The Beginning of System Dynamics

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This evening I have been asked to give not a technical talk but a very personal recollection of how I came to develop the field of system dynamics. There are two threads that ran through the history. First, everything I have ever done has converged to become system dynamics. Second, at many critical moments, when opportunity knocked, I was willing to walk through the open door to what was on the other side. Let me discuss this combination of past experience and the turning points that led from one stage to the next.

I grew up on a cattle ranch in Nebraska in the middle of the United States. A ranch is a cross-roads of economic forces. Supply and demand, changing prices and costs, and economic pressures of agriculture become a very personal, powerful, and dominating part of life. Furthermore, in an agricultural setting, life must be very practical. It is not theoretical, it is not conceptual without purpose. One works to get results. It is full-time immersion in the real world. In high school, I built a wind-driven electric plant that provided our first electricity. That was a very practical activity. When I finished high school, I had received a scholarship to go to the Agricultural College when one of those important turning points intervened. Three weeks before enrolling at the Agricultural College, I decided it wasn't for me. Herding cattle in Nebraska winter blizzards never had appealed to me. So instead, I enrolled in the Engineering College at the University of Nebraska. Electrical engineering, as it turns out, was about the only academic field with a solid, central core of theoretical dynamics. And so, the road to the present began.

Finishing the University brought another turning point. I came to the Massachusetts Institute of Technology for two reasons. First, they offered me a $100 per month research assistantship, which was more money than any other university had offered. Second, my mother had been a librarian in Springfield, Massachusetts for two or three years in her youth and she knew there was such a thing as MIT. In the Midwest of the United States at that time, M.I.T. had tended to mean the "Massachusetts Investor's Trust," not an engineering school. In my first year at MIT came another one of those turning points. I was commandeered by Gordon S. Brown who was the pioneer in "feedback control systems" at MIT. During World War II my work with Gordon Brown was in developing servomechanisms for the control of radar antennas and gun mounts. Again, it was research toward an extremely practical end that ran from mathematical theory to the operating field, and I do mean the operating field. At one stage, we had built an experimental control for a radar to go on an aircraft carrier to direct fighter planes against enemy targets. The captain of the carrier Lexington came to MIT and saw this experimental unit, which was planned for redesign to go into production a year or so later. He said, "I want that, I mean that very one, we can't wait for the production ones." He got it. And about nine months later the experimental control units stopped working. I volunteered to go to Pearl Harbor to see why they were not functioning. Having discovered the problem, but not having time to fix it, the executive officer of the ship came to me and said they were about to leave port. He asked if I would like to come with them and finish my job? So I said "Yes," having no idea quite what that meant. We were off-shore during the invasion of Tarawa and then took a turn down through the middle between the Sunrise and Sunset chains of the Marshall Islands. The islands were occupied on both sides by Japanese fighter-plane bases and they didn't like having a U.S. Navy Task Force wrecking their airports. So they kept trying to sink our ships. After dark they dropped flares along one side of the task force and come in with torpedo planes from the other side. Finally at ll p.m. they succeeded in hitting the Lexington, cutting off one of the four propellers and setting the rudder in a hard turn. Again, it gave a very practical view of how research and theory are related to the field application.

At the end of World War II came yet another turning point. I had about decided either to get a job or start a company in feedback control systems. Gordon Brown again intervened, he was my mentor for many years at MIT. He had a list of projects that he thought might interest me. I picked from the list the building of an aircraft flight simulator. It was to be rather like an aircraft pilot trainer, except that it was to be so precise that instead of acting like a known airplane, it could take wind tunnel data of a model plane and predict the behavior of the airplane before it was built. This project was promoted by Admiral Louis deFlorez of the U.S. Navy. deFlorez was a flamboyant individual with a waxed mustache coming to points at each end. He is the only person who, by some process, had standing permission to land a sea-plane on the sailing basin in front of MIT. He would come to MIT on Alumni Day and the Metropolitan District Police would clear the basin of sail-boats so he could land his sea-plane. He would attend part of the program and, when the speeches became boring, he would rev up the engines of his seaplane and take-off while the noise of the engines would drown out the program.

The aircraft simulator was planned as an analog computer. It took us only about a year to decide that an analog machine of that complexity would do no more than solve its own internal idiosyncrasies. An analog computer could not deal with the problem at hand. Through a long sequence of changes we came to design the Whirlwind digital computer for experimental development of military combat information systems. This eventually became the SAGE (Semi-Automatic Ground Environment) air defense system for North America.

