Global Transition Dynamics:

Unfolding the Full Social Implications of National Decision Pathways

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Abstract

This white paper proposes a new holistic approach to analysis of the national and global development that builds on advances in the mathematics of complexity, methods of probabilistic risk assessment, and techniques for fast computation and interactive simulation. Integrated into a composite analysis technique, these advances raise an unprecedented new possibility for projecting the future implications—social, economic, environmental, human health, political, and technical—of major societal development activities and technology programs for nations individually and the world as a whole. Taken together, they promise both a real-time outlook and a future perspective on the spectrum of outcomes that might result from alternative national decision pathways. Such projection capability could reveal the development options, results, and implications for any strategy for any type of nation, whether primitive, underdeveloped, developing, or industrial. Forcing functions, critical junctures, and pinch points could be identified so that scarce development resources can be allocated to maximize benefit and minimize unintended consequences. The full realization of this next step in analysis technology will require several years of dedicated international effort, but the need is urgent and the potential payoff great. The technical—and organizational—underpinnings for such a holistic analysis approach have been demonstrated. It remains for us to build from them a global tool for a better future.

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Introduction

Science and technology help enhance the quality of human life. During the past ten millennia, fundamental understandings gained through scientific discovery and enabled by innovation have provided us the tools to ascend from savagery to civilization. The 20th Century in particular marked a period of technology triumphs. Electrification, telecommunications and the Internet, fast and efficient transportation, modern medicine, scientific agriculture, and other advances changed the conditions of human life all around the globe. In developed nations, the average human life span nearly doubled in the past century. Many fold greater are the new opportunities afforded by technology to each individual during his or her longer life. It is clear that technology is a major driving force in shaping global society.

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Yet since the Second World War the benefits of technology have come into question. Developed nations now spend heavily to redress imbalance between the environment and past development activities. At the same time the effectiveness of substantial technology development investments in developing countries generally has been disappointing. For many of us directly or indirectly involved, it seems that resources have been dissipated on well-meaning attempts to ameliorate symptoms, rather than towards addressing the underlying structures that create the problems. Planners and decision-makers have a pressing need for "first-order" insights in the dynamics of large-scale transitions associated with development and social programs. With these insights, they could constructively address basic causative issues rather than immediate symptoms. A grand vision of projecting the future is needed, a vision that goes beyond specific scenarios and single fields of interest to encompass the development of societies and the world as a whole with social, environmental, economic, human health, political, and technical aspects all taken together.

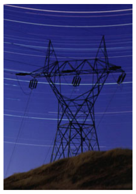
To meet this need for a decision-making guide, we propose the development of an international analytic program on the global transition dynamics affecting the development of nations. Recent advances in mathematics, risk assessment, and computing introduce the very real possibility of integrated analysis of diverse societal considerations to project their future impacts with useful accuracy *(Figure 1).*

Recognizing that projecting the future a half-century or so is a probabilistic venture, such a program could disclose the likely social interactions and real-time consequences of resource allocation choices among major policy options.

The goal of this endeavor is to gain real insight into what may well be the "grand challenge" for the 21st Century: investing the wealth of nations in development programs that benefit society as a whole, rather than in the piecemeal efforts or ineffective symptom-based approaches of the past. The tension between the "haves" and "have-nots" of nations and the world has reached high levels and is driving militant activity; everyone would benefit from successful development in the underdeveloped nations of the world. In addition, most environmental problems appear to be connected to various degrees of poverty, and economic growth depends on social development. Economic factors obviously play significant roles in development, as do government policies; the structures of social, political, and economic institutions; and the interactions of these institutions with indigenous cultures. To thus address all these areas in the context of the whole, the proposed program would explicitly recognize the complex dynamic interactions between the constant growth in science and technology on the one hand and,

Figure 1. What Makes it Possible. Recent advances introduce the possibility of integrated analysis of diverse societal considerations and factors to project their impacts over coming decades with reasonable accuracy. Key are new understanding of the science and mathematics of complexity combined with developments in probabilistic risk assessment and fast computing.

on the other, society, politics, economics, the environment, human health, and indeed all aspects of our existence *(Figure 2).*



Technology: The Hinge

The time is ripe for an integrated planning approach to guide national and global technological development. History suggests that developments in fundamental technology are the principal force affecting most social trends, driving, in recent centuries at least, the major shifts to new life-styles and economic patterns. For example, new energy sources create new sources of political and personal power. Faster transportation and communications hasten social commerce as well as economic commerce. Improved public health leads to new ways of living that reflect longer, healthier lives—or ways that exploit the new ability of medicine to mitigate unhealthy choices. Looking at the changes over the past century alone, the history of technology reveals its seminal influence on fundamental social changes worldwide. An empirical observation is that science and technology are manmade resources that grow faster than the adaptation of social structures that respond to the new conditions. That is, technologies lead and social change follows.

