Making System Dynamics Useful: A Personal Memoir*

Edward B. Roberts
David Sarnoff Professor of Management of Technology
MIT Sloan School of Management

Abstract

During the many years that I was a founding member of the MIT Industrial Dynamics (ID) Group, later System Dynamics (SD), I focused on trying to apply SD concepts, tools and techniques to the real world and to having real impact. That orientation originated from listening to Jay Forrester as he related his personal history and communicated his personal values to our group and to me individually in his forceful and influential manner. Here I review that history and some lessons I learned. As this is a personal memoir I do not attempt to review the entire field, but concentrate entirely on my years of activity in the System Dynamics field from 1958 to 1993 and on the aspects most familiar to me, i.e. my own teaching and research and the work of Pugh-Roberts Associates, Inc.

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I wish to express my deep appreciation to John Sterman, Henry Weil and two anonymous reviewers for their many helpful suggestions. Of course any faults found in this paper rest wholly with the author. Remembering and rethinking my years of experience in System Dynamics was a wonderful stimulus.

You can contact the author at eroberts@mit.edu.

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My MIT Teaching and Research in Industrial/System Dynamics

Jay Forrester had come to the MIT School of Industrial Management (now the MIT Alfred P. Sloan School of Management) from MIT Lincoln Laboratory, where Jay had capped a distinguished career as a leader in computer systems development. In 1958 he started the Industrial Dynamics Group by hiring two assistant professors (Joe Yance and John Enos, both economists) and three graduate students from the MIT Electrical Engineering Department: Willard Fey, Alexander "Jack" Pugh and me. The two faculty members never learned how to build Industrial Dynamics models and left the group after a few years. The ID Group grew rapidly by hiring other grad students at the School of Industrial Management, many as full-time Research Assistants (who could register for only two subjects per semester, devoting the rest of their time to ID research and teaching). Some of the early RAs whom I remember, with apologies to those I omit, were: Ted Jarmain, Fill McPherson, Richard Miller, Ole Nord, David Packer, Jorgen Randers, Michael Spiro, Carl Swanson and Helmut Weymar, and later Tom Bergan, Michael Goodman, Jim Hines, Gary Hirsch, Jim Lyneis and Dennis Meadows.

We had succeeded in quickly building student interest in the early years of Industrial Dynamics (ID) classes. Even before I became an Assistant Professor in 1961 Jay had given me full responsibility for running the several sections of our popular introductory MIT Industrial Dynamics subjects, 15.58 for undergrads and 15.581 for graduate students. Most of our classes were taught by the graduate students of the Industrial Dynamics Group, several of them (including me as the first one) while enrolled as Ph.D. candidates in the MIT Department of Economics. (The Sloan School did not yet have a doctoral program of its own.) Jay was teaching the required Sloan Fellows course in ID (which he turned over to me after a few years) as well as leading a series of sessions for the Sloan School Senior Executive Program, a 12-week residential program for senior practicing managers.

Within a few years after we started our first classes I developed the advanced subject, 15.582 "Application and Implementation of Industrial Dynamics". It was then the only subject at the MIT Sloan School that used the word "implementation" in its title. That class blended classroom discussion of the literature on organizational change processes with information about real-world ID models and applications, combined with major student team projects, usually with local industrial firms. My project grading was based primarily on how far the team had gone in persuading the company executive "client" to accept and implement the recommendations stemming from the team's model development and analyses. Model complexity and sophistication were secondary to what use had been made of the work. The course still exists as 15.875 "Applications of System Dynamics" where students still work in teams with real clients.

Years later I dealt further with my desire to encourage real-world use and impact of System Dynamics by assembling *Managerial Applications of System Dynamics* (Roberts,

1978) which collected many papers describing applications of SD and processes for its successful use. Others continued this tradition, including Jim Lyneis (1980), who was first a faculty member at MIT Sloan and then a senior leader in Pugh-Roberts Associates, who authored *Corporate Planning and Policy Design*. That was followed quickly by the Richardson and Pugh book (1981), *Introduction to System Dynamics Modeling with Dynamo* and later John Sterman (2000) whose *Business Dynamics* text includes numerous discussions of real-world applications. For many years Jay, then I, then others organized and ran an intensive two-week MIT summer program on Industrial Dynamics to diffuse the principles and practices to industry, government and other universities. The two weeks provided sufficient time for the students to engage actively with modeling efforts and to carry away skills as well as concepts. I understand that this summer course is still offered at MIT, but as a one-week subject.

At MIT my principal areas of System Dynamics inquiry over many years were: (1) research and development organization and management; and (2) healthcare organization and delivery. I'll discuss each area separately, describing the significant transfers from MIT research to pragmatic applications in the outside world, just as traditionally occurs from the science and engineering parts of MIT.