The SAGE air defense system was another one of those practical jobs where theory and new ideas were only as good as the working results. The SAGE system had about 35 control centers, each 160 feet square, four stories high, and containing about 80,000 vacuum tubes. Make a quick estimate to yourself as to what percentage of the time you think a center with 80,000 vacuum tubes would be operational. These computer centers were installed in the late 1950s, the last was decommissioned in 1983. They were in service about 25 years. The statistics show they were operational 99.8% of the time. That would be less than 20 hours a year that a center was out of operation. Even today, such reliability is a hard record to match.

People ask why I left engineering to go into management. There were several reasons. By 1956, I felt the pioneering days in digital computers were over. That might seem surprising after the major technical advances of the last 30 years. But, I might point out that the multiple by which computers improved in the decade from 1946 to 1956 in speed, reliability, and storage capacity, was greater than in any decade since. Another reason for moving to management was that I was already in management. We had been running a several billion dollar operation in which we had complete control of everything. We wrote the contracts between the prime contractors and the Air Force. We designed the computers with full control over what went into production. We had been managing an enterprise that involved the Air Defense Command, the Air Material Command, the Air Research and Development Command, Western Electric, A.T.&T., and I.B.M. So, it was not really a change to go into management.

It was time for another turning point. James Killian, who was then president of MIT, brought a group of visiting dignitaries to see us at Lincoln Laboratory. While walking down the hall with Killian, he told me of the new management school that MIT was starting, and suggested that I might be interested.

The Sloan School of Management had been founded in 1952 with a grant of ten million dollars from Alfred Sloan, the man who built the modern General Motors Corporation. The money was given on the expectation that a management school in a technical environment like MIT would probably develop differently, from one in a liberal arts environment like Harvard, or Columbia, or Chicago. Maybe better, but in any case different, and it was worth ten million dollars to run the experiment.

In the four years before I joined the School in 1956, standard courses had been started, but nothing had been done about what a management school within an engineering environment might mean. By that time, I had 15 years in the science and engineering side of MIT and it seemed like an interesting challenge to look at what an engineering background could mean to management.

It was assumed that an application of technology to management meant either to push forward the field of operations research, or to explore the use of computers for the handling of management information. I had a year free of other duties except to decide why I was at the Sloan School. On computers for management information, there were manufacturers in the computer business, there were banks and insurance companies using computers. It did not seem that a few of us in a management school would have major impact because the momentum was already so great. As I looked at the field of operations research, it seemed interesting; it no doubt was useful; but it was not working with issues that made the difference between corporate success and failure. Operations research did not have that practical importance that I had always worked toward.

Again chance intervened when I found myself at times in conversation with people from General Electric. They were puzzled by why their household appliance plants in Kentucky were sometimes working three and four shifts and then a few years later, half the people would be laid off. It was easy enough to say that business cycles caused fluctuating demand, but that explanation was not convincing as the entire reason.

After talking with them about how they made hiring and inventory decisions, I started to do some simulation. This was simulation using pencil and paper on one notebook page. It started at the top with columns for inventories, employees, and orders. Given these conditions and the policies they were following, one could decide how many people would be hired in the following week. This gave a new condition of employment, inventories, and production. It became evident that here was potential for an oscillatory or unstable system that was entirely internally determined. Even with constant incoming orders, one could get employment instability as a consequence of commonly used decision-making policies. That first inventory control system with pencil and paper simulation was the beginning of system dynamics.

Even out of that first dynamic analysis came the early beginning of what are now the DYNAMO compilers. An expert computer programmer, Richard Bennett, worked for me when I was writing the 1958 article, "Industrial Dynamics—A Major Breakthrough for Decision Makers," for the *Harvard Business Review*. That article is chapter two of *Industrial Dynamics*. For that article I needed computer simulations and asked Bennett just to code up the equations so we could run them on our computer. However, Dick Bennett was a very independent type. He said he would not code the program for that set of equations but would make a compiler that would automatically create the computer code. He called the compiler "SIMPLE," meaning "Simulation of Industrial Management Problems with Lots of Equations." Bennett's insistence on creating a compiler is another of the important turning points; it accelerated later modeling that rapidly expanded system dynamics. Jack Pugh has since extended the early system dynamics compilers into the very influential DYNAMO series.