For example, the electric power grid in the United States has evolved over the past 100 years until it now underlies every aspect of American economy and society. Such aspects as "24/7" lifestyles, Internet dating, and microwave popcorn obviously can be linked to national electrification, but so can reductions in crime, the rise of feminism, and improved eating habits in general. Consider ethnic restaurants, where electric communications and electric refrigeration have globalized diets and exotic produce alike. Indeed, anyone born before 1950 or born in a developing country can attest to the critical importance of electricity as an enabling force that powers progress and transforms societies. The effects of electrification are so pervasive that in 2001 the North American electricity grid was hailed by the National Academy of Engineering as the 20th Century's engineering innovation most beneficial to civilization.

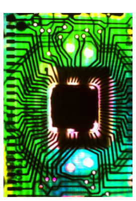
In less-developed regions, the power of technology is likewise great. Even simple technologies can broadly impact societies as the new possibilities they offer ripple across long-established cultures and practices. New spinning wheel technology in medieval Europe, for

Figure 2. Globally Interlocked Dynamics. To unfold the full potential of social progress requires an integrated understanding of the many dimensions of social development, their underpinnings, and the role of science and technology. As suggested by an Asian-style fan, the areas of economics, environment, health, politics, and society can be thought of as blades that hinge upon social development and, ultimately, science and technology. Because all blades of the fan move together, the dynamic couplings, interlocking mechanisms, and crossover points must be treated in an integrated and holistic manner. To concentrate investment on a single blade results in little progress for the whole.

example, gave a single woman acceptable means to support herself independent of marriage, with lasting societal consequences. Likewise, the recent introduction of a rugged "industrial Cuisinart" machine has had profound consequences for life in the small village of Sanankoroni, Mali, as described in the *Wall Street Journal* of July 26, 2002. The diesel device, dubbed the "multifunctional platform" by the United Nations, can be configured to grind grain, husk rice, saw wood, pump water, and charge batteries. With these capabilities, the machine dramatically eases the rigors of daily life in Sanankoroni: a job grinding corn that used to take a worker three days now can be accomplished in 15 minutes, for instance, and the quality of the cornmeal is better. However the biggest impact, as reported by the *Journal,* is social: empowering women. Female literacy is on the rise in Sanankoroni. Before the machine arrived, only 9 women in the village could read and write; after a year more than 40 had attended literacy courses—in part to exploit time freed from hard labor and in part to help keep accounts of the machine's operation, earnings, and worker salaries. Entrepreneurship also was unleashed: the women's committee that runs the machine is looking into recycling earnings to launch other businesses, such as clothes dyeing and soap making. In another Mali village, women raised money to connect a generator to their machine and provide lighting. At the same time, fundamental cultural change arrived with the machine. Sanankoroni men report better family meals because the women are less tired and busy, but some find it trying to work for the newly empowered women. By and large, though, the inhabitants of Sanankoroni are much pleased with the progress afforded by this simple example of technology.

The changes new technologies bring to society are deep in time as well as broad in scope. Fortuitous technology choices have lasting consequences, as shown by the history of electrification in America, and illustrated by the introduction of the multi-functional machines to Mali. A recent example of the pervasiveness of a planning choice is the Washington, D.C., Metro mass transit system installed in the last two decades. This public transportation system is changing the demographics of the city and suburbs, influencing the location of government facilities, shifting housing economics as well as schools, traffic patterns, racial enclaves, and political accommodations with neighboring communities. An established example of a fully utilized public transportation is found in the city of Zurich, Switzerland, where planning choices made long ago make it possible for Zurichers today to enjoy urban living without an automobile.

Many technology successes are obvious, but it's equally obvious that not everything technology is rosy. The results of technology development are not unmixed in the past centuries. As we enter this new millennium, nations around the globe stare at a variety of unwanted and unanticipated side effects from technology programs. In the developed nations, prosperity is threatened by crumbling and overburdened infrastructures, environmental pollution, and increasingly aged demographics and unhealthy personal lifestyles. In developing nations, the very foundations of civil society are shaken by population dislocations and social upheaval driven by uneven distribution of technology benefits, while at the same time these nations labor under massive debt incurred to pay for technology development in the first place. More and more countries are collapsing into political, economic, and social chaos.



Harnessing the Power of Technology

Whatever the scorecard, technology development and its impact on individuals, nations, and global society are not going away. If anything, technology decisions that might have been left to chance 100 years ago—the "automobile-ization" of a society, say, or regional electrification—are being directed more and more by governments and supra-governmental organizations because they alone can bear the increasingly high costs of public infrastructure investments. Far-reaching choices about the distribution of monetary and human resources continue to be undertaken by political leaders and other decision-makers throughout the world. The choices are usually based on personal intuition in anticipation of vaguely perceived future benefits.