Dynamic Models of Research and Development

The System Dynamics work on R&D began with my Ph.D. dissertation in the MIT Department of Economics. When my advisor-to-be, Professor Robert Solow, joined President Kennedy's Council of Economic Advisers, he strongly encouraged me to approach Professor Frank Fisher about becoming my thesis chairman, for which advice I shall always be indebted. Despite Fisher's strong doubts about whether SD was a legitimate approach to modeling economic systems, Frank tolerated my independence and challenged me repeatedly but fairly as I completed my Ph.D. work. It seems ironic that the world's first Ph.D. dissertation in System Dynamics was chaired by a distinguished econometrician!

My dissertation project was a large-scale model of the life cycle of a research and development project, modeling the interactions between a sponsoring customer (e.g, a government agency) and a performing organization (e.g., a private-sector defense/aerospace company). The model was the first *transient dynamics* model developed in SD, in contrast with the *steady state dynamics* models (fluctuations around a static equilibrium) that characterized the production-distribution systems work with which Industrial Dynamics had been launched. Jay had firmly rejected my dissertation proposal twice, then unexpectedly approved it on my third try, laughing as he told me of his own comparable experiences with Professor Gordon Brown in the days of the MIT Servomechanisms Lab. The modeling work in my dissertation was also unique for that time period as I tried very hard to justify the formulation of the equations and the determination of the model parameters by extensive use of the academic literature and

empirical studies of R&D organizations. The dissertation was soon published as *The Dynamics of Research and Development* (Roberts, 1964) and led almost by accident to the large series of project models that supported Pugh-Roberts Associates for years. Following up on my dissertation work others at MIT constructed large-scale models of major projects and programs. For example, Tom Kelly (1970) developed my model into an ambitious Master's thesis that re-examined the NASA Lunar Module program (LEM) that Kelly had managed at Grumman Aircraft before he became a Sloan Fellow, and then he applied that work back home after returning from his Sloan Fellows year. Tarek Abdel-Hamid applied the same basic model to software development projects in his MIT dissertation work (later published as Abdel-Hamid and Madnick, 1991), using empirical data from several companies to test his model.

My own MIT System Dynamics work on R&D turned from the modeling of single project life cycles to multi-project models in which issues of resource allocation among projects became the critical consideration. Here the work became practically rooted from a series of theses that I supervised with MIT Sloan Fellows from major government contractor R&D organizations (MIT theses are available from the MIT library system: Sloan Fellows Donald Beaumariage (1960), Philip Lett (1961) and George Wachold (1963), with additional related SD Master's theses by Gillette Welles (1963) and Joseph Nay (1966)). In a SD research project funded by the Office of Naval Research I demonstrated how the Navy's funding policies for its own internal laboratories could produce a gradual erosion of skills sets within those laboratories, leading some of them eventually to decline from being advanced R&D organizations to just routine test and evaluation facilities. The first real world application of this class of R&D resource allocation models was carried out by Pugh-Roberts Associates with the multi-billion dollar IT systems supplier that is described in this special issue by my long-term and close colleague Henry Weil (2007) and more completely in the Weil *et al.* (1978) chapter in my collection.

My System Dynamics work in research and technology management opened up major opportunities for me at MIT for which I am ever grateful. In 1961, while still a part-time instructor in System Dynamics and just short of completing my Ph.D., I was selected to join three senior Sloan faculty (Donald Marquis, Bernard Muller-Thym and John Wynne) as consultants to James Webb, the first head of NASA. We defined what in 1962 became the first research center at the Sloan School, the Organization Research Center, focused upon the management of technology and led by Don Marquis, with me as the initial Associate Director. Perhaps surprising for a management school at MIT, at that time my SD doctoral work was the only research in the Sloan School that related to technology management. The new research center permitted me to combine my continuing R&D modeling studies with empirical research on R&D organizations, initially stemming from my dissertation, which then led to my studies of technological entrepreneurship, resulting in now almost 50 years of personal engagement in issues of managing all aspects of technological innovation.

Models of Healthcare Delivery

My involvement in modeling healthcare delivery systems grew rapidly from one term project in my 15.582 Applications/Implementation class. A random conversation with a former MIT undergraduate classmate led to my meeting Dr. Mitchell Rabkin, then the new Director of Beth Israel Hospital in Boston, a teaching affiliate of the Harvard Medical School. Rabkin quickly agreed to accept a project team from my class in Spring 1967, despite the fact that neither he nor I had any idea as to what the students might do. His welcoming phrase was "I guess a team of MIT grad students can't do us that much harm!" Rather than assign my Teaching Assistant to help the group (which incidentally included Dennis Meadows, one of my 15.582 students), I decided to get involved personally, wholly out of curiosity. We ended up building a model of the underlying dynamic conflict in a teaching-research hospital between what we labeled as "patient exoticity"— how exotic were the patients' medical needs, a key determinant of attractiveness of the patient population to academic medical researchers and tertiary care practitioners – and the costs of delivering patient care. Clearly the patient cadre needed to be "mainstreamed" to some extent or the hospital would eventually drive itself into bankruptcy. The project was fun and insightful, for us as well as for Dr. Rabkin.

