Interview with Jay W. Forrester on System Dynamics

Interviewers:
Mark Keough and Andrew Doman
McKinsey & Company

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McKinsey: What drives the resurgence of interest in system dynamics now?

Forrester: We are seeing not a resurgence but a natural consequence of exponential growth. Suppose the number of system dynamics practitioners doubles every three years. If you start with one person, in three years there will be two, in six years there will be four, and so on. In the 36 years since system dynamics was started in 1956, there has been time for 12 doublings. Such exponential growth would bring the number now to over 4000. Probably at least that many are today engaged in some aspects of system dynamics.

Such growth resembles that in the pioneering days of digital computers. My first exposure to the field of computation was as a research assistant sitting in a room with the 30 people in the world interested in computation. (At that early stage, a "computer" meant a young woman at a mechanical keyboard calculating machine.) A few years later, I was presenting papers at other people's meetings on digital computers, then organizing sessions for meetings of growing size, and still later presenting keynote addresses at annual computer society meetings of 1000 people. Finally, I went to a computer convention of 20,000 people and found no one there I knew nor anyone who knew me. It was time to get out. So I moved to pioneering in system dynamics.[1] Sometime in the future, if I go to a system dynamics meeting where I recognize no one, and no one there has ever heard of me, it will be long past time for me to have shifted to something else.

McKinsey: Is there any way to accelerate the growth curve of system dynamics?

Forrester: With any field, growth depends on the challenge, persuasiveness, and importance of the field. Actually, interest in system dynamics is growing faster than the supply of skilled professionals in the field. At present, the bottleneck is in education for system dynamics expertise. Educational output is impeded by inherent conservatism of universities. Faculties in existing departments tend to

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[1] Forrester, Jay W. 1961. *Industrial Dynamics*. Waltham, MA. Pegasus Communications, 464 pp.

favor new appointees with the same backgrounds as their own. New fields, like system dynamics, that cut across boundaries of existing fields, but do not lie within any one of those fields, lack a home and a supporting constituency. It is like the early days of physical science and engineering, which for a long time were excluded from the old established universities. Schools of technology were created to fill the vacuum. Perhaps we should be thinking about new institutions set up especially for research and teaching in physical, medical, social, and economic dynamics.

McKinsey: What do you see as the key philosophical milestones in the development of system dynamics?

Forrester: I do not know of any single milestone that I would call a major philosophical change, unless we should include the transition of system dynamics from a process in which a consultant builds a model for a client to a process where the system dynamics objective is to help people alter and improve their mental models. Only by changing mental models will one change decisions. People need to understand better how the structures and policies of organizations shape the behavior of corporations and countries.

Operational milestones include the progression of improvements in system dynamics software. Originally there was only DYNAMO from Pugh-Roberts, running on IBM mainframe computers. The more user-friendly STELLA and ITHINK were developed by High Performance Systems for Macintosh computers. For serious professional work with larger models, we now have PROFESSIONAL DYNAMO or the other powerful software applications such as VENSIM from Ventana Systems. I have recently been using the latter for my work on the national economic model.

McKinsey: Do you expect senior managers to use such software?

Forrester: Yes. Some are already doing so. Others will gradually join. The role of senior management, especially of chief executive officers, should be that of corporate designers and not of corporate operators. The CEO can have assistance for details of simulations. But CEOs will eventually need to be competent in creation and use of models to lead such activity effectively.

I am told that in one large corporation in Europe, the recently appointed president was the first CEO in that corporation to have a personal computer on his desk, and the first thing he wanted on that computer was the VENSIM software for system dynamics modeling. There are not yet many CEOs who are serious about corporate design, but in the future, the most effective CEOs will not be ones making day-by-day decisions, but ones who are designing their corporations. Such

design includes structuring what information is available and to whom, establishing policies that govern decisions, and deciding what decisions should be made where.

Future CEOs will focus on creating corporate designs in which ordinary and available people can succeed. Too often, we see people in corporate positions repeatedly blamed for failure and replaced when the fault lies in the situation into which they are put. That is, the design of the organization is defective. Unnecessary and distracting information may be supplied while necessary information is missing. Often, the corporate design allows, or even specifies, that decisions be made at the wrong places.

Responsibility for decisions should fit the context of available information, authority, and the systems impact of the decision. For example, production managers should not decide production rates and sales managers should not set prices, because the impact of those decisions affect the corporate system outside their own departments.

McKinsey: Why shouldn't a production manager decide production rates?

Forrester: How much to make is tied very closely to sales, pricing, advertising, and inventory that lie outside a production manager's domain. A production manager should decide how to achieve efficient production, how to maintain morale, and how to make good use of machines. Such decisions are in his domain. When management imposes the decision about production rate on the production manager, the decision cannot be made properly; and the person becomes frustrated, is criticized, and often fired for making the production-rate decision incorrectly. Like many production managers, other managers throughout an organization make decisions that should not be theirs. As a result, their attention is diverted from the decisions they should make and that only they can make wisely.

McKinsey: Which department should decide pricing?

Forrester: It should definitely not be the sales department. A sales department has the wrong motivation and lacks a balanced view of the corporate system. When sales of a product stagnate or decline, salesmen want to reduce price to make selling easier. But reducing price often does not revive sales. Rather than price, sales may be limited by unavailability of product with long delivery delays, or poor service, or low quality.

Price setting is one of the system policies that tie together everything the corporation does. Prices interact with production rate, field service, quality,

profits, and product design. Pricing policy should not be set by any operating department but instead as a part of the overall corporate design.