These decision-making operations in every country are implemented by assigning existing resources and future commitments to achieve a priority goal set by those responsible. Leaders must weigh the likely outcomes of each decision option—so far as outcomes can be projected—as each relates to the competing social objectives of the diverse public groups they represent. Modern technology decisions in particular involve a high level of leadership and the creation of a public consensus to provide a political support for action, because of the high cost and large impact of technology programs. The complex real-world interactions among the multiple social systems over time is so far beyond the ability of the human mind to fully comprehend that decision processes and consensus-building tend to focus on one or a few obvious existing trends—number of deaths that might be avoided, jobs that may be created, time saved, income generated, people fed. The realm of unintended or unforeseen outcomes is hidden in the shadows of a future history, but these are usually assumed to be manageable somehow. Else we might do nothing at all.

But there is always something that must be done, and leaders throughout history turned to a variety of aids to help them make their resource allocation decisions. In lieu of other tools, diplomatic and political techniques have been employed for millennia. Traditionally, groups or nations would barter whatever they had for whatever they could get, with little or no attempt to guide development along productive pathways. In last century many new considerations and tools have been applied in a search for better methods of applying the wealth of the world to social development. Modern economics, for example, became prominent in decision-making during the Second World War. The growing availability of computers in the 1950s and 1960s added powerful simulation and operational research methods to the mix of decision-making tools, and computer-based techniques have grown more sophisticated since. A typical computer modeling approach of today incorporates deterministic, scenario-based simulations with feedback models to account for diverse possibilities and impacts.

But it's not good enough. As noted earlier, the performance of recent technology development investments has disappointed. Too many investments failed to deliver on their promise, or else unintended consequences counterbalanced positive outcomes. In an example one of the authors is personally familiar with, Taiwanese leaders in the 1970s planned development of a large industrial infrastructure in the underdeveloped south of their island to exploit available energy resources and spur regional economic growth. Massive development followed in a region where strict environmental controls previously had not been necessary. The project achieved its immediate aims, but also produced widespread environmental impacts that required remedy. Narrowly and in the short-term, it was an economic success; broadly and long-term, the costs are still being assessed.

The lessons of history show that the wisdom of national decisions would be greatly enhanced by insight into the multiple-parameter real-time interactions and their trends that are inherent in society. Such holistic insights also would allow subsequent modifications to be dictated by the ongoing flow of outcomes, much as the driver of a car responds to traffic conditions. Driving is made routine by the ability of the driver to see ahead and the quick response of the vehicle to direction from the steering wheel and brakes. Thus the driver responds to a visible need for adjustment quickly enough to avoid a hazard. Such a simple operation requires a real-time signal to the driver, a mental judgement of speed and distance, and a quick steering or braking response. These key dynamics—real-time signal, analysis, and quick response—highlight a management system that makes acceptable the risk of a decision by enabling reasonably accurate anticipation of results before a choice is made and timely corrective action as necessary after.

Unfortunately in our very complex and interlinked societies achieving such idealized decision management systems for technology development and other resource assessment problems rarely is feasible. Professional experts and sophisticated computer models offer advice in narrow compartmentalized fields. It is left to the decision-makers themselves to somehow connect this apples-and-oranges advice into a complete whole. Until very recently, compartmentalized decision-support analysis was all that could be provided. However, in today’s new world of information-technologies and instant communication, such a holistic management system might be constructively approximated. The authors believe it now is possible to provide decision-makers with a reasonable projection of alternative development pathways extending from real time out to several decades ahead. This would permit a benefit/cost/risk judgment at each step on the time line, providing also the ability to take course corrections as needed.

What are the tools that modern information technology offers? The relatively instantaneous flow of information worldwide provides the rapid observation of real-time events and timely identification of trends. Access to the data collection in computer memories provides the basic information resources. Most importantly, modern computer hardware permits displays of such information compendia in a great variety of ways. Further, modern computer software permits the fast simulation of time-dependent trends, both to replicate the past and to extrapolate into the future. **The latest development, and key to the authors’ concept, is the new understanding of the mathematics of complexity, combined with modern computer simulation techniques, to provide a simultaneous adjustment of the boundary conditions of the software algorithms used to display each major phase of an operating society -- technology, health, environment, economics, politics, etc.**