At about the time system dynamics was starting, I was asked to be on the board of the Digital Equipment Corporation because Kenneth Olsen and other founders of the company had worked for me in the Whirlwind computer days. I did not understand the nature of a high technology growth companies as well as I would like and undertook to model such companies to guide my own position on he board. From the modeling came a number of insights about why high technology companies often grow to a certain level and then stagnate or fail. This modeling of corporate growth moved system dynamics out of physical variables like inventory into much more subtle considerations. Over 90% of the variables in that model lay in the top-management influence structure, leadership qualities, character of the founders, how goals of the organization are created, and how the past traditions of an organization determine its decision making and its future. The model also dealt with the interactions between capacity, price, quality, and delivery delay.

Another turning point in 1968 led to expansion of system dynamics to Germany when Professor Gert von Kortzfleisch of Mannheim University spent several months at MIT and took system dynamics back to his university. Several of his students, including Erich Zahn and Peter Milling who have organized this conference, are now leaders in the field.

Another series of incidents in 1968 moved system dynamics from corporate modeling to broader social systems. John F. Collins, who had been mayor of Boston for eight years, decided not to run for re-election. MIT gave him a one-year appointment as a Visiting Professor of Urban Affairs bringing him into the academic orbit to meet students, interact with faculty, and advise the administration on political issues. Collins had been a victim of polio in the epidemic of the mid 1950s and walked with two arm canes, so he needed an office in a building with automobile access to the elevator level. The building with my office was one of the few that qualified. The professor next door to me was away for a year on sabbatical leave, so John Collins ended up in the adjacent office. In discussions with Collins about his eight years coping with Boston urban problems I developed the same feeling that I had come to recognize in talking to corporate executives. The story sounded persuasive but it left an uneasy sense that something was wrong or incomplete. So, I suggested to Collins that we might combine our efforts, taking his experience in cities and my background in modeling, and look for interesting insights about cities. He immediately asked how to go about it. I told him we would need advisers who knew a great deal about cities from personal experience, not those whose knowledge came only from study and reading. We needed people who had struggled with cities, worked in them, and knew what really happens. And furthermore, we would not know what would come of the effort, or how long it might take. The process would be to gather a group that would meet half a day a week, probably for months, to seek insights into the structure and processes of cities that could explain stagnation and unemployment. Collins listened and said, "They'll be here on Wednesday afternoon." Collins' position in Boston at that time was such that he could call up almost anybody in politics or business, ask for their Wednesday afternoons for a year, and get them. He delivered the people and it was out of the following discussions that *Urban Dynamics* developed.

Urban Dynamics was the first of my modeling work that produced strong, emotional reactions. As you know, it suggested that all of the major urban policies that the United States was following lay somewhere between neutral and highly detrimental, from the viewpoint either of the city as an institution, or from the viewpoint of the low-income, unemployed residents. And that the most damaging policy was to build low-cost housing. At that time, building low-cost housing was believed to be essential to reviving the inner cities. The conclusions of our work were not easily accepted. I recall one full professor of social science in our fine institution at MIT coming to me and saying, "I don't care whether you're right or wrong, the results are unacceptable." So much for academic objectivity! Others, probably believing the same thing, put it more cautiously as, "It doesn't make any difference whether you're right or wrong, urban officials and the residents of the inner city will never accept those ideas." It turned out that those were the two groups we could count on for support if they became sufficiently involved to understand. That is a very big "if"—if they came close enough to understand. Three to five hours were required to come to an understanding of what urban dynamics was about. Urban officials and members of the black community in the inner city would become more and more negative and more and more emotional during those three to five hours. If they were not a captive audience, they would walk out before they understood and accepted the way in which low-cost housing was a double-edged sword for making urban conditions worse. Such housing used up space where jobs could be created, while drawing in people who needed jobs. Constructing low-cost housing was a powerful process for creating poverty, not alleviating it.

My first experience with reactions to *Urban Dynamics* came soon after the book was published. We had been running a four-week urban executive's program twice a year for department-head level people from larger cities to teach various aspects of management. A group was convening shortly after *Urban Dynamics* came out. I was asked to take a Monday afternoon and a Wednesday morning to present the *Urban Dynamics* story. I have never had a lecture on any subject, any place, any time go as badly as that Monday afternoon. In the group was a man from the black community in New York who was a member of the city government. He was from Harlem, intelligent, articulate, not buying a thing I was saying, and carrying the group with him. At one point he said, "This is just another way to trample on the rights of the poor people and it's immoral." At another point he said, "You're not dealing with the black versus white problem, and if you're not dealing with the black versus white problem, you're not dealing with the urban problem." And when I said decay and poverty in Harlem in New York or Roxbury in Boston was made worse by too much low-cost housing, not too little, he looked at me and said, "I come from Harlem and there's certainly not too much housing in Harlem." That is a sample of the afternoon. On Tuesday evening, a dinner was held for the group. Neither Collins nor I could go; but several of our students attended. One student called me at home in the evening to report what was fairly obvious anyway—that the group was very hostile. On that bit of encouragement, I started Wednesday morning.