The American automobile industry is an example of misjudging the role of prices. Detroit believed for two decades that Japan was selling automobiles here on the basis of lower price. So Detroit reduced prices and gave discounts. But aggressive pricing did not increase market share for American automobiles. In fact, just the opposite happened. Market share continued to drop because the American automotive industry took a long time to realize that customers do not buy cars on the basis of price alone. They buy substantially on the basis of trouble-free operation. However, with profit margins reduced by price discounts, the companies lacked the resources to fix the actual reasons for loss of sales.

McKinsey: What role do management information systems play in helping people make decisions that are theirs to make?

Forrester: People running management information systems have a tendency to make information available in more and more detail and variety to more and more people until everyone is overwhelmed with information. Information pollution may be our most serious form of pollution. Excess information focuses attention on information streams that are not appropriate to the decisions being made. The whole area of MIS needs to be designed using system dynamics, so that models can reveal the effect of having or not having certain information streams. The result would be to discontinue much of the present information flow and to supply a few critical information inputs that are not now available.

McKinsey: Does system dynamics support only corporate design, or is it also useful in making decisions on a day-to-day basis?

Forrester: System dynamics is primarily for the design of policy. By policy I mean the rules by which decisions are made. By determining policies, that is, the rules for decision-making, system dynamics establishes how the day-to-day decisions are to be made. A system dynamics model consists of a structure of policies, and shows how the decisions resulting from those policies create corporate stability, growth, market share, and profitability.

For example, production rate is based on backlog, inventories, production capacity, average past sales, profitability, corporate liquidity and other considerations. But how are the many inputs to be combined and interpreted in arriving at changes in production rate? And how quickly should changes be made? The rules used to assign importance to various inputs and to determine speed of response strongly influence stability of employment, market share, and profits. In my experience, an intuitive approach to adjusting production level is apt to be quite

counter-productive. People usually react too quickly and do too much. They forget that often the right advice is "don't just do something, stand there." But only a dynamic systems analysis can show the consequences of a proposed policy.

McKinsey: Could you provide some examples of policies that govern decisions?

Forrester: Yes. Policies exist at every point where decisions are made. Some policies cause harm, others contribute to success. In this electronic age where customers are repelled by electronic telephone answering with its long menu of touch-tone steps before locating someone with whom to do business, it is refreshing to find companies who have customer-friendly telephone policies. I know a furniture company in which the policy regarding customer satisfaction requires that every phone call be answered by a person within one or two rings. Furthermore, whoever answers the phone is authorized and expected to completely settle the issue raised by the customer. If people who normally answer phones are busy, those above or below them in the company receive the call. A caller might get anyone in the organization, and that person would settle the question or complaint. Such a policy builds loyal repeat customers.

The Nordstrom department store chain has policies toward service that have become legendary. One story involves a customer who complained because an automobile tire, which he said he bought at the store, had not stood up properly. The manager responded by giving a full refund on the tire, even though Nordstrom had never sold anything for automobiles! The story is worth many pages of advertising. The company has been conspicuously successful.

McKinsey: What are the situation factors that make it more likely for a corporate designer to succeed?

Forrester: First, management must believe the organization has a serious weakness. System dynamics can't help people who have no problems. Such people have no motivation for changing the way their organization operates.

Second, the organization must come to accept the realization that their problems are largely caused by themselves. At least, they must believe they have influence to change what is causing their problems. Requiring belief that they can create change, rules out many people who prefer to blame their problems on others. Once people recognize that they are part of the system causing their difficulties, it is easy for them to become interested in the nature of systems. They have already admitted that they and the way they are working with one another are causing undesirable symptoms.

Third, there must be a desire to understand what is happening and why, rather than a grasping for superficial quick fixes. To begin to understand "why" one needs a small group of people who have an inquisitive turn of mind, and who really want to understand what is going on. The group should include at least one senior manager, preferably the CEO. The individuals must be willing to sit through sessions in which their assumptions are put on a computer screen and challenged.

Only through such computer simulation will they see that their assumptions often do not lead to the expected behavior. The next step is to review and revise assumptions about corporate policies to get a convergence between new proposed policies and desired corporate behavior.

McKinsey: How often do you find managers who do the things you just described?

Forrester: Twenty years ago, very few managers thought in terms of designing a corporation. But the number is growing. Two reasons lie behind the increase.

First, many organizations sense that things are no longer going well. Consequently, many senior executives see that their primary role is no longer to exert direct control. More CEOs assert their primary job is to educate their people. They may not be sure what education is needed for a successful organization, but they have stepped away from running everyday operations to lay the groundwork through education so that other people can make better decisions.

Second, many managers no longer find a computer frightening. They have had experience with computers and are willing to apply them in a new way. We are moving toward a time when increasing numbers of corporate executives will be ready to take on the role of corporate designers. To succeed, they must realize that redesigning a corporation will take even longer than designing, producing, and marketing a major new product. Corporate redesign can be a ten-year job.

McKinsey: What kind of companies do these CEOs—who view themselves as corporate designers—lead and is there a good time when CEOs should start a redesign?

Forrester: It is not easy to specify a particular kind of company or the best time to start. One group of companies may not qualify: those that are in deep and increasing difficulty right now. They may not have sufficient time or freedom of action for redesign.

A good time for a CEO to play the corporate designer role is when the company is very successful. But when a company is successful, people are less likely to become uneasy about the future.

A second appropriate time for corporate redesign is when a founder-manager, who has built a successful company realizes he is not sure why the company has been successful, and is doubtful about others carrying on after his retirement.