Let's explain this last point. In a functional society, any change in one of its system parameters—say, automobile fuel efficiency—will affect the trends among the mix within its sector, in this case transportation alternatives *(Figure 3).* In order to project the future behavior of that sector based on changes in the selected parameter(s), a computer algorithm usually holds the sector boundary conditions fixed (i.e., its points of contact with other sectors, which for the case of transportation might include driving habits, international trade patterns for autos and fuel, amount of roadways, environmental pressures, and so on). Otherwise the algorithm would need to expand greatly to internalize the externality affects (such as changes in manufacturing jobs and trade

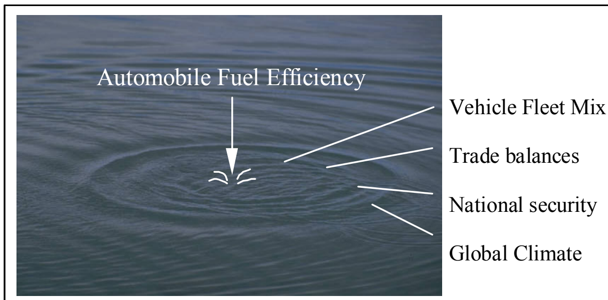


Figure 3. Internalizing the Externalities. Like a ripple in a pond, a change in one parameter in a given sector of society, say automobile fuel efficiency in the transportation sector, creates impacts that spread to other sectors, e.g., a shift in jobs and adjusted political relations with fuel-exporting nations. To project the full future impact of any single change, the external cross-sector impacts must be accounted for as well as the internal impacts within a sector. Until recently, such analysis was not practicable, and boundary conditions between sectors would be kept fixed in analysis. Advances in mathematics and computing, however, make comprehensive, all-encompassing analysis feasible, to the point of projecting the global impact of changes in multiple sectors at once.

balances, shifts in political relations with fuel-exporting nations, ramifications in fuel tax revenue, adjustments in environmental benefits and costs, etc). Fixed boundary constraints are adequate for the short-term, narrow-scope projections typically needed by automobile industry planners and investors, for instance, but they are not very helpful for assessing long-term impacts or for looking at impacts across society as a whole.

The impacts of technology development activities are both broad and long-term, whether they are planned for or not. For example, we saw during the past century how the development of automobile technology eventually changed the physical and even the social structure of society. Thus to be reasonably accurate, a long-term projection requires a constant adjustment of the boundary conditions of all other sector algorithms—economics, politics, environment, human health, demography, and so on. Moreover, such shifting social dynamics produces feedback modifications to the sector algorithm itself, e.g., automobile transportation was itself readjusted to a changed social structure and demography. The proposed program is not aimed only at huge, infrequent development decisions. It is important to apply the results of analysis as much as possible to smaller, everyday planning choices as well as the large choices that may be considered far in advance. On a time line to the future, daily decisions will determine the eventual outcomes.

How it Would Work

Means to handle the concurrent simulation of a suite of complex systems are available and were demonstrated by one of the authors in a recent EPRI/U.S. Department of Defense research program, called the Complex Interactive Networks/Systems Initiative (CIN/SI). This multi-year initiative demonstrated the scientific basis, technical capabilities, and operational procedures required for the large-scale holistic simulation program proposed here.

Scientific Basis: Complex Systems. Necessary scientific capabilities are provided by fundamental new understanding of the mathematics underpinning complex systems. This new understanding, in part developed through the CIN/SI, makes it feasible to create a reasonable computerized composite of multiple interacting simulations—for economics, environment, energy supply, agriculture, population growth, and others—that can project the probable pathways flowing from each optional choice in each simulation. These projections make use of a probabilistic risk assessment approach, which considers an aggregate of all possible scenarios (based on their individual likelihood) to develop a single composite timeline (or a small number of timelines, if necessary to highlight options at critical transition points). This approach advances significantly over today's conventional deterministic scenario-based techniques that examine one future timeline proceeding out from one individual scenario (the representative selection of which thus is critical). The probabilistic approach produces a robust, informative vision of possibilities because it encompasses all knowledge simultaneously and can illuminate hidden processes.

What do we accomplish by our effort to project the future? The specific objective of this broad-spectrum analysis proposed here is to display information about the real-time interaction of science and technology with the subsystems of health, security, economics, environment, politics, and social structure, among the varieties of the world's countries. Analysis can be structured so that the revealed information is "value free," with an emphasis on disclosing the "forcing functions" and critical "pinch points" among these interconnected subsystems that may determine the quality-of-life growth in coming decades. **The aim is to highlight the critical junctures and driving forces along the future development pathway, and to mentor the navigators of each country through the "transition dynamics" that will be part of such growth, fully recognizing the political, financial, and cultural trends that shape the framework *(Figure 4).***

Such an interactive program would be pioneering in its scope and functional purpose. Real-time interactions among all the areas would be performed by an integrated computerized simulation technique developed for such a purpose; analyses for primitive, underdeveloped, developing, and industrial countries would be covered separately to address the specific needs and issues of each type *(see pages 8-9)*. The overall result would be an illumination of the real-time transition dynamics relevant to each country as it goes through its development. The various options could be considered in order to identify and evaluate the potential impacts of each. The operational challenge is to overlay the subsystem structures to show a coordinated pathway for effective implementation of available technologies appropriate for each country. Also important to consider at this point would be the governmental or institutional requirements necessary at each level of development and for each proposed development activity, to ensure effective implementation.

