment and public services, the public and private sectors must accommodate developments in telecommunications infrastructure (such as the creation and use of teleports, metropolitan area networks, managed data networks, and value-added networks for specific sectors); transportation infrastructure (with network-based systems for road pricing, passenger information, route guidance, real-time traffic management, and mobile information services for

urban freight); and energy infrastructure (the creation and use of network-based systems for logistical control, workplace and home energy management, flexible pricing and billing, remote diagnostics and metering, and on-line information services).

Many fundamental questions need answers. Theoretical as well as empirical work is needed to redefine concepts such as "distance," "interaction," and "accessibility" that reflect spatial relations in the modern information economy. What are the new roles of urban areas, at a time when telecommunications and information technologies render distance increasingly irrelevant to business, education, and popular culture? To what extent are "virtual communities" likely to replace neighborhoods as units of social cohesion? Do modern information systems offer new ways to encourage politically active citizens? Can they help make education a more participatory and interactive experience?

Answering such questions will require new kinds of urban indicators, which mirror the traditional economic and social indicators but reflect (a) the growing importance of information in urban life and (b) the growing capabilities of information technology for monitoring and modeling urban processing.

International comparisons are likely to be increasingly important in the future of urban research, and foreign and international research agencies, private foundations, and firms should be interested in supporting comparative international studies of the impact of information technology on urban areas. Since U.S. cities may be among the world's most advanced in their use of information, their study should help predict changes to come in other regions of the world. Several economically advanced nations outside the United States, however, have made the development of advanced information infrastructure a high priority. Even cities in developing countries offer important grounds for study; some are in positions to leap directly from 19th century to 21st century communications systems.

1. Research agendas. NSF should support the following three research agendas to help define the interactions of modern information technology on urban populations and the urban infrastructure:

- *What are the characteristics, needs, and challenges of information-based cities in a time of rapidly advancing information and communications technologies?* The urban area of the information age must be defined, and approaches to understanding, monitoring, and managing it developed. The ongoing changes seem to be accelerating, but have been little studied to date. It is important to determine the impacts of change on various urban population groups, and on the urban area as a system. Cross-cultural and cross-regional comparisons are also of interest. New tools for documenting and modeling these changes (such as geographical information systems) make progress inevitable, with adequate support. Questions include:

  - How can changes resulting from emerging and future technologies be documented, described, and predicted?

  - How can urban flows of information (at least as important as flows of transportation and commerce) be measured?

  - To what extent does information technology enhance tendencies for individual activities to "spread out" in time and space (e.g., through flextime, shared jobs, increases in temporary working, telecommuting, electronic banking).

  - How does electronic commerce influence consumer decisions?

  - How does electronic commerce affect business location decisions?

  - What are the implications of new portable information technologies, such as mobile telephones, for the division between public and private realms? Issues include the potential for erosion of privacy.

  - How does information technology interact with urban ecological systems?

  - How can virtual communities (organized through electronic and other networks) be characterized and understood, and related to our traditional concepts of urban communities? How would a society centered on virtual communities care for urban physical and social capital and ecological systems? The less tangible losses due to a diminished role for face-to-face interaction also need examination.

- *How is urban infrastructure changing in the information age?* The multiple interactions of evolving infrastructure, especially that of communications and transportation, with urban economic, social, and environmental conditions are poorly understood but vital to the urban future. They need to be studied, and guidance provided to those responsible for developing that infrastructure.

- Can the market-driven interplay of information, transportation, and energy infrastructure be described and predicted in a form that is suitable for use by public policy makers or business?

- In what ways does the interaction of communications and transportation infrastructure change human interactions in space? What are the implications of such change for those responsible for developing and maintaining infrastructure? How do they affect the building of urban social capital and the maintenance of physical infrastructure and ecological services (all of which generally involve commitment to the future of a place)?

- How can the concepts of distance and accessibility be redefined to reflect the new realities? Can access to information, for example, be measured? How is it shaped by markets, and how can it be shaped locally by policy makers?

- What services and amenities do urban areas offer that are relatively insensitive to changes in urban infrastructure?

- Can useful international comparisons be made? How do differences in legal, political, and regulatory systems and other conditions influence the use of infrastructure services in the urban areas of other nations?