One month after the term ended I was called by the new Deputy Dean of the Harvard Medical School, Jerome Pollack, who claimed he needed my help. Despite my denial of any knowledge of the health field, I obviously had been strongly recommended by Dr. Rabkin and within weeks I became a key member of the small planning team that was developing a broad program of community-oriented care delivery, which became the Harvard Community Health Plan, one of the first Health Maintenance Organizations (HMOs) in the country (now known as Harvard-Vanguard). The extensive support work needed by the Harvard Med planning team was turned over to Pugh-Roberts Associates, primarily to Gary Hirsch (who had been my Research Assistant and Ph.D. student at MIT) and me. We did all of the work to analyze the tradeoffs between detailed plan features, resulting care costs and fees, overall market attractiveness of the program, and its survival and growth. One critical finding from our analyses was the enormous benefits to society of preventative medicine and managed care.

Just as my initial R&D modeling provided the impetus for dramatic expansion of MIT's work on technology and innovation, so too did my early SD efforts in health care lead to proliferation of MIT health-related activities in the 1970s and '80s. The first step after I got hooked on the modeling of health issues was creation of a class I taught jointly with Professors Jack Rockart and Glen Urban, "Quantitative Approaches to Health and Education Management", the first non-profit management class at the Sloan School. I then also launched the "Seminar in Health Care Management", joined quickly by Dr. Norman Stearns, Associate Dean of the Tufts Medical School, who co-taught with me for sixteen years. Together Norm and I evolved the process/practice of "systems intervention", using SD causal loop diagrams as a means for working with health care executives to diagnose their complex organizational issues and to lay out bases for change

(Roberts and Stearns, 1976, 1978). By the way, the Industrial Dynamics Group had used causal loop diagrams as a teaching and communications tool from the earliest ID classes. They were introduced by Helmut Weymar, one of our Ph.D. students and teaching faculty, in about 1960 or so. My wife Nancy Roberts further developed causal loop diagramming as part of her doctoral dissertation on assessing and improving the systems thinking capabilities of young children (N. Roberts, 1975). These early practices were the bases for their later popularization in System Dynamics and system thinking.

Rapid growth of student and then faculty interest in health organization and management led to the development of a Master's Concentration in Health Management in the Sloan School, and then to an interdisciplinary Ph.D. program in Health Policy and Management co-sponsored by the Departments of Economics, Political Science and Sloan. Richard Beckhard, Sloan's first Adjunct Professor, and I created and ran for a decade an extensive executive education program for the Association of American Medical Colleges, teaching with many colleagues from Sloan and elsewhere all the Deans of Medicine in the U.S. and Canada, the Chief Executives of the major teaching hospitals, and the Chiefs of Medicine, Surgery and other medical departments. We even replicated the program for Deans of Dental Schools and Law Schools. That program became internalized at Sloan for about a decade in the Health Management Executive Program within the Sloan Fellows Program, so that medical leaders constituted about ten percent of each year's Sloan Fellows class. The close ties with the medical establishment that resulted from these programs influenced the formation of MIT's Whitaker College of Health Sciences, Technology and Management, which included our interdisciplinary Ph.D. program and our new Laboratory for Health Care Practices. In all of these internal and external activities, what we called "health dynamics modeling" was a basic part of the program. I also organized and ran for many years a one-week MIT summer program, "Dynamics of Health Systems", to aid in external dissemination of our work. To accommodate all of this I renamed our Sloan School Technology Management Group as the Technology and Health Management Group. Gradual decline of student interest in the public sector, and departure of several key faculty from Sloan, eventually led to closing down each of these health care-linked endeavors.

Pugh-Roberts Associates, Inc.

In 1963, as just a second year Assistant Professor, I approached Jack Pugh, another founding member of the ID Group and at that time an MIT Research Associate, to join me in establishing Pugh-Roberts Associates, Inc. (PRA) to focus upon bringing SD to the real world. I felt strongly that without such a practical consulting thrust the field would not advance beyond meager academic efforts. Jay Forrester advised me that my starting a company would cause many people to assume that I wasn't serious about having an academic career. Fortunately I have managed to overcome that impression. From the perspective of real world utility Pugh-Roberts Associates became a wonderful organization. What I had not anticipated was that along the way Pugh-Roberts would

make numerous major contributions to the methodology of SD modeling and use, which I had assumed would primarily be the role of MIT and other universities.