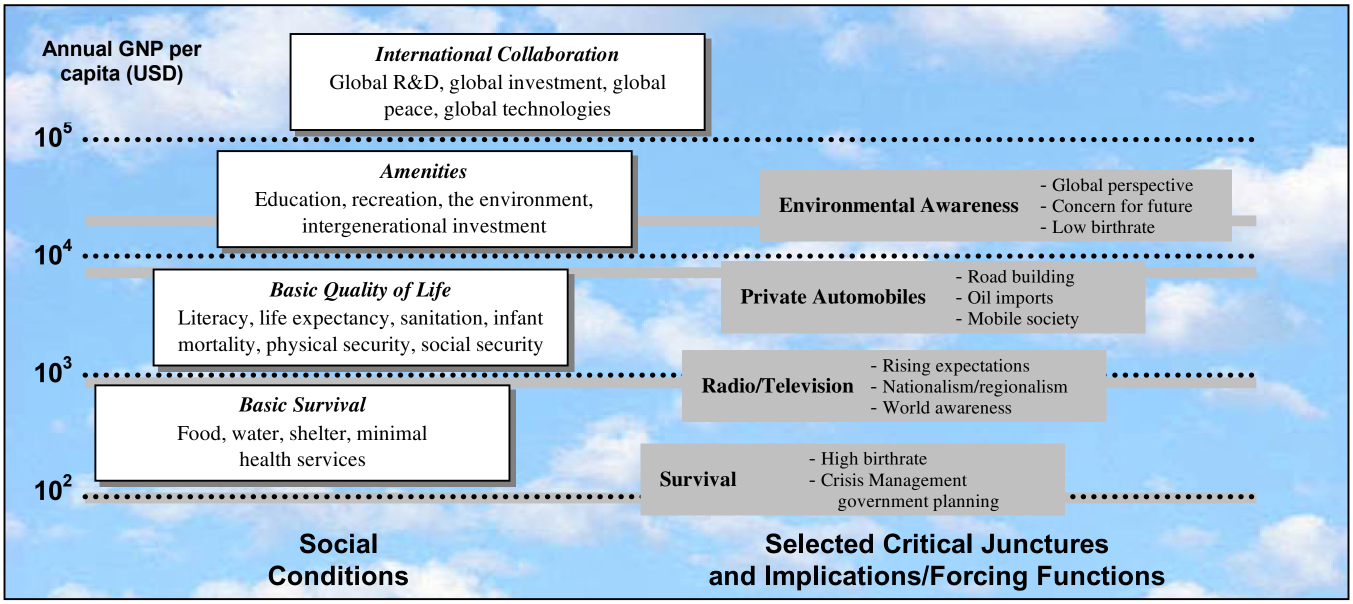


Figure 4. Critical Junctures in Technology Development. The objective of projecting future development pathways is to shed light on the critical junctures, forcing functions, and pinch points that may determine quality of life in nations as they develop, i.e., the "global transition dynamics" of technology development. This figure shows a few critical junctures and forcing functions that intuition and limited analysis link to the single quality-of-life dimension of income. The research program proposed herein seeks to extend such on analysis to fully understand the qualitative dynamics governing development across all quality-of-life dimensions and assign quantitative relations as possible.

Technical Aspects: Complex Simulation. Methods for connecting individual simulation studies of a complex mix have been thoroughly explored in recent years. Recommended by a 1997 U.S. Presidential Commission on Critical Infrastructure Protection, such exploration was undertaken by the CIN/SI collaborative program with universities and industry. Exploration focused on the electric power grid but also considered telecommunication networks, banking and finance networks, and transportation and communication networks. These systems have in common large scale, nonlinear and deep interconnections, and time-dependency. Before this work was undertaken, available mathematical models of these systems were superficial and lacked insight to system dynamics.

Understanding the electric power infrastructure was a challenging choice for CIN/SI, because the North American power grid can be considered the largest machine in the world based on its network of interconnected generators, lines, and switches. Grid behavior cannot yet be simulated in real time, so operators rely on ready-made contingency plans developed from analysis of deterministic scenarios. These "off-the-shelf" plans rarely fit a situation perfectly.