- *How can advanced information and communications technology be used to build an urban citizenry that is better educated and informed about science, the world, and its immediate local environs?* Community information technology can offer greater variety and quality of educational opportunities for citizens, inside and outside of schools. If used wisely, it could help in the pursuit of democratic goals and social equity. If left unchecked, these technologies could worsen inequalities. To the extent that they displaced physical school facilities, it would reduce the costs of construction and maintenance. At the same time, it would degrade local control and the democratic mixing that takes place in local schools; it might also exacerbate distribution problems, by dividing the population into those with adequate access to computers and communications, and those without, at a time when the Internet is becoming an important tool of citizenship and education.

  - What are the potential benefits of network technology for urban education (e.g., equalization of access to information regardless of place, avoidance of acute problems of physical plants and safety, expansion of education resources)?

  - What are the threats (loss of local control, social isolation of some populations)?.

  - How can the problems of social equity in access to communications networks be defined and addressed? Cities can address this question to some extent by offering public access sites, and by providing young students and their teachers adequate training in the use of computers and networks.

  - How can advanced information technology improve the ways data are organized and presented, making information easier for the public to filter and use?

2. Research plan. NSF, under the auspices of its Urban Interactions working group (mentioned earlier), should hold a multidisciplinary planning meeting to identify specific research issues bearing on the impacts of information technology on the forms and functions of urban infrastructure (telecommunications, transportation, energy, and other public and private services, including ecological services). Interested outside organizations (including all levels of government, foreign and international research organizations, and business) should be invited to participate. The results of the initial planning meetings on Modeling Urban Systems should be included in the meeting's agenda. The meeting should prepare a list of research areas that show promise of significant advances in knowledge of urban interactions.

The Urban Interactions working group should convene a second, larger meeting to expand and elaborate on the research areas identified in the first meeting, and to discuss organizational structures to support multidisciplinary activities in these areas over the long term, with appropriate links to urban research programs elsewhere in the world.

NSF should issue a program announcement in Information Technology and Urban Infrastructure, built on the list of research areas identified at the second meeting. Among the criteria for awards should be (a) multidisciplinary systems-level approaches, (b) fundamental contributions to one or more disciplines, and (c) implications for public policy.

3. Data needs. Data on information flows, comparable in scope and detail to the data available on movements of persons and goods, are needed. To what extent is telecommunications being substituted for travel? How are the temporal and spatial patterns of use of information changing in response to new technology, such as mobile communications? How is access to information changing?

Detailed longitudinal data sets on social and environmental indicators are also vital, especially at small scales (such as that of the census tract and the neighborhood cluster). Census data are a central tool of social scientists, admirably disaggregated and consistently gathered over the decades. It would be valuable to have parallel longitudinal data sets on other social and ecological indicators related to income, education, crime, and environmental conditions, that are spatially disaggregated at the same scale. Data have been collected carefully and consistently on a wide variety of such indicators, but, because the data are aggregated differently, it is impossible to make longitudinal correlations with census data at the same small scale. In many cases it should be possible to reaggregate such data in useable form.

4. Research funding sources. NSF supports research in these areas under the crosscutting programs of Educating for the Future and Knowledge and Distributed Intelligence. The Computer and Information Science and Engineering (CISE) Directorate supports research in the technical and social implications of communications networks through programs in Information Technology and Organization; Interactive Systems; Networking Research; Communications Research; and Special Projects in Networking and Communications. The Social, Behavioral, and Economic Sciences (SBE) Directorate has relevant programs in Geography and Regional Science; Social Psychology; Decision, Risk, and Management Science; Economics; Societal Dimensions of Engineering, Science, and Technology; Law and Social Science; Political Science; and Sociology.

NSF's Division of International Programs (in the Social, Behavioral, and Economic Sciences Directorate) is charged with supporting international research activities, linking U.S. and foreign scientists and engineers. The three research councils in the United Kingdom are currently funding a range of complementary urban programs, including "Sustainable Cities," "Cities, Competitiveness and Cohesion," and the "Virtual Society"; all of them could involve international comparative research. Similar research programs are supported by France and the Netherlands, as well as the European Union, the Organization for Economic Cooperation and Development, and the World Bank.

Public-private partnerships with telecommunications, energy, and transportation firms, among others, can also be developed to support these initiatives. Several of the NSF-sponsored Engineering Research Centers, Industry/University Cooperative Research Centers, and State/Industry University Cooperative Research Centers are engaged in research relevant to these concerns.