A third excellent time for corporate design occurs when a new company is being organized. Many venture capitalists do not understand the ensemble of policies necessary for success. Very often a company is doomed to failure by the initial incompatibility among policies regarding growth, financing, pricing, and product development.

McKinsey: Does the ability to look ten years ahead come easier to CEOs in pharmaceutical and automotive companies, with long decision cycles or lead times?

Forrester: Willingness to take a long-range view seems to depend more on the person than the kind of company. System dynamics is equally applicable to companies with either long or short product cycles.

The automobile industry in the United States has had long product lead times, but has persistently taken a short-range view of decisions. A Detroit automobile company that resists recalls of defective cars undermines its long-term reputation for quality. A company that takes the short-term view in identifying its customers may see auto dealers as customers and produce cars to satisfy dealers who make most of their profits from a high frequency of automobile repairs. However, in the long-run the ultimate customers, the car owners, turn elsewhere to find cars that do not require frequent service.

McKinsey: How would system dynamics help the CEO of a Detroit company?

Forrester: A system dynamics model usually shows how management is creating the problems that the company is experiencing. Very often policies adopted to solve a problem are actually causes of the problem. Then, as matters get worse, pressures increase to apply more strongly the very policies that are causing the problem.

One sees the corporate equivalent of the "dead man's spiral" in aviation, which happens when a pilot without skill or instruments for blind flying enters a cloud bank. The pilot may feel the airplane is diving, so he pulls back on the

controls. But the sensation of diving continues and the pilot pulls back more. In fact, the plane is not diving but is in a tight turn. The pilot keeps pulling back until stresses of the tightening turn tear off the wings. The pilot is led to doing more and more of what is causing the problem until the airplane comes apart. One repeatedly sees the equivalent of the dead man's spiral in corporations.

To answer your question, a careful system dynamics examination of consequences of current policies in Detroit companies should suggest the road to more effective management.

McKinsey: Does a CEO have all the information needed to create a system dynamics model?

Forrester: Usually, everything needed to build an effective system dynamics model is available. The information is in the tremendous data base in people's heads. People know who uses what information, what decisions are made at each point in the system, and what has happened in the past. A system dynamics model is built from knowledge about policies. Usually enough is known about existing policies. Policies are statements specifying how people make decisions. One finds that people have sufficiently clear insight into why they do what they do.

Many times, I have had the experience of going into an organization with serious and widely-recognized difficulties, such as falling market share or high instability of employment. One can talk to Manager A about the pressures and reasons for decisions at that location in the company. Then in talking to Manager B about Manager A, the same picture emerges. In other words, people see themselves and each other in very much the same way. Repeating this exercise across several managers gives a good sense of how the organization operates. A system dynamics model, based on known policies, will behave like the corporation. It generates the same troubles. The troubles are inherent in the policies that people have known they were following. Often those policies are the very ones that people adopted because the policies were erroneously thought to solve the problem.

McKinsey: How much does the CEO need to know about technical details of system dynamics to create a good model?

Forrester: Creating a good system dynamics model requires the professional art of the field. A CEO without that skill should create a model along with someone who understands the system dynamics process. The modeling process needs to be guided by an advisor with an appreciation for the kinds of feedback structures capable of causing the problems that led to the modeling effort. The advisor must be sensitive to little things that are said, to where political power lies, to influence

centers, and to who is afraid of whom and why. All these are important ingredients of a policy structure. Such leadership in advising the modeling process cannot be provided by the average manager or someone out of an ordinary business school or consulting company. They will not know what dynamic structures to look for in conversations with the operating managers.

The advisor must be careful not to dictate what goes into creating a model. The model must come from the corporate participants and be done by them. This is delicate ground because the advisor must focus the managers on issues that matter, to avoid cluttering the model with unnecessary details. If managers undertook a model without a system dynamics background, they would probably fail. By themselves, system dynamics software and computers do not guarantee an effective model.

We can expect a growing number of CEOs who understand system dynamics modeling well enough to fill the role I have just reserved for professional advisors.

McKinsey: How does one know to avoid the dead ends?

Forrester: How does one know how to design a successful airplane? Or become a successful manager? Like all the professions, system dynamics is an art based on education and experience. There is no guaranteed way to develop a worthwhile model, just as there are no rules to guarantee that everyone can become a successful McKinsey consultant. Success in system dynamics comes from understanding some deep fundamentals about the nature of structure and the dynamics of behavior in feedback systems.

McKinsey: Can you provide an example of the fundamentals?

Forrester: There are two and only two kinds of variables in a system dynamics model—levels and rates (or policies). Once you believe that there are only two kinds of concepts in a system, everything you look at is one or the other of the two. It is much easier to organize thoughts around two kinds of variables than around some unknown large number.

The idea of two and only two kinds of variables should not be new to a manager. Accounting statements of a corporation are cleanly divided between the balance sheet and the profit and loss statement. Balance sheet variables are system levels or accumulations. Profit and loss variables are system rates that cause the balance sheet levels to change.

This idea, seen in accounting, of there being only two kinds of variables—levels (accumulations or integrations) and rates—is true of all systems. Levels state the condition to which a system has arrived at any point in time. Other level variables, which would not be included on a financial balance sheet, include number of employees, reputation of the firm, degree of trust within a group, and quality of products. All of these are gradually built up or degraded by streams of actions.

Actions (or rates) constitute the other class of variables. Actions are controlled by system policies that describe how decisions result from system levels.

All of society and nature are organized around these two kinds of variables.

As another fundamental, levels and rates always exist within feedback loops. A decision causes something—like employment, or product quality, or debt—to change, and those changed conditions affect the next round of decision making. There is no beginning or end, every action happens in an ongoing, recirculating structure in which every decision causes a result that sets a new stage that influences future decisions.