Fundamental understanding of the electricity grid or any other complex system is difficult because these systems are not simply giant assemblies that can be readily decoupled and broken down into many small, "self-similar," and more-or-less independent parts for consideration on their own. Instead, components large and small are linked by an intricate internal structure that is difficult to unravel: how one thing leads to another in these systems is not at all clear. This interlinked-ness is the heart of what made such systems complex rather than simply gigantic. The problem is not one of accounting for tremendously large numbers of parts—computers can do that efficiently—but one of accounting for the connections among all the non-linear, often uncertain, and heterogeneous parts. Fundamentally, the behavior of each part depends strongly on that of others, and a great deal of information must be exchanged among numerous parts about what is going on with still other parts in order to understand what will happen for any one particular part. Comprehensive analysis gets messy fast (as fast as n^2 for analysis time in a complex system of n parts, suggests Frederick Brooks Jr. in *The Mythical Man Month*, in which he discusses his discovery as an IBM manager that adding more programmers to a late job usually just made it even more late). As a result, analyzing behavior is a major problem for individual infrastructures—electricity, transportation, communications, etc.—and it gets much more difficult when the interdependencies and externalities among different infrastructures, societal sectors, and technologies are considered.

(Continued on page 9)

Global Transition Dynamics for Countries at Sequential Stages of Development

The proposed holistic simulation program for transition dynamics is not "one size fits all," because countries at different states of development face different resource allocation challenges. The program will consider resource allocations and key dynamics for countries at four stages (primitive, underdeveloped, developing, and industrial) as follows.

Primitive Countries Survival Allocations

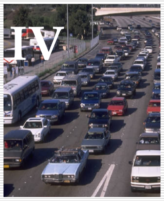
- Introducing/reinforcing sustainable food agriculture, preservation, and land use.
- Investing locally in efficient use of available fuels (biomass, solar, animal wastes) for cooking and heating. Replace indoor domestic hearths with chimney-ventilated wood stoves (e.g., cut lung cancer in half and reduce fuel need to one fourth) to release women and children for other employment, such as weaving, pottery, teaching, area marketing, etc.
- Reducing communicable disease by modifying social habits (e.g., hand washing, funeral customs, open toilets, primitive medicine, raw unboiled water, etc).
- Establishing acceptance of visiting medical services (e.g., treatment of AIDS and tuberculosis).
- Initiating elementary reading and writing: "the single-room school."
- Establishing the rudiments of self-government within tribal traditions.
- Introducing/reinforcing a self-policing and justice system.
- Formalizing civilian self-government.

Underdeveloped Countries Resource Allocations

- Initiating clean water and sewage systems.
- Shifting from barter trade to elementary financial systems based on property rights.
- Transitioning local transportation systems from the animal-drawn carts or rickshaw to bus and truck, to support trade with neighbors.
- Establishing full-schedule elementary education.
- Developing resident health facilities.
- Providing voice and television centers for communication contact within the country.
- Introducing more sophisticated lighting and cooking (kerosene, gas, moving to electricity).
- Funding of community services, such as diesel electricity generation for community facilities.
- Implementing legal and judicial system.
- Establishing elementary international trade mechanisms. (e.g., Japanese trading companies).
- Implementing state economy management (central bank).
- Ensuring private property rights and non-confiscatory tax system.

Developing Countries Resource Allocations

- Expanding a public health system of doctors, hospitals, ambulances, pharmacies.
- Establishing environmental pollution controls for industrial activities, water, sewage, food, and civic amenities (transportation, garbage collection, etc).
- Providing transportation choices: local bicycle, motorcycle, light trolley or bus; regional railroads (oil or electric), canals, highways (buses, autos, trucks); airplanes (highways and railroads are competitive and very capital intensive).
- Universalizing communications: hardwire telephone network, cell phones (wireless locally or nationally or satellite), television (bandwidth cable or satellite-dish).
- Guaranteeing postal service (security and privacy).
- Expanding financial services (international banking).
- Enforcing private property and credit arrangements.
- Instituting central bank economic policies for currency stability
- Establishing higher education system for technicians, professional engineers, physicians, business managers; to supply indigenous leaders for a fully developed industrial country.
- Shifting state sponsorship and ownership toward a balancing free-market.
- Ensuring judicial and police systems, enforceable and corruption-free, compatible with international relationships.
- Provide regional physical security (piracy, banditry, etc.).