5. Related educational initiatives. Research in this area could lead to K-12 educational programs, inside and outside of schools, that are better focused on the needs of urban populations. These programs could make full use of interactive media to widen students' access to information and expertise. They could be designed to correct for distributional and other problems raised by network-based education. The development and testing of such programs could be supported by NSF's Directorate for Education and Human Resources (EHR). That Directorate's Division of Elementary, Secondary, and Informal Education (ESIE) funds projects in "informal science education," in addition to teacher training and development of instructional materials for schools. Informal education takes place out side of schools, such as in community centers and museums. It is intended to use various media, including interactive networks. It stresses collaboration with outside organizations, and outreach to population groups traditionally underrepresented in science, mathematics, and engineering, such as racial and ethnic minorities, women, and inner city youth. The Division offers "supplements" to existing research grants (from any NSF directorate) that make possible activities that disseminate research results more widely or promote scientific literacy.

NSF's Urban Systemic Initiative, a grant program for urban educational innovations, would be available to support and evaluate such programs. Comprehensive Partnerships for Mathematics and Science Achievement (capacity-building grants to school systems not eligible for Urban Systemic Initiative, in partnership with institutions of higher education, business, professional organizations, and community-based organizations) are supported by the EHR Directorate's Human Resources Development (HRD) Division.

6. Graduate training requirements. This research area will require graduate training in the entire range of social and behavioral sciences, as well as economics, urban planning, civil engineering, and information management (including geographical database development).

C. Adapting to Change: Toward Sustainable Urban Systems

Whether—and if so, how—urban areas can be developed sustainably (to "meet the needs of the present without compromising the ability of future generations to meet their own needs," in the words of the 1987 Brundtland Commission on Environment and Development) is perhaps the most basic and most challenging question urban research can confront. Urban land use, infrastructure, environmental protection, and economic development programs hinge on complex decision criteria with strong political components. Many of the public and private decisions made in urban areas lack a sound basis for estimating costs and benefits. In addition, many urban areas are metropolitan patchworks of smaller jurisdictions, which find cooperation difficult and so tend to pursue solutions that are less than optimal in the long run and on the larger scale. Every urban area, even the youngest, contains relics of such decisions, reflecting economic and policy incentives that no longer apply or that cannot be sustained in the long run. Older cities, built to take advantage of river transportation or water power, or the proximity of industrial resources, may show this pattern most starkly, with

large areas of derelict real estate. Urban redevelopment or adaptive reuse of urban core areas is often possible, but it is often costly and requires substantial subsidies, and runs the risk of becoming quickly obsolete in turn. Similarly, urban land use patterns of recent decades that disrupt natural watersheds and other ecological services are likely to have large unforeseen costs in the long run. But there is no agreement on how to evaluate these long-term costs and give them a place in urban decisions.

Clearly, urban infrastructure can be designed to for better adaptation to change, on time scales ranging from responding to natural disasters to gracefully accommodating obsolescence, and on spatial scales from the neighborhood to the metropolis and beyond. Advances in the techniques of infrastructure valuation, made possible by improved tools of simulation and modeling, can help place decisions on a more rational foundation by allowing decision makers and citizens to test options more thoroughly and more publicly than before. These tools need to be further developed and made available more conveniently to decision makers and the public.

More broadly, however, systems-level models of urban decisions and their long-range implications are not available today. Building such models will require a multidisciplinary fundamental research program to define the conditions of urban sustainability. In carrying out this program, engineers, social scientists, and ecologists will gain new access to findings and insights from outside their disciplinary boundaries. Sharing their knowledge will let them describe in more detail the mutual interactions of human activities with ecological systems and of physical infrastructure with social and political structures. These more comprehensive and multidisciplinary models will give us a measure of predictive power in testing a richer variety of alternatives, at all spatial and temporal scales.

1. Research agendas: It is necessary to bridge the gaps between social sciences and the ecological and engineering communities in defining the ways urban research issues are addressed. In supporting studies of urban sustainability, NSF should address the following four research agendas:

- *How can we define viability and sustainability of urban areas, at scales ranging from the metropolitan to the community or neighborhood?* What are the relationships of viability and sustainability at those three scales? What are reasonable indicators of viability and sustainability? How do human activities interact with the physical, social and natural environments over the long term?