McKinsey: Is system dynamics the only tool available that helps design an organization?

Forrester: Almost all existing organizations have been created without system dynamics. But many people are unhappy with the results as seen in families, cities, corporations, and countries. Conventional methods of planning or designing organizations are not able to deal with dynamic complexity. In mathematical terms, realistic organizations are much more complex than a tenth-order, nonlinear differential equation. No engineer or mathematician can solve such a system by intuition and debate. It is unreasonable to expect managers to do so.

It may be my biased perspective, but I see system dynamics as the most powerful methodology for designing organizations.

McKinsey: The phrase "systems thinking" is becoming popular. How is it related to system dynamics?

Forrester: A clear distinction should be made between "systems thinking" and "system dynamics." These terms may be confusing to those coming to the systems field for the first time.

"Systems thinking" is becoming a popular phrase. Its definition is best derived from looking at what people do who profess to be involved in systems thinking. The term is coming to mean talking about systems. It is thinking about systems. Its is observing that systems are important. But, in general, it is not the quantitative and dynamic analysis that constitutes system dynamics. In systems thinking, I would include management games. Management games demonstrate the existence of complexity. Games show people that they can not get the best results from using merely experience and rules-of-thumb. But management games are usually not presented in a way that carries the participant into the inner working of the game and to an understanding of why the dynamic behavior occurs. Management games focus on decision-making, whereas system dynamics emphasizes the design of policies for guiding decisions.

Systems thinking can be a door opener to system dynamics. The danger lies in people believing that systems thinking is the whole story. Systems thinking is a sensitizer; it calls attention to the existence of systems. Some people feel they have learned a lot from the systems thinking phase. But they have gone less than five percent of the way into understanding systems. The other 95 percent lies in the system dynamics structuring of models and simulations based on those models. It is only from the actual simulations that inconsistencies within our mental models are revealed.

McKinsey: How do you know that a model you have created to represent a system is right?

Forrester: There is no proof that Einstein's theory is correct. There is no proof that Ohm's low in electricity or Boyle's law in gasses are right. There is only experimental demonstration that such laws are useful for specific limited purposes. There is no way of proving that a model or law or theory representing the real world is correct.

A system dynamics model is in the same philosophical category as Einstein's Theory of Relativity. A model is a law about structure and behavior that purports to represent something in real life. There can be no proof that it is right. The relevant question regards the degree of confidence one has in a model.

The competition for a system dynamics model is not a comparison against perfection, but rather a comparison with models that would otherwise be used. All decisions are made on the basis of models. The assumptions in a person's head are not actual systems but assumptions about actual systems. One does not have a family, or city, or corporation in one's head. Rather, one has mental models of those real-life systems. Such mental models are poorly and incompletely defined. Any attempt at mental simulation derived from the mental models will most likely

be dynamically incomplete and incorrect. Nevertheless, mental models are the basis for almost all actions taken in private life, business, and government.

So, one should discuss relative confidence in alternative models. The alternative to a system dynamics model is almost always a mental model that is already in use. It should be quite possible to develop a system dynamics model of a national economy in which people would have more confidence than they would in the mental models in the heads of elected government officials.

McKinsey: Given the long lead times in designing organizations, how can system dynamics help CEOs in situations where accelerated change is required?

Forrester: Accelerated change is required only in an organization that is already in or near extreme difficulty. Such an organization may be desperate enough to act on models and recommendations that have not yet become part of management's accepted way of thinking. Therefore, a good system dynamics model created by a professional consultant may be useful. In the hands of an expert, a model can arrive relatively quickly at what can or cannot be done. If accelerated change is clearly necessary and if there is a sufficient sense of urgency and desperation, management may say: "That looks reasonable. We do not have a persuasive alternative. We accept the model." In such a situation the first thing to find out is whether or not policies exist that will help the corporation get to where it wants to go? If so, the policy changes should be made.

However, if conditions have already deteriorated far enough, there may no longer remain policies capable of reviving a company. If all alternatives are sufficiently unattractive, the organization should be liquidated. When failure becomes inevitable, it is usually true that the sooner the enterprise is terminated the better. Many banks, airlines, and real estate companies are now going into bankruptcy with results that are less satisfactory than if their weaknesses had been fully acknowledged earlier. A system dynamics model should be helpful in evaluating possible future alternatives, identifying policies for survival if they exist, and clarifying the timing for disbandment if that is the unavoidable ultimate outcome.

McKinsey: Is there an entry point and a sequence of actions that can make sure that the process of accelerated change is the most effective?

We do not know the best way to accelerate change. However, some guidelines have emerged:

First, the undertaking must have the personal participation and enthusiasm of the CEO and top management for the most rapid

results. If one starts lower in the organization, new insights and understanding can evolve in junior people, but another round of education must follow to bring top management into the process. If change is urgent, there may not be time for a step-by-step sequence of bringing people into an understanding of new policies. Of course, even when top management understands and accepts the necessary changes, extensive education may still be required at lower levels before the changes can be sufficiently implemented.

Second, one should start modeling with the most serious problem facing the company. Many beginners think the serious problems must be the most difficult and should be deferred until experience has been gained with minor problems. I find that the important challenges are no harder to attack than the unimportant ones, and the payoff from success is much greater.