An hour into Wednesday morning, the New Yorker's comments began to change character. He was no longer tearing down what was being said. His questions began to elicit information. Two hours into the morning, he said, "We can't leave the subject here at the end of this morning. We must have another session." I ignored the request to see what would happen next. In about twenty minutes, he repeated it. I agreed to meet them again if he could find a time and place in the program. I was not trying to put him off, however, that usually ends such an exchange. But he went to the administration and scheduled another session. Later he made an appointment to come to my office to ask that I talk to a group he would invite in New York—his colleagues on his home turf. He sat in my office as relaxed as could be and said, "You know, it's not a race problem in New York at all, it's an economic problem," after telling me four days earlier that I was not even addressing the urban problem if I was not dealing with the black versus white issue. He gave me a report out of his brief case documenting the amount of empty housing in every borough of New York and the rate at which it was being abandoned. My point had been that too much housing meant that there was too much for the economy of the area to support. He had all the proof right in his brief case. He simply had not realized what his knowledge meant until it was all put together in a new way.

Two years later a journalist asked me what people thought in the aftermath of *Urban Dynamics*. I suggested that he talk to others, and especially with the man in New York whom I had not contacted in the intervening two years. After the interview, the journalist called me to report that he had been told that "they don't just have a solution to the urban problem up there at MIT, they have the only solution." The lesson about urban behavior had stayed clear and alive for two years even back home in his native environment. The five hours of exposure to *Urban Dynamics* had made a lasting impression. But we have not solved the challenge of how to bring enough people across the barrier separating their usual, simple, static viewpoint from a more comprehensive understanding of dynamic complexity.

Urban Dynamics was the key that led to both the System Dynamics National Model, and the *World Dynamics* and *Limits to Growth* projects. The urban work established my contact with the Club of Rome through a meeting on urban difficulties in Italy at Lake Como. There I first met Aurelio Peccei, founder of the Club of Rome. Later I was invited to a meeting of the Club in June, 1970, in Bern, Switzerland, which became another turning point in my career with system dynamics. What followed is more fully described in the introduction to *World Dynamics*.

The world problems discussed at the Bern meeting became the basis for the model in *World Dynamics*, which was used in a two-week meeting with the executive committee of the Club of Rome at MIT in July 1970. The executive committee included Eduard Pestel, president of the Technical University of Hannover. Pestel was a very forceful person and quickly saw the power of system dynamics. The executive committee decided to support research at MIT to go beyond the material that had been presented at the meeting. Pestel arranged for the

Volkswagen Foundation to support research that produced the *Limits to Growth* book.

As we meet here in Stuttgart, we should note the influence that Germany has had on system dynamics. Professor von Kortzfleisch and his students are leaders in the field. Eduard Pestel was primarily responsible for the convergence of system dynamics and the Club of Rome. Pestel was one of the most able people that I have met. He spoke six languages that included Russian and Japanese. He was decisive and had a forceful approach to problem solving. I have been told one story that illustrates his unique handling of difficult situations. It seems that around 1970, while he was president of the Technical University of Hannover, he was afflicted by more than his share of dissident students who were followers of Chairman Mao. So how would one deal with them? As I understand it, Pestel memorized Mao's Red Book from cover to cover by page number. He would take on anyone who wanted to argue according to Chairman Mao. Like many great books, one could find quotations to justify either side of an argument. The students felt it very unfair that Pestel could defeat their arguments based on their own source of wisdom!

The public responses to system dynamics have always surprised me. People ask me how I think people will react when the National Model books are released. I don't know. Usually I have been wrong in anticipating the effect that system dynamics books will have. In 1971 World *Dynamics* seemed to have everything necessary to guarantee no public notice. First, it had forty pages of equations in the middle of the book, that should be sufficient to squelch public interest. Second, the interesting messages were in the form of computer output graphs, and most of the public do not understand such presentations. Third, the book was brought out by a publisher that had published only one previous book and I doubted that it would have the commercial status to even get reviewed. I thought I was writing for maybe 200 people who would like to try an interesting model on their computers. But, as you know, I was wrong.