  - Questions of scale arise in considering how local activities and decisions, at the neighborhood or individual level, affect the viability of the entire urban area (and vice versa). For example, can poor, heavily subsidized communities that provide high quality of life endure and replicate themselves? To what extent does spatial segregation by activity, class, and race bear on productivity and other measures of sustainability?

  - At a larger scale, how do changes in world markets and demographic patterns affect the viability of urban areas throughout the world?

  - How can financial flows among jurisdictions within urban areas be measured and predicted most effectively? Many of the costs of urban activities are unaccounted for, because they cross political boundaries. For example, local efforts to entice employers through tax credits and other subsidies lead to serious inefficiencies if they merely attract employers from one jurisdiction to a neighboring one. These costs commonly exceed the budgetary costs of the subsidies, but do not appear on any public account. Tools for their estimation would have great value.

  - What are the appropriate valuation techniques for ecological services in urban infrastructure decisions? Can concepts of environmental quality and other urban resources be broadened to take in the views of all populations in cities? Stewardship of these resources would be easier if consensus could be achieved on what it is that must be preserved.

- *What is required to produce resilient and adaptable social and physical infrastructure in cities, able to withstand change, hazards, and disruption?* Building and maintaining social and physical infrastructure is a major challenge to local government and a major cost to citizens. Integrating public and private infrastructure programs with trends in social, environmental, and economic indicators would make possible more robust urban systems, better tailored to needs and more adaptable to change. Systems-level models will soon have the scope and predictive power to permit comparison of the costs and benefits of alternatives in great detail, and over a wide range of decision variables.

  - How can change and stress, ranging from extreme events to deterioration and obsolescence, be accommodated by urban infrastructure?

  - How can interactions at different spatial and temporal scales be treated in an integrated fashion? The viability of urban areas is shaped by interactions with both global developments (such as world market trends) and highly localized change (at the scale of the neighborhood or block). Similarly, these interactions can be measured over both the short

term and long term. To what extent can these patterns be placed in the same frame of reference in urban studies?

- *What factors—technological, infrastructural, institutional, educational, social, behavioral, and informational—determine the political participation of urban citizens?* One aspect of sustainability for an urban area is commitment by citizen to its future, a primary indicator of social capital. Political participation at all levels—in the affairs of neighborhood associations, school boards and city councils, and national decision making bodies—is said to be declining. It has been suggested that information technology can help encourage and enable civic participation by citizens. It could facilitate public consensus, for example, by allowing public simulations of local and regional decisions, on the model of SimCity™. (The *Washington Post*, with that purpose, recently made available SimCity modules representing the planning problems of the Washington, D.C., area.) In practice there are many uncertainties, about access to the technology and the skills and motivation to use it. The developers and distributors of the technology will need to think about the selection and presentation of information. They will also need to think deeply about the political and other purposes for which people use information technology. Individual and group contexts and values must be identified and addressed to provide technology that serves a productive social purpose.

  - How do urban citizens see their futures and their links to political and administrative leadership structures? How do their patterns of political participation differ from those in nonurban areas?

  - What incentives best motivate participation? (Candidate incentives should be tested through formative and summative evaluation.)

  - What organizational structures best support the goal of participation?

  - What aspects of modern information technology help and hurt political participation? Citizens, in principle, will be more able to inform themselves about their local governments and about decision alternatives, and better able to form pressure groups to influence decisions. On the other hand, the rise of "virtual" (network-based) communities could decrease individuals' willingness to assume stewardship of their physical neighborhoods. Information technology could also accelerate the decline in urban populations, by making possible telecommuting and other shifts in the locations of homes and workplaces. Lack of access to information technology could degrade their economic and educational prospects of the poor. How can universal access by all segments of the population be defined, and how can it be achieved? What kinds of information technology is appropriate for producing, presenting, and integrating data?

- *What are the characteristics of life and institutions in extreme social environments?* Social scientists have many questions about the extreme social conditions of some urban communities (in which inadequate social capital and educational, and political institutions and poor are accompanied by a degraded physical environment). The determinants of social stability are poorly characterized at the neighborhood level. Better studies of these relationships would go to the heart of one of society's most important problems. Far more detailed measurements of social capital and its links with physical infrastructure and political, economic, and ecological factors are needed at neighborhood scale.