I should note at this point that Henry Weil joined Jack and me as our first full-time employee when he returned from military service. Henry's leadership for 25 years as the Managing Director of Pugh-Roberts, and in the final years as its President, made possible many of Pugh-Roberts' achievements. He too was very concerned with the reality and effectiveness of our work, as is documented by many of his publications (Weil, 1979, 1981, 1983, 1989). We sold Pugh-Roberts Associates to PA Consulting Group in 1990, and I maintained ties with them for just the next three years, so I can report on only the first 30 years of PRA's efforts and results.

Project Dynamics Models

The real world applications of my Ph.D. R&D work began with a telephone call to my MIT office from two staff people at Litton Industries. They were in New York searching in the library of the American Management Association (long before Google totally changed that process) for some way to estimate costs for the relatively small R&D portion of Litton's multi-billion dollar project with the U.S. Navy to design, develop and build two new naval ship designs (a class of destroyer and the LHA aircraft carriers) in Litton's new "automated" shipyard. They had found my book (Roberts, 1964), had skimmed it in the library, and wanted to know if I could build a model of their R&D cost-incurrence process to aid their negotiations with the Navy to recover a part of the project's overall "billion-dollar overrun". They flew up to Boston and we met that evening for two hours. Two weeks later PRA's Henry Weil and Ken Cooper were off to Pascagoola, Mississippi to begin the work. During the next year our assignment expanded to cover modeling the entire ship-building project, including R&D, design and engineering, and construction of both ships, and we were engaged very closely with Litton's outside corporate attorneys to determine the precise claims that Litton would eventually make. Because of government contracting rules all of the Pugh-Roberts work was done with complete public disclosure and scrutiny, and turned over to the Navy periodically for its review. All of the modeling had to be carefully supported by detailed empirical analyses, to validate both the model equations and parameters and, more importantly, the model's results. In the intensifying negotiations the Navy hired Booz Allen & Hamilton consultants to support them and Booz Allen in turn hired some other MIT SD faculty to do detailed analysis of the Pugh-Roberts model and to find some way of fighting Litton's claims. The work required that the PRA consultants become highly skilled in utilizing SD models to testify in court and commission hearings. In the end Litton received nearly half a billion dollars from the Navy in additional payments of which the Litton CEO publicly stated that the Pugh-Roberts work was responsible for the bulk of that amount (see Cooper, 1980 and Sterman, 2000, ch. 2.3 for details). That work earned significant public recognition for the successful application of System Dynamics modeling, and Ken Cooper, our project manager for the Litton efforts, received a TIMS-ORSA award for the effective application of management science. This was quite important in a world in which many management

scientists were skeptical and even openly hostile toward System Dynamics modeling. The work itself significantly advanced the scale of SD models and the methods of verification, validation and real world use of our models. Not incidentally, the work also required Pugh-Roberts to dramatically expand DYNAMO's capabilities and to add a variety of new features that facilitated data usage and comparative analyses of model results with actual project histories.

This suggests an aside about DYNAMO and other intellectual products of Pugh-Roberts Associates. It became clear soon after the formation of Pugh-Roberts that we needed far more powerful and flexible versions of DYNAMO than MIT was likely to be able to fund and develop. In discussions with Jay Forrester, Jack Pugh, who had been carrying out all of MIT's DYNAMO development (Pugh, 1961, 1963, 1970, 1973, 1976), and I agreed that Pugh-Roberts Associates would move forward to do what we needed to do for ourselves without any MIT support. Further, Jay periodically discussed with Jack what might be reasonable prices for us to charge other organizations that wanted to purchase DYNAMO for their own SD work, to be sure we weren't taking advantage of our essentially monopoly position. We always gave MIT free copies of whatever we developed to help MIT SD faculty and students carry out their work. In a similar manner, when my wife Nancy Roberts began to introduce SD modeling into K-12 education she felt that a version of DYNAMO was needed that was simpler, less expensive, and more usable by schools, teachers and children. Jack Pugh readily agreed to develop Mini-DYNAMO for small computers and Micro-DYNAMO for the Apple II computer. Pugh-Roberts sold these at minimal prices, far below a cost-recovery level, to help Nancy's initiative and to broaden the base of the SD constituency. We even arranged with her publisher to distribute Micro-DYNAMO along with Nancy's SD book (N. Roberts *et al.*, 1983) to encourage K-12 schools to build the underlying market for SD modeling. Our DYNAMO work eventually gave birth to Ventana and Vensim through the spin-offs of David Peterson and Bob Eberlein, Jack Pugh's key Pugh-Roberts assistants.