Developed Industrial Economies Resource Allocations

- Implementing political incentives for developing a free market culture that protects market integrity, protects the environment, invests for the future, and cooperatively supports those long-term public services that must be nationalized because of their inherent commonality (e.g., public health, security, intergenerational R&D, environmental criteria, international relationships, etc.).
- Intensifying pioneering science research and applied science R&D so that the creation rate of new options for social use exceeds the growth rate of population numbers and associated quality-of-life needs (e.g., housing). The objective is to raise the living quality for the bottom economic sectors of the population, without sacrificing the quality of the upper sectors.
- Instituting remedial technologies to overcome the residual environmental impacts and social remnants of past neglect, past wars, and unrestrained exploitation for short-term profit (e.g., bioremediation of pollutants, ecology restorations, etc).
- Investing in the development and use of transition technologies for the less developed countries in order to reduce the amount of protection needed by the developed countries from the social failures of the less-developed (e.g., refugees and immigration). The "Unfolding the Future" program might show the way.
- Emphasizing the replacement of low-skilled processes by technological means, so as to make better quality living available to more people at low cost (e.g., laundry machines).
- Intensifying the creation of new technologies to substitute for depletable resources of energy and materials (e.g., renewables and nuclear vs. gas and oil, synthetics vs. minerals, water recycling & desalting).
- Developing technologies to increase the efficiency with which end uses are met with reduced demand on resources and the natural environment. (e.g., cuts smog in cities).
- Recognizing that developed countries can afford to emphasize the half-century view. Invest in speculative R&D that might provide useful outcomes decades ahead.
- Tackling urban sprawl by integrating service level transportation, communication, manufacturing, entertainment, education, etc., within outlying communities, assigning to urban centers the most expensive and specialized services (e.g., museums, graduate schools, research laboratories, medical specialties). The target is more even population distribution to minimize the undesirable effects of congested living conditions (e.g., slums).

The CIN/SI overcame the longstanding problems of complexity, analysis, and management for large interconnected systems – and systems of systems—by opening up new concepts and techniques. Dynamical systems, statistical physics, information and communication science, and computational complexity were extended to provide practical tools for measuring and modeling the power grid, cell phone networks, Internet, and other complex systems. For the first time, global dynamics for such systems can be understood fundamentally *(Figure 5).*

In all, more than 300 technical papers have been published to date, and 19 promising technologies have been extracted from CIN/SI findings for commercial development. These results address diverse areas, including electricity grid analysis and control, Internet communications and security, manufacturing process control, command and control networks, traffic flow over highway nets, long-term design of critical infrastructures, and integrated assessment of design and policies in a global context. CIN/SI results also addressed the difficult qualitative aspects of modeling the bounded rationality of the human participants in complex systems. Such analysis is critical because humans are the components in any system most susceptible to failure and the most adaptable in managing recovery. Together, these results provide an initial technical foundation for projecting key societal dynamics on a global scale.

Operational Considerations: Organization. The CIN/SI was a successful venture operationally as well as technically. The Initiative ran from 1999 to 2001 and cost $22 millions (shared by EPRI and the U.S. government), with $15.6 millions going directly to universities. The CIN/SI operated as a virtual organization on a national scale, with management provided by a dedicated core team representing the Initiative funders. Six consortia were organized, involving some 200 researchers, advisors, and managers representing more than 40 separate organizations from academia, industry, and civilian and military government agencies. Large size and diversity were necessary to address the research challenge of complex interactive systems, which was beyond the scope of any single university or private contractor. The Initiative was highly successful despite its large size and diversity of members. Important research results were achieved, objectives were met, and the work was professionally and personally rewarding for participants. This success was no accident, but reflected the effort of many people. CIN/SI fostered true innovation in an emerging field of science and technology. Innovation is well thought of as a team sport; most often achieved when ideas and tools are brought together as never

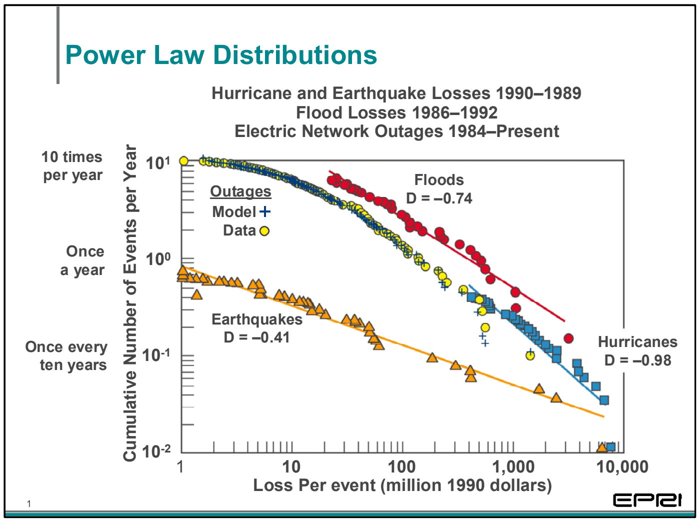


Figure 5. Understanding Global Dynamics. Complex Interactive Networks/Systems Initiative (CIN/SI) research provided new under-standing of the global dynamics of complex systems. For example, economic losses from disasters were found to follow a power law distribution—for hurricanes, floods, earthquakes, and even electrical outages. Fundamental power law distributions also were found for forest fires, Internet congestion, and other systems. CIN/SI results such as these translate in new approaches for optimizing complex systems in terms of productivity and robustness to disaster.

before. Continued innovation as was achieved through the CIN/SI will help us overcome the challenges of today and tomorrow.