  - How can destructive environments be defined and identified through the interactions of social capital, physical infrastructure, and political, economic, and ecological conditions?

  - Is the analogy of disaster useful? (Can social early warning systems be imagined?)

2. Research plan. NSF, through the Urban Interactions working group, should convene a multidisciplinary planning meeting (including social and behavioral scientists, economists, ecologists, urban planners, and geographers) to identify specific research issues bearing on the sustainability of urban communities. Interested outside organizations (including all levels of government, private nonprofit and for-profit corporations, and foreign and international research organizations) should be invited to participate. The results of the initial planning meetings on Modeling Urban Systems should be included in the meeting's agenda. The meeting should prepare a list of research areas that promise significant advances in knowledge of how urban areas adapt to change and how the decision processes underlying urban investments can be improved.

The working group should hold a second, larger, planning meeting to expand on the list of research areas produced by the first meeting. It should also outline an organizational structure to support a continuing effort over the long term, including international activities as appropriate.

NSF should issue a program announcement in Sustainable Urban Communities. Criteria for awards should include (a) multidisciplinary systems-level approaches, (b) fundamental contributions to one or more disciplines, and (c) implications for public policy.

3. Data needs. Spatially precise longitudinal data on a variety of social, economic, and ecological indicators, with data formats compatible with Census Bureau census tracts. In addition, data are needed on public and private decision processes used in planning land use, economic development, and infrastructure investments. Data on costs of public and private infrastructure are needed, as the basis of system-level financial models of land use and economic development policy.

4. Funding sources. Research in social decision making is supported by various NSF programs. A program called Societal Dimensions of Engineering, Science, and Technology; in the Directorate of Social, Behavioral, and Economic Sciences, funds research on science and technology management. The Joint NSF/Private Sector Research Opportunities Initiative, in the same directorate, funds research that is grounded in theory, but has an operational component in the private sector (with private sector cost-sharing); the focus is on managerial studies and decision making. The NSF crosscutting research initiative Life in Earth's Environment also provides broad scope for urban research with an environmental theme.

The Division of Environmental Biology (DEB) in the NSF Directorate for Biological Sciences (BIO) supports studies in ecology and population biology that would bear on the question of urban sustainability. The research area of Long-Term Projects in Environmental Biology includes urban Long-Term Ecological Research (LTER) sites (2 new urban sites to be added to the existing the 18 LTER sites established to date), whose longitudinal emphasis is consistent with concerns for sustainability.

The EPA/NSF Partnership for Environmental Research includes competitions in Technology for a Sustainable Environment and Water and Watersheds, both of which would be suitable for aspects of this research area.

International comparisons should be sought wherever possible. NSF's Division of International Programs funds international research activities, bringing together U.S. scientists and engineers with their colleagues overseas. The UK programs "Sustainable Cities," "Cities, Competitiveness and Cohesion," and the "Virtual Society" could offer opportunities for international comparative research, as could programs in other European countries and in the European Union, the Organization for Economic Cooperation and Development, and the World Bank.

Public-private partnerships, such as the various NSF-sponsored research centers, would be likely to support aspects of this research based on valuation of long-term investments.

5. Related educational initiatives. The ecological and infrastructure problems of urban areas have great potential as the basis of hands-on education at all levels. For grades K–12 new discoveries about these problems could be the basis of challenging and exciting integrated science and mathematics curricula that involve students in the latest research results and technology such as GIS, and apply them to tangible local problems. The popularity of entertainment/education software such as SimCity suggests that students could be motivated to learn by thus blending experiences of the real world, including scientific and technical career opportunities. These initiatives would promote public understanding of the systemic nature of urban issues and lead to coherent approaches to solving them. Local and state government, corporations, and nonprofit institutions could be involved in developing and funding these curricula, as contributions to community improvement.

NSF supports development of such educational innovations through the Education and Human Resources (EHR) Directorate, Elementary, Secondary, and Informal Education (ESIE) Division. These programs include the Statewide Systemic Initiatives; Urban Systemic Initiatives (focused on cities with the highest rates of children in poverty); Instructional Materials Development; Informal Science Education; and Advanced Technological Education (for technicians)

At the undergraduate level, the EHR Directorate, Division of Undergraduate Education (DUE), offers funding for Course and Curriculum Development Projects (emphasizing introductory courses) and Institution-Wide Reform of Undergraduate Education in Science, Mathematics, Engineering and Technology. The CISE Directorate, Office of Cross-Disciplinary Activities (CDA) offers cost-shared grants for Educational Innovations, Research Infrastructure, and Instrumentation that would be appropriate for educational initiatives building on this research area.