In the world of contract litigation and dispute resolution I guess that nothing is so important as winning. Within two months of the Litton case closing we received a call from another prestigious national law firm telling us that the Litton attorneys had strongly recommended us. The new lawyers also had a client that had incurred a significant cost overrun in a shipbuilding effort. Soon Pugh-Roberts Associates was off to the races, carrying out shipbuilding modeling projects throughout the U.S. and Europe, in all cases generating very favorable results for our litigious clients. Then we got a call from another law firm that wanted to know if the way we modeled ship building might be applied to missile and space satellite development. That began a series over several years of about a dozen major projects for a giant aerospace contractor. Our SD project modeling had become the litigation support technique of choice for so-called "delay and disruption" cases, where changes of scope or specifications lead to increased demands for engineering work, increased chaos of staffing and organization, shifts in work quality and timing, etc. etc. etc. Very large and complex feedback systems abound in such situations.

Next in line was a call from lawyers working with a major utility that was building a multi-billion dollar nuclear power plant. As was typical those costs had grown enormously from their original estimates and the state Public Utilities Regulatory Commission was refusing to accept those "overruns" within the utility's rate base. Success in our SD modeling support of that case then led to what perhaps was the coup of all construction cost escalation projects, our many years of work for the British-French "Chunnel Project" contractors. Over all of these years, in all of those companies and cases, the base model was the same, but configured and calibrated for each particular project. The internal champion at Pugh-Roberts and the leader of all the project-related efforts was Ken Cooper, one of our earliest hires. His concept of "undiscovered rework" was a key intellectual addition to the base R&D project model. Ken went on to run the Pugh-Roberts Division of PA Consulting Group after Henry Weil and I concluded our relationships there.

Healthcare Models

As mentioned above, Pugh-Roberts entered the field of healthcare modeling with the initial project to help launch one of the first HMOs in the United States. Gary Hirsch and I led that work, which grew rapidly, primarily under Gary's direction.

Concurrent with the Harvard Medical work in 1967 I decided to approach Dr. Gilbert Levin, a psychologist and faculty member of the Albert Einstein School of Medicine in New York, who had spoken to the MIT SD seminar a year earlier about his general interests in systems approaches to mental health. Levin, Hirsch and I prepared a grant proposal to the National Institute of Mental Health, which funded us to perform a series of exploratory studies of how SD models might assist mental health program delivery. That collaboration lasted many years, producing two books and a spin-off company (Public Sector, Inc.) as side effects.

The multi-year program, then a new application area for SD, advanced research in the mental health field and was carried out in an implementation-oriented consulting manner. Our "client" was Dr. Jack Wilder, Director of the Sound View-Throgs Neck (SVTN) Community Mental Health Center in the Bronx, New York, and his senior managers, who included Dr. Levin as an Associate Director. We began our work by interviewing the senior staff to identify their most significant clinical problem, which they quickly agreed was "patient drop-out", i.e. patients who stopped coming to the Center for help before they were "cured" or at least helped to the extent deemed possible by the medical staff. But an SD perspective soon emerged in which the dual actors of patient and staff interacted strongly, each affecting the other's expectations and reactions. The underlying issue turned out to be as much "staff hold-on" as "patient drop-out", i.e. many staff tried to keep patients under care longer than the patients felt to be necessary. This led quickly to a changed intervention process at the mental health center (Kligler *et al.,* 1971).

But the work also produced simultaneously an insight by Nancy Roberts that precisely the same system structure existed between the teacher and the student in the elementary

classroom, leading to system-created wide variations in observed classroom performance, including student drop-out (N. Roberts, 1974)! The generality of this underlying system phenomenon of staff-client interaction and its consequences caused us to extend our modeling work into other areas, including dental care, and led us to author the book, *The Dynamics of Human Service Delivery* (Levin and Roberts, *et al.,* 1976).

As our initial "clinical problem" work began to draw to a close at SVTN, we asked the next question of the Director and his colleagues. "What is your major 'outreach problem', in which you try to help the surrounding community to cope with its issues?" Showing our naivete our modeling team rejected as not credible the overwhelming arguments presented by the staff that its key community issue was dealing with the facts and consequences of a growing epidemic of heroin addiction. We assumed that might be a real problem in New York City's ghettos but couldn't imagine it was real in the lower middle class and mixed racial neighborhood of SVTN. A few months later, our innocence gone, we were engaged heavily in analyzing all aspects of heroin addiction, including what influences both supply and demand, the responses of addict-produced crime, the law enforcement system, and the variety of prevention and treatment modalities. In line with Pugh-Roberts values and style, we recruited a team of outside experts to become our collaborators, including leaders of all aspects of the heroin world. They provided insights for model formulation, data, and credibility for model acceptance.