World Dynamics came out the first week of June, 1971. The last week of June it was reviewed on the front page of the *London Observer.* I received a letter from a university professor in New York asking for more information because he had been reading about the book in the *Singapore Times.* In August the book had the full front page of the second section of the *Christian Science Monitor*, in September a page and a half in *Fortune*, and in October a column in the *Wall Street Journal*. It was running through editorial columns of mid-America newspapers, it was the subject of prime time documentary television in Europe, it was debated in the environmental press, the zero population growth press, and the anti-establishment underground student press. And, if you don't like your literature on either the establishment right or the establishment left, then right in the middle of the political spectrum, it had a full-length article in *Playboy*. *Playboy* was a disappointment as a vehicle for system dynamics. Out of eight million copies in circulation, the only response I ever received was a request for putting on a two-day meeting after the article was read by a man at the National Council of Churches.

Nine months after *World Dynamics, Limits to Growth* was published. The message was essentially the same, although much more work had been done and the book was more popularly written. Even so, after the earlier attention from the media, it seemed that the second book would be an anti-climax. One can be wrong twice in succession in the same way. Public attention seemed to go up another factor of ten after appearance of *Limits to Growth*.

The *Urban Dynamics* book also led to our work on the National Model. After I gave a talk at a joint NATO/US conference on cities in Indianapolis, Indiana, William Dietel, recently retired as president of the Rockefeller Brothers Fund, came up from the audience to discuss their future programs. From that meeting came initial funding for our work in applying system dynamics to behavior of economic systems.

One often sees in the social science literature assertions that the act of studying an organization, say a corporation, will alert people to questions about their actions and that the study process itself will cause changes in behavior. I do not believe this is true. It is much harder to change the decision-making procedures than we first realized when system dynamics started. Old mental models and decision habits are deeply ingrained. They do not change on the basis of only a logical argument. Early system dynamics analyses were in the "consultant" mode in which the system dynamicist would study a corporation, go away and build a model, and come back with recommendations. Usually these suggestions would be accepted as a logical argument, but would not alter behavior. Under pressure of daily operations, decisions would revert to prior practice.

Recent trends in system dynamics aim at changing those mental models that people use to represent the real world. To do this a person must become sufficiently involved in the modeling process to internalize lessons about dynamic feedback behavior. Such exposure to dynamic thinking should start at an early age before contrary patterns of thought have become inflexibly established. Apparently exposure to cause-and-effect feedback thinking and computer modeling can successfully begin in schools for students around ten years old.

Through the efforts of Barry Richmond and others, system dynamics is being brought into a dozen or more junior and senior high schools. Macintosh computers and the STELLA software are particularly user friendly and suitable for pre-college education. I am pleased to learn that the System Dynamics Society has given this year's Forrester prize for the best publication to Barry Richmond for the *User's Guide to STELLA* and the software.

At the beginning of my talk I mentioned having been introduced to feedback systems by Gordon Brown in the MIT Servomechanisms Laboratory in the early 1940s. He later became head of the Electrical Engineering Department and then Dean of Engineering before retiring about 17 years ago. In the meantime, I went on to develop computers and the field of system dynamics based on that early background in feedback systems. In recent years Gordon has completed the circle by picking up system dynamics and introducing it into a junior high school in Tucson, Arizona where he spends the winters. He started by loaning STELLA software for a weekend to Frank Draper who teaches 8th grade biology. Draper came back on Monday to say, "This is what I have always been looking for, I just did not know what it could be." At first he expected to use computer simulation in one or two classes during a term. Then he found that systems thinking and simulation were becoming a part of every class. That led to concern that he would not have time to cover all of the biology subject if so much time were spent on the system dynamics component. But two thirds of the way through the term, he had completed all of the usual biology content because of the more rapid pace made possible by the integrative aspects and the greater student involvement made possible by the systems viewpoint and the "learner-directed learning" organization within the class that was introduced at the same time. To quote Draper, "There is a free lunch."[1]

In management education we should look forward to a major breakthrough in scope and effectiveness when system dynamics is fully adopted to move beyond the case-study method of teaching managers. Case studies were pioneered by the Harvard Business School beginning around 1910. That approach is widely used around the world. A case study starts in the same way as a system dynamics analysis, by gathering and organizing information from the actual managerial setting. But the case study leaves that information in a descriptive form that cannot reliably cope with the dynamic complexity that is involved. System dynamics modeling can organize the descriptive information, retain the richness of the real processes, build on the experiential knowledge of managers, and reveal the variety of dynamic behaviors that follow from different choices of policies.[2] I anticipate

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[1] See Forrester (1990) for a more complete description of the combination of systems thinking and learner-directed learning.