6. Graduate training requirements. Graduate training will be needed in political science, regional economics, information theory, ecology, urban planning, geographical database development, and other fields.

III. EXISTING NSF INITIATIVES IN URBAN RESEARCH AND EDUCATION

The NSF, through its Urban Communities Education and Research Initiative, has carried out a number of efforts across its directorates that bear on the understanding of urban areas.

Three of NSF's "integrative themes" are especially pertinent to urban research:

Educating for the Future. Urban schools are central civic institutions, with well-documented needs. An urban research initiative would offer new knowledge about schools and their links with other urban institutions. In addition, it could serve as a resource for new environmental education curricula, which would give K–12 students opportunities to learn science and mathematics in the context of tangible community problems. The application to community development would provide substantial motivation for learning. The focus on problems of infrastructure and ecological degradation would prepare students for productive careers.

1. *Knowledge and Distributed Intelligence*. The goal of the KDI initiative is to achieve, across the scientific community, the next generation of human capability to generate, gather, and represent more complex (including cross-disciplinary) scientific data and information; to transform this information into knowledge by combining, classifying, and analyzing it in new ways; to deepen understanding of the ethical, legal, and social implications of new types of interactively; and to collaborate in groups and organizations, sharing knowledge and working together interactively across time, space, disciplines, and scientific cultures.
2. *Life and Earth's Environment*. Among the elements of multidisciplinary theme of Life and Earth's Environment are Urban Communities (including human interactions with the environment) and Life in Extreme Environments. Both offer scope for research in urban problems. Two new urban sites for the Long Term Environmental Research program were funded in fiscal 1998. Fiscal 1999 themes will include the diversity of life (including urban and industrial environments); interactions across multiple scales ; and stability and change (scaling of short-term and longer term phenomena).

Three planning activities were authorized in fiscal year 1997:

1. *Urban Approaches Grantees' Workshop*. This workshop, held July 29-30, 1997, brought together 28 grantees from a range of disciplines to (1) identify problems they have encountered in developing systematic approaches to urban education, infrastructure, ecological monitoring, and social behavior and (2) identify important areas of basic research, including methodological development, that are not being addressed by NSF's existing integrated research areas or program activities.
2. *Urban Approaches Open Forum*. This event, to be held in late 1997, will focus on current and planned approaches to urban system management, opportunities for new connections and now uses of existing data resources, and research needs. The object will be a long-term Urban Communities vision for the 21st century. It will bring together representatives of local, state, and federal government; public and private infrastructure owners and operators; professional organizations, and political and community leaders.
3. *Urban Approaches Long Term Ecological Research*. Two urban sites will be added to the existing NSF network of 18 Long Term Ecological Research sites. The object is to broaden the network with sites that shed light on human interactions with the environment.

IV. REDEFINING THE CITY FOR THE INFORMATION AGE

The information-based urban area of the future will have much in common with the city of past, including much of its physical infrastructure and many local cultural and environmental assets. Each city, however, will draw on the entire world for many of its defining characteristics: economic links, cultural resources, and (increasingly) community ties. Each must find its role in the global information economy, at the same time as it tends to its strictly local infrastructure. Citizens and officials will need to define the city in terms of both concrete local facts and amorphous information flows that have no place. In this global information environment, they may ask themselves what makes their city special, worth participating in. Social scientists, ecologists, and engineers, in measuring and describing the city of the information age, will help answer that question. For citizens, this research would lead to better policy tools, though which government services such as education, environmental protection, public infrastructure, and law enforcement could be provided more effectively and consistently. It would offer new avenues of political participation. The private sector would also benefit from the resulting finer grained picture of urban economic and social structures and environmental patterns. To the extent that the urban economy functions as a principal engine of technological change, such research could lead to a more efficient and equitable overall economy. By permitting more efficient allocation of scarce resources over the long term, the fruits of this research would lead to safer neighborhoods, cleaner cities, more effective tax regimes, and stronger local—and even national—economies.