Based on this success, the global transition dynamics program we propose here would operate like an enlarged international version of the CIN/SI. The process itself is a massive tree-like simulation structure, with interconnected branches for each of the many sectors and fine structures. The operation of the simulation processes could be monitored by a full-time group of "scholar/statesmen/directors," each representing a key branch such as technology, human health, security, economics, environment, politics, and social structure. An external advisory structure of specialists and reviewers would add support with regular meetings.

The practical simulations in each of the branches would be conducted under consortia subcontracts to create a "virtual international research organization." The latest Internet "collaboratory" tools could be employed to link researchers in remote locations. The subcontractors would be chosen by competitive solicitation among international knowledge sources such as academia, research centers, government laboratories and agencies, and other entities with specialized insights. The contracting procedures and relationships involved in such a virtual organization were pioneered by EPRI thirty years ago, and today are common to many large research programs. By now, the administrative techniques, human factor considerations, and inherent conflicts among participating organizations (reviews, publication, intellectual property, etc.) have been mostly resolved.

The scope and size of the project would depend on the level of support achieved. To start discussion, we envision a ten-year program, with the first year funded at $10 million, a second at $30 million, and annual commitment of $60 million thereafter. While U.S. institutions may predominate initially, it is important to stress international participation where feasible. International entities already working in relevant areas should be included, such as the International Institute for Applied Systems Analysis (IIASA), which was established diplomatically during the cold war jointly by U.S. & USSR with a global problems mission and a focus on energy and regional supplies. Another group to consider is the World Energy Council (WEC), which functions through subcommittees in each country that meet periodically to consolidate country-specific data into a global view. Their low cost organization base might be expanded beyond energy. The World Bank Group has a vital role in funding major projects, and could contribute to (and use) in-depth perceptions on global issues. National academies, professional academic organization, and engineering societies in all countries also should be solicited.

The Key Question

Can this undertaking—aggregating issues of technology, health, society, ecology, and economics to produce a probabilistic vision of the future that illustrates key development decisions, pinch points, and forcing functions—be accomplished? The authors believe so, recognizing that extending the CIN/SI approach to projecting international issues is a very ambitious technical undertaking. More obvious than its complexity, though, is the crucial need for such an endeavor. The key question before us is to consider what lasting monuments are we building now for future generations and how wisely are we applying our resources of wealth?

As a risk analysis judgment of future benefits, costs, and failures, this endeavor is an investment worth making. Even a modest initial success, such as analyses of specific development alternatives, would make a significant contribution, both in tangible policy suggestions and in stimulating continuing studies of an integrated approach to such national and global problems. The establishment of a professional analytical approach to decision-making that routinely integrates all the major social elements at the start of the decision-making process, rather than at the end, would be an important by-product. The holistic approach should be the starting step. The experience of one of the authors in the field of quantitative risk analysis shows that the persistent application of this process to decision-making has born much more fruit than the historical intuitive process. After about two decades, quantitative risk analysis is now generally sought by decision-makers on most new risk issues; efforts now focus (rightly) on quantification approaches, probability methods, and computation techniques. The program proposed here would help move decision-support analysis to a holistic level.

The routine of an integrative simulation approach for holistic social outcomes should be expected as another important byproduct of this program. The effect in academia would be to broaden the scope of teaching in the applied scientific and engineering specialties, as a broad mode of thought becomes commonplace and the technology faculties become involved in fundamental R&D. Moreover, the sophistication of international academic and political participants would be enhanced. Hopefully international collaboration will become a habit. However it should be recognized that the global problems being addressed will take a long time to dissect, and partial progress should be taken as encouraging.

It is the authors' firm belief that technology development is an important key to improving the quality of life for coming generations, a key that adds hope for the planet and for those who will inherit the future. In the coming century there will be many new choices made about technology development, and it will be important for decision makers to have a systematic, reasonably defensible, and comprehensive perception of the future social impact and feasibility of these choices in order to make wise choices and invest our wealth well. The projection tool proposed here provides a real opportunity for the "have" nations to use their technology capability and resources to help the "have not" nations identify for themselves an appropriate level of development and economic activity.

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Additional Reading

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Author Biographies

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