Although we had started our client implementation work for the heroin issue with the senior management of Sound View-Throgs Neck CMHC, one of our expert team, Dr. Jerome Jaffe, was soon appointed to head New York City's overall efforts to combat and cope with heroin addiction, so the scope of model application grew dramatically. The next year Dr. Jaffe was named by President Nixon to become the nation's "drug czar" and suddenly we were making many trips to Washington to influence drug policy in the Food & Drug Administration and the White House. Our book, Levin *et al.* (1975), *The Persistent Poppy: A Computer-Aided Search for Heroin Policy*, documents all aspects of our SD work and communicates our dismay at the low likelihood we perceived of ever being able to eradicate the global problem, given the overall system in effect. The analyses evidenced the futility of supply interdiction policies unless coupled with even more vigorous efforts to reduce demand. In 2007 the world situation strongly confirms our early diagnosis of the poppy's persistence.

Over many years, under Gary Hirsch's leadership within Pugh-Roberts and later on his own, along with active help during much of this time from Michael Goodman, another early PRA employee, we applied SD to a wide variety of health care delivery problems. We worked on such areas as the supply and demand system for dental care, strategic planning for major medical schools and their hospital complexes, and policies for diminishing the smoking problem. Of course others have later continued and expanded these initial health oriented modeling endeavors.

Economic Models in Practice

When Jack Pugh and I started Pugh-Roberts we assumed that all of our clients would be large corporations working on internal corporate problems. Clearly our imaginations were too limited as to the identity of our clients or their problems. Over the years Pugh-Roberts staff developed numerous economic models, all very strategic for their sponsors. The first major project that we (Jack and I personally did almost all of the work on this one for several years) undertook as a consulting firm was for the Susquehanna River Basin Utility Group, the consortium of all of the private electric power companies serving most of Pennsylvania, and parts of New York, Maryland and Delaware. This also was the first attempt to apply Industrial Dynamics to the field of economic modeling. The U.S. Army Corps of Engineers had begun studies of the potential need for public power in this multi-state region and the consortium of utilities had reluctantly agreed to accept such an "invasion" of their territory if the needs justified it. The utilities hired Battelle Memorial Institute to assist them in their analyses and Battelle in turn hired Pugh-Roberts to undertake the development of a comprehensive regional economic model. Henry R. "Ron" Hamilton, a Sloan alum who had loved SD, was the Battelle project manager. The model required detailing each of the several sub-regions of the Basin as an economic, industrial, demographic and electric power-related entity. But the model also had to include considerations of water quality and availability of the river basin itself (issues of power and water were clearly intertwined), as well as the feedback loops among environmental characteristics, overall regional attractiveness, and industrial and population change. Again, because the work would be done in public with anticipated public scrutiny, testimony and debate, we had to develop SD models that were consistent with detailed population, economic, environmental and industrial data.

Battelle assembled a team of external expert consultants to work with us, including Professors Jerry Milliman (University of Illinois) as a regional water resource and economic development guru and Arnold Zellner (University of Chicago) as an expert in econometrics methodology. They were supplemented by large numbers of internal Battelle consultants in the many fields pertinent to the Susquehanna Region and to electric power generation and utilization. The model development process became the framework for determining which supplemental studies needed to be carried forward by these internal and external sources and their results were embedded into our SD model formulations. Jack Pugh needed to modify DYNAMO to enable it to include special models for evaluating such things as the oxygen content of the river itself, affected by industrial and population-based pollutants, and permitting the enhanced DYNAMO to carry out statistical analyses of our model's baseline correspondence with economic history. The Susquehanna work was cited repeatedly by academics, government officials and even competing consultants as pioneering in its thoroughness and innovative integration of economics, water resources and the environment. After many years of public presentations and discussions throughout the region and in Washington DC hearing rooms, the Army Corps of Engineers concluded that there was no overriding need for their intervention in the region, and we wrote and published a major book on our work, Hamilton *et al.* (1969), *Systems Simulation for Regional Analysis: An Application to River Basin Planning*.

The Susquehanna work led rather quickly to our creation of a short-lived "spin-off" company, Environmental Impact Center, Inc. (EIC), that combined Pugh-Roberts Associates, the Environmental Sciences faculty group of Boston College, and some environmental chemistry entrepreneurs. Our mission was to develop "packaged SD models" to assess typical environmental impact issues, providing support for the "statements" that were newly required for all major construction projects that might produce environmental consequences. Highway construction, river works, power plants would all need such analyses of their environmental side effects and we intended to create the off-the-shelf System Dynamics models for use in these deliberations. We soon received funding from two government agencies to develop some prototypes of these models and EIC was progressing well as a firm when the 1973 OPEC (Organization of the Petroleum Exporting Countries) oil embargo hit. Energy costs zoomed overnight, with gasoline prices tripling. Almost immediately the country abandoned environmental concerns and turned to energy issues. EIC saved itself as a company by moving quickly too. Our electro-chemists found that they could easily be funded on research into alternative energy approaches, and the SD models disappeared from the firm.