Third, one must realize that a company may not be able, at first, to identify its most serious problem, or even to identify what constitutes a problem. People respond in curious ways to being asked to state their important problem. An answer may be, "The problem is to train my middle management," without saying why they should be trained, or why they are not already adequately trained, or what the symptoms are that suggest training is needed. One may have to go through several layers of management and many discussions before the real nature of the fundamental source of difficulty becomes clear. People often do not distinguish causes from symptoms, or from solutions. Yet these are very different things.

Fourth, a wide range of people should be involved in the actual model building. One needs the involvement of people throughout the structure involved in the dynamics of the problem being addressed. Often this cuts across departments, may involve many layers of personnel, and may require discussion with customers, bankers, and even competitors. Such a network of inputs may not need a large number of people, but does need to include key inputs from critical parts of the feedback loops that are creating the undesirable behavior.

McKinsey: How does identification of problems and structures work in practice?

Forrester: Several kinds of people may identify important problems and structures. Sometimes the CEO has a clear vision of the situation. Often, in a company that does not have system dynamics expertise, an experienced consultant organizes information from inside the company into an integrated picture that leads

to an effective model. Sometimes, people below top management have the best understanding of how symptoms of trouble are being generated. Even when understanding already exists in a company, established traditions and practices often keep a corrective policy from being adopted.

I am reminded of an insurance company in which the reason for loss of market share was understood and the proper corrective action had been identified, but decentralized managers resisted implementation. Customers were dissatisfied because claims were not being settled quickly. Several concerned vice presidents saw that more claims adjusters were needed. The reputation of the company in claims settlement was declining. Claims costs were rising because, under pressure for faster settlement, adjusters were not inspecting ordinary automobile damage, but were only phoning customers to ask what the repair cost would be. Does paying the customer what he asks lead to satisfaction? No. The customer may ask for $700 and the adjuster answers, "OK. We'll send you a cheque." But the customer is unhappy; he could as well have asked for $900. If the adjuster had time to visit the customer and inspect the damage, and discuss a settlement, $500 might have seemed reasonable to the customer.

The insurance company executives had written memos to field offices recommending more adjusters, but local managers were sure that more employees would reduce profits. Nothing happened. System dynamics advisors were called in to develop a model and an associated interactive computer game for allocating expenditures in a field office. The model clearly demonstrated greater success in the long-run with a higher allocation of budget to adjusters, although in the short run costs were higher until a reputation for better service could be established. However, the powerful influence of corporate culture became immediately apparent. The executives who had written the memos recommending more adjusters, and who had commissioned the computer game to drive home the point, played the game several times without trying more adjusters. Faced with the psychological pressures generated by the game, they reverted to the traditional company practices. Getting successful implementation is often a greater challenge than getting a good system dynamics model.

You asked how problems and corporate structures can be identified for a model. In the early days of system dynamics, my practice had been to carry on extensive discussions with people in a company, then go away to pull the ideas together into a model. But such working apart from managers has serious disadvantages. They see the result as the consultant's model, not their own model. They have not worked through the considerations in what to include and what to ignore. More recent system dynamics practice gets much better response by keeping managers involved in every step of the process. It is even possible to bring a Macintosh computer and the STELLA software to a first meeting and put

ideas about structure and policies on the screen as people talk. The process makes the discussion more explicit and disciplined. The group moves back and forth between discussing assumptions and seeing the simulation consequences. The process produces a much deeper understanding and leads to more productive contributions from managers. When a useful model emerges, managers know how it happened and are more willing to accept the relevance of the results.

McKinsey: If one is clever in designing an organization around structures and policies, does everything else take care of itself?

Forrester: No. Education for implementation and getting acceptance of the required policies may be a greater challenge than the design. Implementation is especially difficult unless measurements of performance and rewards are designed at the same time to support the recommended policies. For example, one often finds measurements that operate against efficiency. A corporation may have a quarterly quota for production and sales. To meet the quota, the plant works overtime in the last two weeks of the calendar quarter. Then, at the beginning of the next quarter, factory operation is cut back because parts and materials were so depleted by the end-of-quarter rush that production can not be maintained. It would be far better to have a continuous daily-computed moving average of production for the last 3 to 12 months as the goal to be exceeded so that there would be no discontinuities.

Often there are traditions, fears, and influences from outside of operating management that inhibit the adoption of improved policies. I worked several years as advisor to a company where the symptoms were falling market share and severe instability of employment. A comprehensive system dynamics model combined production, employment, inventories, customers, competitors, some important policy conflicts between production and finance, and ability to borrow in the financial markets. The model was derived from known information within the company and showed that intentional and recognized policies were actually causing both instability and declining market share. In fact, the model demonstrated company behavior even in characteristics that had not previously been recognized. The model showed that market share had not declined continuously, but fell in steps that occurred during recessions. A closer examination of company records showed the same had actually happened. (System dynamics models often show surprising behavior that turns out to be true but had not been previously detected in the real-life situation.)

Throughout the company, operating people were conditioned by a fear of being discovered with excessive inventories. As a result, when a business-cycle recession began to develop, ordering of materials and production rates were cut back in anticipation of falling sales. Actually the reductions exceeded the degree

to which sales would have fallen. Consequently, delivery delays became longer when the factory was operating below full capacity than when it had been operating with multiple shifts and overtime. Faced with the longer delivery delays during recessions, customers shifted to other suppliers who had better deliveries.

I do not know of anyone in that company who disagreed with the model assumptions, or that the model was demonstrating how the employment instability and declining market share were being caused, or with the logic of the proposed policies for correcting the difficulties. But there was an almost insurmountable hurdle in the way of implementing the new policies. The corrective action called for reversing policies that three generations of top management had made public speeches about as the basis for their success (it was a successful company). The three generations of former management were all alive, in town, on the board, and stockholders. Logic has great difficulty prevailing in that kind of setting.