[2] See Forrester (1985 and 1988) for system dynamics in management education.

this will become the frontier of new developments in management education during the next twenty years.

Whether we think of pre-college or management education, the emphasis will focus on “generic structures.” A rather small number of relatively simple structures will be found repeatedly in different businesses, professions, and real-life settings. One of Draper’s junior high school students, working with bacteria in a culture and in computer simulation, looked up and observed, “This is the world population problem, isn’t it?” Such transfer of insights from one setting to another will help to break down the barriers between disciplines. It means that learning in one field becomes applicable to other fields. There is now a promise of reversing the trend of the last century that has been moving away form the “Renaissance man” toward fragmented specialization. We can now work toward an integrated, systemic, educational process that is more efficient, more appropriate to a world of increasing complexity, and more compatible with a unity in life.

REFERENCES

Alfeld, Louis Edward, and Alan K. Graham, 1976. *Introduction to Urban Dynamics*, Waltham, MA: Pegasus Communications. 333 pp.

Forrester, Jay W., 1961. *Industrial Dynamics*, Waltham, MA: Pegasus Communications. 464 pp.

Forrester, Jay W., 1968. *Principles of Systems*, (2nd ed.). Waltham, MA: Pegasus Communications. 391 pp.

Forrester, Jay W., 1969. *Urban Dynamics*, Waltham, MA: Pegasus Communications. 285 pp.

Forrester, Jay W., 1973. *World Dynamics*, (2 ed.). Waltham, MA: Pegasus Communications. 144 pp.

Forrester, Jay W., 1975. *Collected Papers of Jay W. Forrester*, Waltham, MA: Pegasus Communications. 284 pp.

Forrester, Jay W. (1980). Information Sources for Modeling the National Economy. *Journal of the American Statistical Association*, 75(371), 555-574.

Forrester, Jay W. (1985). *System Dynamics in Management Education* (D-3721-1). System Dynamics Group, Sloan School. Cambridge, MA. Massachusetts Institute of Technology. June 3. 5 pp.

Forrester, Jay W. (1987). Lessons from System Dynamics Modeling. *System Dynamics Review*, 3(2), 136-149.

Forrester, Jay W. (1988). *Designing Social and Managerial Systems* (D-4006-1). System Dynamics Group, Sloan School. Cambridge, MA. Massachusetts Institute of Technology. October 20. 10 pp.

Forrester, Jay W. (1990). *System Dynamics as a Foundation for Pre-College Education* (D-4133). Cambridge, MA 02139. System Dynamics Group, Massachusetts Institute of Technology. April 10. 14 pp.

Forrester, Jay W., and Peter M. Senge. (1980). Tests for Building Confidence in System Dynamics Models. In A. A. Legasto Jr. (Ed.), *System Dynamics* . Studies in the Management Sciences. (pp. 209-228). New York: North-Holland.

Goodman, Michael R., 1974. *Study Notes in System Dynamics*, Waltham, MA: Pegasus Communications. 388 pp.

Mass, Nathaniel J., ed., 1974. *Readings in Urban Dynamics: Volume I*, Waltham, MA: Pegasus Communications. 303 pp.

Meadows, Dennis L., William W. Behrens, III, Donella H. Meadows, Roger F. Naill, Jørgen Randers, and Erich K. O. Zahn, 1974. *Dynamics of Growth in a Finite World*, Waltham, MA: Pegasus Communications. 637 pp.

Meadows, Dennis L., and Donella H. Meadows, ed., 1973. *Toward Global Equilibrium: Collected Papers*, Waltham, MA: Pegasus Communications. 358 pp.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. (1972). *The Limits to Growth*. New York: Universe Books. 205 pp.

Pugh, Alexander L., III, 1986. *Professional DYNAMO Plus Reference Manual*. 5 Lee St, Cambridge, MA: Pugh-Roberts Associates.

Randers, Jørgen, ed., 1980. *Elements of the System Dynamics Method*, Waltham, MA: Pegasus Communications, 488 pp.