But the OPEC crisis produced other strategic needs for sophisticated economic models. In the post-1973 world, oil availability and prices had suddenly become key questions, no longer constants, especially to the world's largest integrated oil companies. Soon we were working with the Corporate Planning Group of one of those global giants, building a world model of oil supply, demand, pricing and allocation. It was indeed an economic model of the world, detailed by regions, and modeling the drivers of country-level economic growth, associated demands for oil, regional supply of oil, alternative strategies for allocating available oil, and the consequences for market prices, which of course in turn affected economic growth. We modeled the anticipated behavior of major oil-producing countries in response to various endogenous and exogenous factors. We modeled the anticipated investments by oil companies in research, exploration, drilling and capacity change, including how technology would be affected by all this and in turn technology's impact upon oil production. A typical simulation run of our model was for a thirty-year period and large numbers of analyses were made to develop the model so that it was accepted for regular use by the firm's corporate planners. That model became a continuing tool for the firm's ongoing strategic analyses and operations. Concurrent with our own efforts we learned of comparable simulation modeling (but not SD) work being done by another oil giant, as well as strong interest in these models by senior government intelligence agencies. So large-scale dynamic simulation models had become accepted methodology for these strategic petroleum studies.

The U.S. government also responded to OPEC by establishing within the Office of the President a special group to examine strategic materials other than oil. Pugh-Roberts was invited to undertake major work in modeling the global copper industry to assess the probability of an effective "COPEC" being formed, yet another global economic model but with a different focus. By the way, we concluded that an attempt to invoke a COPEC boycott would not work.

Our most anxiety-producing economic model was the one we created for FEMA, the Federal Emergency Management Agency. The problem was to better understand how long the United States economy would require to recover to a reasonable extent from a nuclear attack. This was a very serious effort, in which our assignment was to forecast what might happen and why, given various assumptions about the magnitude of initial destruction to the U.S. The model was very involved in its multiple and interdependent sectors. The dismal result coming from our model that caused greatest concern to FEMA officials was our demonstration that human and organizational chaos, not physical destruction, would be the most significant impairment to the recovery process. Recent experience in the United States with the impact of Hurricane Katrina and the chaotic multi-year recovery process that has heavily involved FEMA suggests that the lessons from our long ago nuclear disaster analyses might well have explained and assisted the continuing Katrina crises. I thank John Sterman for reminding me that the Pugh-Roberts FEMA model was later used by Anjali Sastry, *et al.* (1987) to examine the impact of small nuclear attacks on strategic sectors of the U.S. economy, such as attacks targeted at oil production and refining. The Sastry, *et al.* work, described in a front-page article in the New York Times, showed that these attacks could cripple the economy by triggering ripple effects.

PRA also engaged in modeling strategic aspects of other countries' economies, in classified work for U.S. intelligence agencies, but it is inappropriate even today to discuss these.

Organizational Models

One of my own fascinations was in the possible use of SD to model complex organization design issues. The earliest effort in this domain arose from a chance luncheon at MIT between Jay Forrester and his next office neighbor, Professor Douglas McGregor (1960), which led to a small group task force to model and better understand aspects of organizational dynamics (McPherson, 1965). In PRA our growing portfolio of real world strategy and organization projects led me to hire Alan Frohman, a newly minted Ph.D. from Sloan's Organization Studies Group. Our goals were threefold: To have Alan help us to understand and embed in our consulting models better representations of human decision-making and responses; to help us better implement organizational change as a consequence of our projects; and eventually to develop an additional consulting practice focused upon organizational issues directly, rather than have PRA be limited to modeling projects alone. Alan helped PRA to achieve all these outcomes and launched the PRA group that eventually undertook high-level consulting for major corporations in the U.S. and Europe on the key problems of organizing and managing research, technology and innovation.

Our first "heavy" organizational modeling project was carried out for a major technology-based consumer products company. The company's founder and CEO had publicly and proudly stated an early human resources objective of "10 percent blacks at all levels",

taking the number from the racial population distribution surrounding its offices and factories. As we worked together those HR goals broadened to become less restrictively numeric, more encompassing of racial diversity, and inclusive of gender considerations as well. The modeling project pushed us to probe issues of training and education, recruitment and retention, internal promotion policies, "white backlash", and a host of "soft" variables and phenomena. The corporate working group was a specially-appointed task force headed by a pioneering Vice President of Human Resources. The company developed and implemented major policy changes over a three year period, and the PRA team gained enormous insights into modeling human behavior (Frohman *et al.,* 1978).

That work led directly to two major projects with the U.S. Agency for International Development (US AID). A new Agency head called for a fundamental change in AID's relationships to the developing world, shifting the donor-recipient relationship into a project partnership approach. PRA undertook to model several sample projects in Africa to understand better the new dynamics that this dramatic policy change would produce.