McKinsey: It's 27 years since you wrote "A New Corporate Design," where you suggested replacing the authoritarian power structure of corporations with an entrepreneurial, free-enterprise structure.[2] Is the elimination of the superior-subordinate relationship as you describe in that article applicable to today's corporations?

Forrester: I believe it is. Many managers argue that centralized control and the superior-subordinate relationship are essential in a large corporation. They assert that a corporation can not be controlled except through the superior-subordinate chain of command. But our largest economic institutions do operate successfully without depending on a superior-subordinate structure. The national economies of democratic, capitalist countries do not coordinate activity by having a superior-subordinate relationship between legal entities. There is no superior-subordinate relationship between a dentist and an automobile manufacturer, or between a grocery store and a law office.

Business leaders make impassioned speeches about the advantages of a free-enterprise economic system while running some of the largest socialist bureaucracies in the world. They have central planning, central ownership of capital, central allocation of resources, subjective evaluation of people, lack of internal competition, and decisions made at the top in response to internal political pressures. These are the fundamental characteristics of a socialist country. The speeches by corporate executives are right, but their practices are not.

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[2] Forrester, Jay W. 1965. "A New Corporate Design." *Industrial Management Review (MIT)*, Vol. 7, No. 1, pp. 5-17. Also appears as Chapter 6, pages 93-109, in the author's *Collected Papers,* 1975, Waltham, MA, Pegasus Communications.

Many large corporations are now showing the same strains that led to the downfall of the Soviet Union. In fact, corporations are the most pervasive training ground for national socialism—they set the pattern of big brother taking care of everything, they suppress individual responsibility and initiative. The paper you mentioned needs to be updated and expanded and filled out with detail, but it does show how a very different and more effective kind of internal organization could be created. Corporations that are already organized at least part way in the direction of that paper show the advantages to be derived from a sweeping reconsideration of how to organize economic activity in the modern world of better educated people and computerized information systems that make possible very different working relationships.

McKinsey: What keeps you occupied these days?

Forrester: Three things: I do some consulting; the largest part of my time is devoted to completing books on economic behavior based on several years of work with the System Dynamics National Model; and I getting involved in system dynamics as a foundation for a new kind of education in junior and senior high schools.

McKinsey: What kind of consulting do you do?

Forrester: I do some work with corporations when there is a very important challenge of special interest to me. I also occasionally work on dynamics of urban and governmental systems.

McKinsey: Do you find the same counterintuitive behavior and internal inconsistencies in national economies as in corporations?

Forrester: Yes, economic systems are even more complex and obscure than corporations. Many national policies that are adopted in hope of solving problems actually make matters worse. As in corporations, the belief in popular policies is often not shaken by failures created by those policies. Instead, people continue to believe in the policies and conclude that failures came from not executing the policies strongly enough.

For example, in the United States low-cost housing programs were created as a response to decay of old cities. Officials assumed that such housing construction would alleviate hardship. Real-life urban consequences have borne out our modeling of urban growth and stagnation.[3] Construction of low-cost

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[3] Forrester, Jay W. 1969. *Urban Dynamics*. Waltham, MA, Pegasus Communications. 285 pp.

housing is a powerful force for driving down the economic well-being not only of a city as an institution but also of the low-income residents who were presumably to be helped. Such housing occupies space that could have been used for industrial job-creating structures while at the same time attracting people who need jobs. It is a double-edged sword for creating, not alleviating, poverty.

McKinsey: What does your System Dynamics National Model tell us about present economic conditions?

Forrester: Our work shows two different dynamic modes in an industrial economy—ordinary short-term business cycles, and the economic long wave. Business cycles are the familiar variations of economic activity with peaks 3 to 10 years apart. The economic long wave, also called the Kondratieff cycle, is much larger in amplitude with peaks 45 to 60 years apart. These two economic disturbances arise from quite different processes in an economy.

Business cycles are driven primarily from over production of consumer products followed by cutbacks and labor layoffs while inventories are brought back into balance. Rise and fall of inventories and production of goods occurs over a short span of a few years. Business cycles are small economic variations compared to rise and fall of the economic long wave.

The economic long wave is caused by over building of capital plant during several decades of economic expansion, followed by a depression lasting 10 or 15 years while capital-producing sectors collapse and the excess of factories, hotels, and office buildings are worn out and depreciated on the account books. The economic long wave creates, and is accentuated by, large changes in prices, debts, money supply, and real interest rates. I believe we are now in the early stages of a long-wave downturn. The late 1920s and early 1930s were the last time that conditions were similar to what is now happening in economies around the world.

McKinsey: How widely accepted are your views about the economic long wave?

Forrester: Most American academic economists do not believe in the economic long wave. Such skepticism is understandable because there has been no theory for how the long wave could be generated in an economy. The long wave is taken

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

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

more seriously in Europe. Although, from our system dynamics perspective, the Great Depression of the 1930s was a characteristic long-wave depression, most economists have tried, rather unsuccessfully, to explain it as nothing more than an unfortunately severe business-cycle recession.

We feel that a theory for long-wave behavior now exists. A simulation model is a theory describing the behavior that the model exhibits. When we started this work we had not heard of the long wave but first encountered it in behavior of the System Dynamics National Model. A huge oscillation with about 50 years between peaks resulted from interactions among ordinary, everyday, policies existing mostly in the private sector. However, governments do participate in making the long wave more severe; for example, easy credit during the 1970s, and especially the 1980s, encouraged over building that is now leading to collapse of real estate values in many countries.