Richardson, George P., and Alexander L. Pugh, III, 1981. *Introduction to System Dynamics Modeling with DYNAMO*, Waltham, MA: Pegasus Communications. 413 pp.

Richmond, Barry, Steve Peterson, and Peter Vescuso. (1987). *An Academic User's Guide to STELLA*. Macintosh computer program, 45 Lyme Road, Hanover, NH 03755: High Performance Systems, 392 pp.

Roberts, Edward B., 1978. *Managerial Applications of System Dynamics*, Waltham, MA: Pegasus Communications. 562 pp.

Roberts, Nancy. (1978). Teaching Dynamic Feedback Systems Thinking: an Elementary View. *Management Science*, 24(8), 836-43.

Roberts, Nancy, David Andersen, Ralph Deal, Michael Garet, and William Shaffer, 1983. *Introduction to Computer Simulation: A System Dynamics Modeling Approach,* Waltham, MA: Pegasus Communications. 562 pp.

Schroeder, Walter W., III, Robert E. Sweeney, and Louis Edward Alfeld, ed., 1975. *Readings in Urban Dynamics: Volume 2*, Waltham, MA: Pegasus Communications. 305 pp.

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System dynamics modeling should build on all available information, including the voluminous mental database. By contrast, most analyses in the social sciences have been limited to information that has been numerically recorded. The numerical information is an extremely small part of all the information that is available.Â A topic came up that was not on the agenda. They began to talk about a doctor who was doing an experimental treatment, which clearly those present did not approve. They had described the experiment but had said nothing of the results when I suggested an outcome. System dynamics was created during the mid-1950s by Professor Jay W. Forrester of the Massachusetts Institute of Technology. Forrester arrived at MIT in 1939 for graduate study in electrical engineering. His first research assistantship put him under the tutelage of Professor Gordon Brown, the founder of MIT's Servomechanism Laboratory.Â These hand simulations were the beginning of the field of system dynamics. During the late 1950s and early 1960s, Forrester and a team of graduate students moved the emerging field of system dynamics, in rapid fashion, from the hand-simulation stage to the formal computer modeling stage. Academic journal article The McKinsey Quarterly. The Beginning of System Dynamics. By Forrester, Jay W. Read preview. Academic journal article The McKinsey Quarterly. The Beginning of System Dynamics. By Forrester, Jay W. Read preview. Article excerpt.Â Adapted from a speech given in 1989 by the inventor of system dynamics. Jay Forrester, the following article is both a short history and a helpful primer. Forrester describes how the ideas he used to uncover the real causes of cyclicality in industry could be adopted to explain why low-cost housing has failed to renew inner city neighborhoods. At the end of the article, a postscript sums up developments that have taken place in system dynamics in the past six years.

System Dynamics Society Stuttgart, Germany July 13, l989. 2 D-4165-1. This evening I have been asked to give not a technical talk but a very personal recollection of how I came to develop the field of system dynamics. There are two threads that ran through the history. First, everything I have ever done has converged to become system dynamics.Â Even out of that first dynamic analysis came the early beginning of what are now the DYNAMO compilers. An expert computer programmer, Richard Bennett, worked for me when I was writing the 1958 article, "Industrial Dynamicsâ€"A Major Breakthrough for Decision Makers," for the Harvard Business Review. That article is chapter two of Industrial Dynamics. ðŸŽ¦ System dynamics. Quite the same Wikipedia. Just better.Â We have to loop back to the beginning. This happens continually all the way through the project. And it's that feedback that's critical here.Â Topics in systems dynamics. The elements of system dynamics diagrams are feedback, accumulation of flows into stocks and time delays. As an illustration of the use of system dynamics, imagine an organisation that plans to introduce an innovative new durable consumer product. The organisation needs to understand the possible market dynamics in order to design marketing and production plans. Causal loop diagrams. Main article: Causal loop diagram. The system dynamics is an essential part of the EMTDC solution process. It serves to encompass the electric network, providing the ability to interface with it on either side: Data may be controlled from one side, while extracted from the other. Essentially a Fortran program in its own right, the system dynamics is built according to customizable specifications.Â The BEGIN subroutine is used for time zero operations, such as variable initialization and storage. Although the use of BEGIN is not mandatory, it is required if a component is to support its use within modules with multiple instances. Components with source specified for the BEGIN subroutine are said to be Runtime Configurable.