One outcome of this initial AID work was the immediate recognition by the Agency's senior management of its need to reassess the entire organizational development and human resources aspects of AID. AID quickly realized that its traditional staffing patterns would be inadequate to cope with its new approach to global partnerships. Our second AID project thus modeled AID's full set of people processes – recruitment, training, retention, human resource allocation – and their consequences over time for agency effectiveness.

Strategic Models

As is evident from what I have described above, over the first thirty years of Pugh-Roberts Associates for which I had provided direction, a substantial fraction of our total work was in strategic modeling. Henry Weil (2007) describes and discusses in this issue the system structures that characterize many of these strategic models. Henry personally led many of the projects he describes, often sharing these responsibilities with Jim Lyneis or several other senior managers at PRA.

The strategy issues we tackled ranged across many fields, sometimes unexpected ones such as our Sports Dynamics activities that were directed by Bill Killingsworth. That area of work was initiated by a major project we did for The Jockey Club on the issues of thoroughbred racing in the United States. The organization's "chairman emeritus" was "Jock" Whitney, whose strong communications industry ties assured that the Pugh-Roberts work and recommendations were widely publicized by the media, encouraging critical changes in tax legislation affecting thoroughbred breeding. The jump from horse racing to greyhound racing wasn't difficult, and from there we struggled into modeling the development and effective management of professional football teams. To us at Pugh-Roberts it was both amazing as well as fun to tackle the wide range of questions for which SD models could provide insights and answers.

More conventionally we developed many models of firm-level strategic questions, such as those encountered in insurance, banking and credit card companies. Industry-wide strategic modeling was also quite common, such the work we did in telecommunications, airlines, utilities and petroleum, some of this work being carried out for investment bankers who were attempting to enhance their sector analysis capabilities. And strategic models that explicitly examined head-to-head competition dynamics were also undertaken on a regular basis.

In all this we relied entirely on the time and talents of an increasing number of well-trained MIT alumni/ae to develop and apply System Dynamics modeling capabilities to the benefit of many very large organizations in North America and Europe. We leveraged our own capacity by also working with several other strategic consulting firms to apply System Dynamics modeling to their clients' problems, bringing our skills to their needs. We could never have done this without MIT, which provided a great supply of motivated and well-educated graduate students who received their base training in the core System Dynamics classes at the Sloan School.

I am quite concerned, however, with what I have observed as an apparent drift in recent years to system thinking as the primary identity of System Dynamics. In particular I am wholly skeptical about the linkage of the field with some individuals' personal advocacy of specific views and approaches to organizational learning and change. To me, rigorous modeling, supported by empirical observation and data gathering, is and ought to remain the essence of useful System Dynamics.

Some Observations About Making System Dynamics Useful

I have thought often about how to produce a high degree of impact from System Dynamics modeling (see my early papers on the subject in Roberts 1978). Many of my conclusions in this regard came from listening to and learning from Jay Forrester. Some of these observations inevitably are my own, while trying to do useful work in the MIT "Mens et Manus" tradition. On the occasion in 1995 of the 32nd anniversary of the founding of Pugh-Roberts Associates, Ken Cooper, then well ensconced in PA Consulting, decided to hold an anniversary party for the no longer existing PRA. He presented plaques to Jack Pugh and me that traced in causal loop fashion the growth and development of Pugh-Roberts. The celebration was enjoyable, but I was most taken by the quote that Ken Cooper insisted I had repeatedly asserted nearly 30 years before: "We will do high-quality System Dynamics work that is important, and at a profit if possible." Perhaps attitudes and expressed priorities provide a guiding basis for implementation and impact.

1. Don't undertake trivial projects. Expend your intelligence and efforts toward significant goals, not tiny ones.

2. Seek implementation in all you do. Modeling doesn't stop at comprehensive analyses and reporting. That is merely a midway point toward the objective of impact.

3. In all modeling undertakings identify and work closely with a “client” who can take responsibility for achieving change. If that is not possible, decline the job.

4. Think about the possible paths toward implementation of change at the outset of your modeling, rather than at the end. Implementation focus will likely alter your very conceptualization of the model itself, its scope and its structure.

5. Don’t be afraid to turn away from modeling topics that seem inappropriate, even after you have begun the work. For example, my refusal to go further in an intended investment decision-making model-building effort for a major North American insurance company led to a total redefinition of the project and to three years of high-level consulting work by PRA in reorganizing the primary aspects of that company.

6. Assume that your models must embed or carefully reflect real data. Few organizations will be willing to make changes that are unsupported by what they would regard as a validated model formulation and results that can be defended in detail.

7. Be totally ethical in all you do.

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