We have identified several feedback loops, all related to building of capital plant, that contribute to the excesses of the long wave. These coupled loops include ones involving inflation, real interest rate, the "self ordering" of capital wherein capital sectors order from themselves to cause further expansion of their productive capacity, and the increase in household income resulting from rising money supply that in turn results from borrowing to buy capital plant.

McKinsey: Assuming confidence in your economic modeling, are there policies that could now avoid a downturn?

Forrester: Economies in most industrial countries are now so unbalanced that there is probably no magic wand to bring conditions immediately back to a healthy equilibrium. There is an excess of capital plant and production capacity, at least given existing prices and wages. Extreme levels of debt must be paid back slowly or be defaulted. Either alternative produces disruption. The best hope lies in not taking actions that will make matters worse. However, one can make several observations about dealing with the existing threats to economic stability:

> First, there is no one to blame. The policies that created this long-wave downturn were supported, in fact insisted on, by every segment of society during the last two decades. We are in this together. If one sector of society vents its frustration by blaming another, it will only prolong the period of economic difficulty.
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> Second, it will help if the public can realize that the economic troubles will not last forever. A long-wave down turn is a reaction to past economic excesses, but it contains seeds for its own recovery. In the

meantime, we should do everything possible to alleviate individual hardship.

Third, to the extent possible a long-wave depression is a good time to rebuild the infrastructure of a country—roads, bridges, schools, and public buildings. However, some countries, like the United States, have lost the freedom to run a government deficit to pay for such rebuilding because of the debts that were accumulated during the prior economic boom. Excessive expenditure during good economic times is one of several processes by which governments can make the long wave more severe. The United States has engaged in pro-cyclic policies, that is, government actions that accentuate swings of the long wave. By incurring large fiscal deficits during the expansion, the additional stimulus made the expansion more extreme, necessitating a deeper contraction to correct the imbalances. Furthermore, the accumulated debt resulting from the sustained deficits is creating financial and political pressure for a balanced budget at the very time when a fiscal deficit could cushion a major downturn. Some countries may be more fortunate by having maintained fiscal discipline during the expansion of the last two or three decades and by now being in a position to use increased deficits to combat a depression.

McKinsey: Because there are independent corporate policies and legal environments in different countries, people ask, "Why will not the peak of a long wave in the United States occur at the time of a valley in Europe, with the peaks and valleys cancelling each other in the world economy as a whole?"

Forrester: Such independence of timing is impossible to maintain. In all dynamic systems, similar modes of behavior lock together with even very slight coupling between systems. The technical term is "entrainment." Very small signals will entrain or synchronize systems that have approximately the same dynamic character. For example, my friends who collect antique pendulum clocks describe such entrainment. If one has several clocks in a room, all adjusted to keep accurate time, there will probably be enough flexibility in the structure of the room to cause all the pendulums to swing in synchronism. I have been told that when the National Bureau of Standards used pendulum clocks for the basic time standard, entrainment was enough of a concern that two clocks would have separate concrete foundations down to bed rock, and then the clocks would be turned at right angles to one another to keep synchronizing forces from being transmitted between them.

In the world economy, there are tremendous forces to lock together the long waves of different countries. For example, daily international money flows are greater than the annual GNP of most countries. One also sees entrainment within a

single economy. There are theoretically dozens of fluctuating modes in an economy, but only two are clearly visible—business cycles, and the economic long wave. Only these two dominant modes appear because all modes with periods between 3 and 12 years tend to be entrained into the single business cycle, while modes with periods from 40 to 70 years tend to be entrained into a single long wave having an intermediate interval between peaks of 45 to 60 years. One should expect the expansions and depressions of the long wave to occur approximately at the same time in all countries.

McKinsey: You mentioned involvement in junior and senior high school education. Have you decided to shift to educating the younger generation rather than trying to influence corporations?

Forrester: I think we will have only limited success in achieving widespread understanding of business and social systems until the ideas take root very early in a person's education and are nourished and reinforced continuously thereafter. System dynamics deals with concepts that have been almost entirely absent in education, even though those concepts underlie everything that happens. We have found that the same teaching materials and methods can be used anywhere from junior high school to chief executive officers. The ideas and the way they can be learned is equally accessible, new, and relevant at all ages. But the systems viewpoint is a paradigm, a frame of reference, a way of looking at one's surroundings, that takes a long time to internalize, probably several years. Developing such a systems perspective takes less time with a young, inquisitive, and open mind than with one that has already been conditioned to see the world in terms of unidirectional cause to effect.

McKinsey: Have any schools adopted systems dynamics as a basis for education?

Forrester: Some dramatic experimental successes have already been achieved in using system dynamics as a foundation that gives underlying unity to the teaching of mathematics, physics, social studies, biology, economics, environmental change, and even literature.[4] System dynamics should not be taught as a separate subject but as a common thread running through all subjects. In the U.S. there are dozens of schools making significant progress with system dynamics and probably several hundred doing something. At a recent conference on system dynamics in pre-college education, 200 people attended from many parts of the country. I have a book of exercises developed in Germany for using system dynamics and the

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[4] Forrester, Jay W. 1991. "System Dynamics—Adding Structure and Relevance to Pre-College Education." In Kenneth R. Manning (ed.), *Shaping the Future*. pp. 118-131. Cambridge, MA: MIT Press. Also available as memo D-4227-2, System Dynamics Group, MIT Sloan School of Management, Massachusetts Institute of Technology, Cambridge MA 02139, USA.

STELLA software for teaching physics in high schools. The Scandinavian countries have a coordinated program for introducing system dynamics in pre-college education.

McKinsey: Can system dynamics be integrated into a traditional class room?

Forrester: The greatest success is coming from a combination of system dynamics and "learner-directed learning." Learner-directed learning defines a classroom environment in which students, even as early as age 10 years, work in teams of two or three on significant projects. The teacher is no longer a lecturer, or the source of all wisdom, or an authoritarian figure. Instead the teacher becomes a coach and advisor. The atmosphere is more like that of a research laboratory. Problems are encountered before necessary information has been presented. The project creates motivation to find the background information that is required.

McKinsey: But is not such an education suitable for only the most able students?

Forrester: It appears that the prior academic ranking of students does not correlate with how well they will do in a school organized around system dynamics and learner-directed learning. Some of the students who have ranked at the top are there because they can repeat information from lectures and books, but may not truly understand its significance, so they may do less well in dealing with dynamic relationships. On the other hand, some of the students, who have ranked at the bottom because they see school as irrelevant, may have keen insight into how the world around them is working and be inspired by the way system dynamics allows them to build on the mental models they have already acquired.

SIDEBAR: HOW SYSTEM DYNAMICS CAME TO BE:[5]

People see a great break in my career in going from my original field of electrical engineering to management. But the shift was gradual. During World War II at the MIT Servomechanisms Laboratory directed by Professor Gordon S. Brown, I worked on military control equipment based on the emerging theory of feedback control mechanisms. After the war, I was in charge of the laboratory

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[5] For a more complete history, see Forrester, Jay W. 1992. "From the Ranch to System Dynamics: An Autobiography." In Arthur G. Bedeian (ed.), *Management Laureates: A Collection of Autobiographical Essays*. Vol. 1 of 3, Greenwich. Conn.: JAI Press. Also available as D-4197-3, System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA 02139

where Whirlwind, the first digital computer at MIT, was built. My group then became part of the Lincoln Laboratory doing the design and managing implementation of the Semi-Automatic Ground Environment (SAGE) air defense system that was installed throughout North America in the 1950s. That undertaking succeeded at least as much due to our managerial leadership as to the technical expertise.

As the SAGE program drew to a close, the management school at MIT was being launched with a $10 million grant from Alfred P. Sloan. Mr. Sloan felt that a management school in a technological environment would develop differently from one in a liberal arts setting like Harvard or the universities of Chicago and Columbia. The technological setting might work better, but at least it would be different and Sloan felt it worth the experiment to see what would happen.

I moved to the management school to think about what the technological side of MIT might contribute to management. Everyone assumed, probably including myself, that the opportunity would lie in one of two possibilities—either the use of computers for management information processing, or further development of the field of operations research, which had started during World War II for analysis of military operations. I had my first year at the management school with nothing to do except decide why I was there. Both of the prior assumptions were discarded. Banks, insurance companies, and computer manufacturers were moving into management data processing; it seemed that our small activity would have little effect on the already growing momentum. Operations research looked interesting; it probably paid for itself in results, but it does not deal with the big issues that make the difference between corporate successes and failures.

Then, a series of happenstance encounters brought together my prior backgrounds in feedback control systems, digital computers, simulation, and management. Discussions with people from General Electric revealed puzzlement about why their household appliance divisions would work overtime at full capacity one year and then two or three years later would lay people off and be operating at half capacity. Blaming the instability on business cycles was easy but not fully convincing. I did some pencil and paper simulations showing how employment and production were being managed based on orders, inventories, and backlogs. One page of computation was sufficient to show that the policies being followed would create major instability in production, even if orders from customers arrived at a constant rate.

In system dynamics we emphasize “transferability of structure,” wherein, if one understands behavior of a structure in one setting one understands it in all settings. In the inventory-production system, inventory and employment are

structurally in the same relationship to one another as are position and velocity in a swinging clock pendulum. Both structures tend to produce sustained oscillation. In a production system, that oscillation can grow larger or be diminished depending on the details of the control policies. The instability of inventory and distribution systems is extensively illustrated in my *Industrial Dynamics* book.

Soon our work evolved into more comprehensive management situations than production and inventories. The people who started the Digital Equipment Corporation (DEC) worked with me in the MIT Digital Computer Laboratory. When they started the company, I was invited to be on the board of directors, and remained for about the first ten years. I did not understand high-tech growth companies as well as I should to be effective on the board, so I built one of the most interesting models with which I have been involved to guide my own recommendations in board meetings. The model defined 250 variables of which about 95 percent dealt with intangibles such as attitudes of the management, origins of goals in an organization, past history of the company as it influenced current decisions, effect of people being overloaded, internal financial pressures, and relationships to customers. Out of that model came an understanding of why so many new companies grow to a certain point and then stagnate. Policies were identified that sustained growth. They involved the relationships between prices, delivery delay, capacity expansion, design quality, and reputation in the market.

In the late 1960s, discussions with John F. Collins, former mayor of Boston, led to our working together on the "urban crisis" in a study leading to *Urban Dynamics* and associated books. The urban studies were widely debated and established contacts culminating in *World Dynamics*[6] and our work on the System Dynamics National Model. The research on the National Model has been supported by sponsors, mostly from the private sector, who have worked with us to understand better the behavior of national economies and alternative policies for improving economic behavior. Some sponsors use the results of the project in their own business thinking, while others support the work as a public service to enhance national policies.

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[6] Forrester, Jay W. 1971. *World Dynamics*. (1973 second ed.). Waltham, MA, Pegasus Communications. 144 pp. Second edition has an added chapter on physical vs. social limits.